JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
CHAIR OF ENVIRONMENTAL ENGINEERING

Runoff and sediment yield Estimation using Soil and Water Assessment Tool (SWAT) model in Fincha watershed, Western Ethiopia

By
Seifu Kebede Debela

A thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Masters of Science in Environmental Engineering

October, 2017
Jimma, Ethiopia

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Main advisor: 1) Dr.-Ing. Fekadu Fufa (PhD)

Co-advisor: 2) Mr. Dida Aberra (PhD. Candidate)

October, 2017

Jimma, Ethiopia

Declaration

I, Seifu Kebede, declare that the content of this thesis is entirely my original work with the exception of quotations or references which have been attributed to their sources or authors. This thesis has not been previously submitted to any other university for requirements of degree.

Seifu Kebede Debela	…………………	…………………
	Signature	Date

APPROVAL SHEET

The undersigned certify that the thesis entitled: " Runoff and sediment yield Estimation using SWAT model in Fincha watershed, Western Ethiopia " is the work of Seifu Kebede and we here by recommend for the acceptance by school of Post Graduate Studies of Jimma University in partial fulfillment of the requirements for Degree of Master of Science in Environmental Engineering.

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As member of board of examiners of the MSc. Thesis open defence examination, we certify that we have read, evaluated the thesis prepared by Seifu Kebede and examined the candidate. We recommended that the thesis could be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Environmental Engineering.

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Chairperson	Signature	Date

ABSTRACT

Runoff and sediment yields are the main problems that affect environment and dams by reducing the storage capacity of reservoirs and the life expectance of the dam. These effects were due lack of appropriate prediction of the problems and lack of best watershed management practices. The aim of this study was to estimate runoff volume, annual of sediment yield and to identify vulnerable area of Fincha watershed at sub basin level.

The main input data used were weather data, spatial data and hydrological data and were collected from different sources. The main sources of these data were Ministry of Water, Irrigation and Electricity of Ethiopia, Ethiopian Mapping Agency, National Meteorological Agency, and International Water Management Institute.

Soil and Water Assessment Tool (SWAT) version 2012, Geographic Information System (GIS) version 10.3 interfaces has been used to attain the aims of the study. Simulated model was resulted with 21 sub basins and 205 HRUs. For sensitivity analysis, calibration and validation of monthly stream flow, SUFI2 uncertainty program of SWAT CUP version 2012 has been used.

Calibrated and validated monthly stream flow at the outlet of watershed were resulted with coefficient of determination R^2 *and Nash- Sutcliffe,* E_{NS} *0.81 and 0.78 and 0.76 and 0.74 respectively. The model was evaluated using coefficient of determination,* R^2 *and Nash- Sutcliffe,* E_{NS} *based on monthly stream flow data since the available data for sediment was limited. From* R^2 *and* E_{NS} *results, the model has good capacity to estimate runoff volume since the values were satisfactory.*

The maximum and minimum annual surface runoffs at sub basin levels were 567.43 mm and 10 mm respectively. Average annual values of surface runoff from Fincha watershed was 242.7mm and average annual sediment yield was 25.7 ton/ha. Both surface runoff and sediment yield were discussed at sub basin level to identify the prone area of the catchment.

From the spatial distributions, the values of sediment yield vary from 0.3 to 65 ton/ha/year depending properties of the sub basins and the prone areas were sub basins 1, 11 and 14 when compared with the rest of sub basins. The estimated values of runoff and sediment yields in Fincha watershed have significant impacts on the catchment, water bodies, communities and Fincha hydropower reservoir. Therefore, further detail investigation and appropriate watershed management practices should be applied.

Keywords: Annual Runoff, Annual Sediment yield, Fincha Watershed, Modeling

ACKNOWLEDGMENTS

First and above all praise to be Almighty God, for endless love and for He gives me healthy mind to think and to do my works and great thanks be to Him forever.

My special thanks and warmest appreciation is for respected and diligent for my advisors Dr.-Ing. Fekadu Fufa (PhD) and Mr. Dida Aberra (PhD. Fellow) for their guidance, helpful moral support and advices in order to complete my work successfully and their continuous and timely comments regarding to the study.

My special and deep thanks goes to my parents for their forward me encouragement, love and advices every time and every place till know especially my mom Sedari Debela since the security of my today's success was the efforts of my mom yesterday.

I heartedly gratify my lovely wife Derartu Bultum, who has took all responsibilities of handling issues of family during my study period and who stood in my side for the successful accomplishment of my vision

I sincerely appreciate the cooperation of those individuals who directly or indirectly contributed to the realization of my thesis, all my chairs, Dr. Dejene Beyene and specially to acknowledge Mr. Megersa Kebede, Mr. Tolera Abdisa, Fayera Gudu and Mr. Wakjira Takala for their well-organized ideas and our department secretors.

Lastly, my gratitude goes to Jimma University, Jimma institute of Technology for allowing me to take part in the Graduate Study Program of Environmental Engineering and my friends who stand with me through their advice and support especially Mr. Adisu Befekadu since he walked with me on ladder starting from 2002 till know and Mr. Wagari Mosisa.

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ACRONYMIES

DO	Dissolved Oxygen
ENMA	Ethiopian National Metrological Agency
FAO	Food and Agriculture Organizations
GIS	Geographical Information System
GLUE	Generalized Likelihood Uncertainty Estimation
HRUs	Hydrologic Response Units
MCMC	Marckov Chain Monte Carlo
MoWIEoE	Ministry of Water, Irrigation and Electricity of Ethiopia
ParaSol	Parameter Solution
SCS	Soil Conservation Service
SUFI2	Sequential Uncertainty Fitting
SWAT	Soil and Water Assessment Tool
SWAT CUP	Soil and Water Assessment Tool Calibration Uncertainty Program
USLE	Universal Soil lose Equation
WSE	Water- induced Soil Erosion

1. INTRODUCTION

1.1. Background

Sediments are one of the major problems of dam operation. They reduce the storage capacity of the reservoir and they can cause serious problems concerning the operation and stability of the dam [1]. Many reservoirs are suffering from excessive sedimentation often due to the fact that either the upstream sediment supply is less or never considered or that the seriousness of this process is underestimated mainly due to lack of sufficient data.

Change in sediment yield due to changed land use in the upstream catchments causes detrimental sedimentation. One of the important factors in reservoirs design and operation is the sedimentation problem. Sediment delivered to the reservoir comes from two main sources. The first is the main river entering the reservoir and the second is the side valleys on both sides of the reservoir.

The sediment transport causes the reduction of storage capacity of rivers and reservoirs due to runoff appeared on the surface become increased [2]. Sediment yield of coarse particles starts and gradually fine particles is deposited to large distances. The sediment load of the watershed output accounts for a sediment yield [3].

Sediment deposition in reservoirs is a reflection of catchment erosion and deposition processes, which are controlled by terrain form, soil, surface cover, drainage networks, and rainfall-related environmental attributes [4]. Also 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 [5].

Because of the rugged terrain, the rates of soil erosion and land degradation in Ethiopia are high. The soil depth of more than 34 % of the land area is already less than 35 cm. Ethiopia loses about 1.3 billion metric tons of fertile soil every year and the degradation of land through soil erosion is increasing at a high rate. In the Ethiopian highlands, soil and water are the most critical resources [6].

Soil erosion and river sedimentation can cause critical environmental, ecological and economic problems world [7]. Soil erosion from the upstream area of the Blue Nile River Basin and the subsequent sedimentation in its downstream area caused a rapid loss of storage volume due to excessive sedimentation [8].

Inappropriate uses of lands and natural resources which takes place as a result of agricultural practices, deforestation, overgrazing of livestock in pastures and road construction results in disrupting the natural balance of the land and causes the loss of vegetation and soil fertility, and consequently can result in the loss of soil worldwide [9].

Due to greater population pressure and consequently more intensive cultivation, erosion losses have been increasing to an annual areal average of 7 ton/ha equivalent to 0.5 mm depth. Therefore, food security and unsustainable development are the main problems in the reduced availability of land per capita countries [10].

Ethiopia experiences pervasive land, water and environmental degradation due to localized and global climatic change. These leave the country to recurrent crop failures and severe food shortages. The poor land use practices, improper management systems and lack of appropriate soil conservation measures have played a major role for causing land degradation problems in Ethiopia. These factors were responsible for the high runoff rate and sedimentation in steep lands [11].

Surface runoff can translocate very large amounts sediment. Rainfall-runoff-sediment yield was the most complex hydrological phenomenon to comprehend due to tremendous spatial variability of watershed characteristics and precipitation patterns, making the physical modeling quite complex [12]. Quantity of runoff and sediment yield resulting from a given rainfall depends mainly on rainfall intensity, duration, and distribution besides others, such as initial soil moisture, land use, slope.

The determination of runoff is critical to many water resources activities that include design of flood protection works, protection of agricultural lands, planning of water storage. The erosion in the watershed may be occurred due to rainfall- runoff, and degrades its land.

Therefore, integrated analysis of reservoir sediment yield data with respective environmental attributes of catchments could facilitate understanding of the dominant factors governing sediment yield variability and identify cause–effect relationships at the catchment scale. Due to the significance of the problem, several empirical methods were developed and later modeling techniques were adopted [13].

These models (empirical and physical) use different methods to estimate the runoff and sediment yield from the catchment. The empirical models like Universal Soil Loss Equation USLE, Modified Universal Soil Loss Equation MUSLE are easy to apply and correlate directly the sediment with rainfall and soil properties based on measured values, while the physically based models are based on physical equations for estimating the runoff and sediment transportation process. [14]

Several types of models are used to predict sediment load. Among these USLE or modified forms, WEPP and GeoWEPP were applied [15]. The WEPP is a physically based model developed by United State Department of Agriculture and Interior to estimate runoff, sediment load and soil erosion based on soil and climate data, while GeoWEPP is a geospatial model combine between GIS and WEPP.

Erosion caused by rainfall and runoff is computed with Modified Universal Soil Loss Equation (MUSLE) [4]. It improves sediment yield estimation, eliminates the need of delivery ratio and allows the equation to be applied to individual storm events.

The SWAT model is a basin-scale, continuous time model that operates on a daily time step and evaluates the impact of management practices on water, sediment and agricultural chemical yields in ungauged basins [16] . The model's major components include weather, hydrology, erosion, soil temperature, plant growth, nutrients, pesticides, land management, channel and reservoir routing.

In SWAT model, the watershed is divided into multiple sub-basins, which are then further subdivided into hydrological response units (HRUs). These units consist of homogeneous land-use, management and soil characteristics. The SWAT model has been widely applied for the simulation of runoff, sediment yield and total phosphorus losses from watersheds in different geographical locations, with varying conditions and management practices [17, 18].

1.2. Statement of the Problem

Sediment loading from different watershed was increased from time to time due to different factors in general. These factors include both natural and human induce activities. As sediment loading from the catchment, soil losses its fertility that decreases agricultural productions, reduces reservoir capacity, carry important nutrients, affect aquatic animals and plants, carry different diseases causing insects that causes agendas of scientific researchers.

Siltation of water body caused by sedimentation reduces sunlight penetration and affecting water temperature, reduces photo synthesis and as a result the survival of submerged aquatic vegetation, degrades the fish habitat (muddy water fouls the gills of the fish) and upset the aquatic food chain. Sedimentation also causes eutrophication due to excessive load of nutrients such as nitrogen and phosphorus and it's deposition at higher level creates an increased level of non-living periphyton or otherwise degrades water quality [19].

The quantification of spatially distributed sediment yield and precise identification of sediment source and erosion vulnerable areas is noteworthy for watershed conservation prioritization. Reduction of the socio economic and environmental cost posed by sedimentati on on various irrigation and hydropower reservoirs, channels and conservation areas increased [20].

The gradual expansion of agricultural land from gently sloping land onto the steeper slopes of neighboring mountains on the one hand, and into the flat swampy plains of the plateau on the other hand accelerated soil erosion [6]. The transformation of marginal lands from forests, shrubs, and grazing lands to agricultural land was basically to fulfill the ever increasing demand for food, fuel wood, fodder, and timber.

Deposition of sediment in reservoirs can cause serious problems. They reduce the storage capacity of the reservoir and they can cause serious problems concerning the operation and stability of the dam [7]. A number of researchers have conducted erosion studies in Ethiopia, the lack of compelling tool or method has hindered adoption and implementation of their findings for present and feature solution [21].

Fincha reservoir was the under serious problems sediment yielded from the upstream. Fincha River was the tributary of Nile River. Similarly, Fincha catchment and Fincha hydropower reservoir was affected by soil erosion, sediment loading due to its topography. Bezuayehu reported that Fincha watershed was a typical example of many watersheds in the country that had undergone land use change and presently undergoing environmental degradation and causing serious problems [22].

It was one of those highland areas of the country with severe soil erosion problem draining to the Nile River. Fincha hydropower reservoir was a highland area with a severe soil erosion problem that drains to the Blue Nile River due to increasingly mountainous and steeper slopes area cultivated, in many cases without protective measures against land erosion and degradation [23].

The total amounts of runoff volume and sediment yields annually leaving the watershed were not easily quantified. The magnitude of runoff and sediment transported within and from the watershed become a serious concern for planning, design and implementation of numerous national development projects in the area and the watershed management practice.

Furthermore reduction in the soil production capacity, reservoir siltation, change in river bank and flooding due to sediment deposition were problems calling for estimation of annual runoff and sediment yield within and from catchment to Fincha hydropower reservoir. Assessment of soil erosion, transport and deposition of sediments in reservoirs, irrigation and hydropower systems were considered essential for land and water management, but these were not studied in-depth in the catchment.

In general, assessment on runoff volume and sediment load from Fincha watershed was not well studied in detail. As the sediment was loaded from the catchment and yielded to Fincha hydropower reservoir, storing capacity of the reservoir decreased due to sediment deposition but recently not identified what amount of sediment was yielded annually. So, before implementing watershed management practices, knowing annual runoff volume and annual sediment yield were pre-request for planning, implementation, decision making and giving solution.

1.3 Objectives

1.3.1. General objective

To determine the spatial variation of runoff and sediment load from Fincha watershed and yield to Fincha hydropower reservoir using SWAT 2012 model

1.3.2. Specific objectives

In order to achieve the general objective of the study, the following specific objectives were set for major indicators of the study

- ✓ To evaluate the performance of SWAT model for runoff and sediment yield estimation.
- ✓ To predict spatial distribution of runoff in the catchment at sub basin level and annual runoff volume that causes the formation of soil erosion.
- ✓ To determine spatial distribution of sediment yield in the catchment at sub basin level and annual sediment yield from the whole watershed
- ✓ To identify vulnerable part of the catchment or sub basins based on runoff and sediment distributions in Fincha watershed at sub-basin level.

1.4. Research questions

1. How to evaluate performance of the model for runoff and sediment yield estimation from the catchment?
2. How the spatial distribution of runoff and what annual runoff of volume could be predicted from the catchment?
3. How the spatial distribution of sediment yield and what amount of annual sediment was yielded from the catchment?
4. Which parts of the watershed has the most vulnerable soil erosion at sub basin level?

1.5. Significance of the study

In Fincha watershed, land was under different land use activities both anthropogenic and natural phenomena, those changes original land and accelerate rate of runoff formation, resources degradation and sediment yield. When the soil become eroded, losses its fertility and agricultural production decreases. These can affect the environment, social and economic growth of the country and the communities around it.

Therefore, to design efficient conservation strategies for the sustainable development, it is essential to know the status of runoff volume; sediment yield and part of the catchment at sub basin level. From different modeling techniques, Arc SWAT model Arc GIS interface is the best and the simplest model that can solve soil erosion problems by predicting runoff volume, sediment yield, and identifying prone area of the sub-watershed and watershed of Fincha watershed in this study.

The result allows the planners, decision makers and any concerned persons to understand the impacts of runoff and sediment yield generated on hydropower reservoirs, water resource planning management, environment, aquatic life, communities and accordingly take appropriate decision and management.

1.6. Scope

The scope of the study was focused on Fincha watershed, Abbay basin that is located in the Horro Guduru Wollegga Zone, Oromia Regional State, Ethiopia, between latitudes 9°9′53″ N to 10°1′00″ N and longitudes 37°00′25″ E to 37°33′17″ E according to geographical location. Based on objective, the scope of study was to analyze the spatial distributions of sediment yield at HRUs level, at sub basin level, classify them into different classes and show which part of Fincha watershed is highly affected due to soil erosion problems and not focused on watershed management practices.

1.7. Limitations

1) For model simulations process:

Lack of daily well recorded input data for the model. In this study there are four stations where necessary data should be collected. From these stations, only one station has full metrological data and the rest stations have only daily precipitations and maximum and minimum temperature. Even with recorded data, there were lots of missed data. These problems decrease the efficiency of the model.

2) For evaluations of the model

The hydrological data in this catchment were not fully recorded. These hydrological data are required for sensitivity analysis, calibration and validation process and classified into two parts. The first part was for stream flow/runoff calibration and validation. For this part it was ok with some missed observed stream flow.

The second part was for sediment calibration and validation. In this case daily recorded sediment data was limited and difficult to calibrate and validate the model using these limited data.

3) There was no data concerning with Fincha hydropower reservoir. Therefore, it was difficult to discuss on reservoir in detail whether it was under high sediment deposition problems or not exactly.

1.8. Plan for dissemination of findings

The results of the study will be presented with presence of external examiner, internal examiner, chairperson and the audiences during final defence. Finally, thesis findings will be disseminated through different ways, such as: through media, online or web based, written fo rm including illustrations, graphs and figures, oral presentation at community meetings, scien tific conferences and publications.

1.9. Organizations of the study

Dissertation of the document was organized from five chapters. Chapter 1 has focused on introduction, statements of the problems, general and specific objectives, research questions, significance of the study, the scope of the study, limitations, and plan for disseminations. Chapter 2 focused on literature review related with the study.

Chapter 3 was focused on methodology and materials used which includes location of the study, data collection, data processing, model simulation, sensitivity analysis, calibration and validation. Chapter 4 was about results and discussions and chapter 5 focused on the conclusi ons and recommendation.

2. LITERATURE REVIEW

2.1. Critique of existing literature review relevant to the study

Land cover change and unsustainable agricultural practices in recent decades appear to be the main impact on land degradation. The lands have been used for traditional livestock grazing or cultivation and causes pressure on existing vegetation and it leads to increased levels of soil erosion in current and future time [11].

The linkage between surface runoff, WSE amplification, intensive land uses and deforestation has been analyzed by various scientists [24]. Knowledge of rainfall, runoff, and soil loss, and their relationships as well as variation in time and space are very important for soil and water management such as designing soil and water conservation and water harvesting structures [25]. The consequences of surface runoff and soil erosion increase the risk of declining land availability and downstream water quality [26].

Therefore, food security and sustainable development are the main problems in the reduced availability of land per capita countries [27]. Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water [28] Sediment yield refers to the amount of sediment exported by a basin over a period of time, which is also the amount that will enter a reservoir located at the downstream limit of the basin [29].

Sediment transport in the channel network is a function of two processes, degradation and aggradation (*i.e.* deposition), operating simultaneously in the reach. Deposition of sediment in reservoirs can cause serious problems and reduce the storage capacity of the reservoir and they can cause serious problems concerning the operation and stability of the dam [13].

2.2. Factors Affecting Runoff

There were different factor that can affect runoff and the major factors were:

A) Climate

Climatic influence on vegetation and LULC was manifested by the response in land using activities to its rainfall and temperature. In area where rainfall was adequate with good distribution and mild air temperature, people prefer to grow crops and keep livestock i.e. to undertake settled mixed agriculture which may increase runoff if not appropriately used [27].

B) Vegetation

The amount of rain lost to interception storage on the foliage depends on the kind of vegetation and its growth stage. More significant was the effect the vegetation has on the infiltration capacity of the soil. Dense vegetation shields the soil from the raindrop impact and reduces the crusting effect as described earlier. In addition, the root systems as well as organic matter in the soil increase the soil porosity thus allowing more water to infiltrate. Vegetation also retards the surface flow particularly on gentle slopes, giving more time to infiltrate and to evaporate [30].

Forests are checkers of soil erosion. Protection was largely because of under store vegetation and litter, and the stabilizing effect of the root network. On steep slopes, the net stabilizing effect of trees was usually positive. Vegetation cover can prevent the occurrence of shallow landslides. However, large landslides on steep terrain were not influenced appreciably by vegetation cover [29].

C) Soil type

Soil functions essentially as medium that provides a large number of passage ways for water. Water flow in soil depends on the size and permanency of the pores. The size of the conduits depends on the size of the soil texture, the degree of aggregation and the arrangements of particles and aggregates [31]. The infiltration capacity was among others dependent on the porosity of a soil which determines the water storage capacity and affects the resistance of water to flow into deeper layers.

D) Slope and catchment characteristics

In general, the volume and peak rate of runoff increases with catchment area. However, for the same rainfall event, a long narrow catchment would be expected to have a lower peak rate of runoff than a more compact or circular one of the same area. In the longer catchment, it takes more time for the runoff from the most remote part of the catchment to reach the outlet [32].

The runoff efficiency (volume of runoff per unit of area) increases with the decreasing size of the catchment i.e. the larger the size of the catchment the larger the time of concentration and the smaller the runoff efficiency. Investigation on experimental plots has shown that steep slope plots yield more runoff than those with gentle slopes. In addition, it was observed that the quantity of runoff decreased with slope length to some extent [1].

2.3. Factors Affecting Soil Erosion and sediment yield

Also, there were a number of site specific factors which have a direct or indirect bearing on the occurrence of soil erosion. The major factors are reviewed below.

1) Erosivity

Erosion by rainfall occurs from raindrops striking soil, and water flowing over the soil. Several variables could be used to describe the capacity of falling or flowing water to erode land surfaces, which refers to be erosivity of rainfall. These variables include rainfall amount, kinetic energy, momentum, and intensity [33].

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

This simple relation was obvious for erosion by raindrop impact, and it is also applies to erosion by surface runoff. Erosion by surface flow is related to both rate and amount of runoff. Amount of runoff was related to rainfall amount, less the amount of infiltration, and peak runoff rate was related to peak rainfall intensity, less infiltration rate.

2) Erodibility

Erodibility defines the resistance of the soil to both detachment and transport. Although soil resistance to erosion depends in part on topographic position, slope steepness and the amount of disturbance created by man, for example during tillage, the properties of the soil are the most important determinants. The main soil properties affecting erodibility include soil texture, structure (aggregate stability), organic matter content, shear strength, infiltration capacity moisture content, density or compactness, chemical characteristics and biological characteristics [34].

3) Effect of plant cover and management

Land can be used for the purpose of forests natural grazing land, pasture, farmland, settlement (housing), roads, water reservoirs, lakes etc. Rates of erosion are different in different land uses. Vegetation cover acts as a protective layer or buffer between the atmosphere and the soils.

The above ground leaves and stems absorb some of the energy of falling raindrops, running water and winds which in fact depends on the height, continuity of canopy, and density of the ground cover. Below ground, the root system contributes to the mechanical strength of the soil. Vegetation also improves soil structure, infiltration capacity and reduce amount of runoff and as a result reduce erosion rate [35].

4) Effect of slope

Topography refers to the geometry of the land surface. Topographic features that influence erosion are slope, size and shape of a watershed and aspect of a mountain. There are three factors of a slope affecting erosion, namely steepness, length, and curvature of a slope. Slope steepness and length increase velocity and the volume of surface runoff; as a result more soil erosion will take place. In other words the steeper the slope and the longer the slope length the more will be the erosion [32].

In general rill erosion is primarily caused by surface runoff and increase in a down slope direction because runoff increases in a down slope direction. Inter rill erosion is caused primarily by raindrop impact and is conceptualized to be uniform along a slope. There are two types of slope curvatures, namely convex and concave. Soil loss was greatest for convex slopes that were steep near the end of the slope length where runoff rate was greatest [34].

The size of a watershed can be small or large. Larger watershed cause more erosion than the smaller ones. The shape of a watershed can be long and narrow or broad and compact. Broad and compact watersheds cause more erosion than long and narrow ones. Aspect was the direction that a mountain faces. Especially in temperate zone, one part of a mountain gets sunshine most of the time and animals go to that side in search of sunshine.

5) Infiltration

Infiltration was another factor that can affect soil erosion and sediment yield. Depending on the soil type and soil properties, soil erosion and sediment yield may increase or decrease. As infiltration rate increase, soil erosion and sediment yield decrease since runoff became decreased.

2.4. Impacts of land use on stream flow regimes

Afforestation and deforestation were two of the most important land use changes influencing the hydrological response of catchments. Catchment experiments worldwide have demonstrated that substantially altering the type and extent of vegetative cover on a catchments can significantly affect the interception and evapotranspiration (ET) processes, consequently cause a change in the runoff volume.

Generally, land use changes that reduce ET increase annual runoff from catchments, whereas land use changes that increase ET decrease annual runoff. Coniferous forest, deciduous hardwood, brush and grass cover (in that order) have been found to have a decreasing influence on annual runoff of the source areas in which the land covers are manipulated [36].

The generalized relationship based on catchments experiments worldwide was that a 10% reduction in coniferous forest (deciduous forest, shrub), being converted to grassland, causes an average increase of 40 mm (25 mm for deciduous forest, 10 mm for shrub) in annual runoff. Land use activities may affect storm flow response and in turn flood peaks through changes in vegetation cover, soil infiltration capacity, conveyance system, increased erosion and sedimentation [32].

The potential impacts of land use changes on surface and near surface hydrological processes (fluxes or storages) under normal conditions in humid temperature zones. Forests and forest soils have popularly been thought to influence the timing of stream flow by storing water during wet periods and releasing water during dry periods because of their high infiltration and soil moisture storage capacities, and hence reduce flood peaks. Conversely, deforestation was generally accepted to be a cause of increased flooding downstream [37].

2.5. Models that have been reviewed in this study

Modeling of the rainfall-runoff processes of hydrology, sediment yield were required for many different reasons. Therefore, main models were:

2.5.1. Soil Erosion Models

Soil erosion and sedimentation by water involved the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water [5]. The major forces originate from raindrop impact and flowing water. Figure below shows the mechanisms of soil erosion, in which water from sheet flow areas runs together under certain conditions and forms small rills.

The rills make small channels. When the flow was concentrated, it can cause some erosion and much material could be transported within these small channels. A few soils were very susceptible to rill erosion. Rills gradually join together to form progressively larger channels, with the flow eventually proceeding to some established streambed.

The Universal Soil Loss Equation (USLE) model was suggested first based on the concept of the separation and transport of particles from rainfall in order to calculate the amount of soil erosion in agricultural areas [38]. It was the most widely used and accepted empirical soil erosion model developed for sheet and rill erosion based on a large set of experimental data from agricultural plots.

The USLE has been enhanced during the past 30 years by a number of researchers. Modified Universal Soil Loss Equation (MUSLE), Revised Universal Soil Loss Equation RUSLE. U.S. Department of Agriculture (USDA) developed a method for calculating the amount of soil erosion under soil conditions besides pilot sites such as pastures or forests, RUSLE was announced to add many factors such as the revision of the weather factor, the development of the soil erosion factor depending on seasonal changes [39].

USDA developed the Water Erosion Prediction Project (WEPP) model to replace the USLE family of models and expand the capabilities for erosion prediction in a variety of landscapes and settings [40]. This model was a physically based, distributed parameter, single-event simulation erosion prediction model that include erosion, sediment transport and deposition across the landscape and in channel via a transport equation.

2.5.2. Hydrological Models

Hydrological models were characterizations of the real world system. Modeling of the rainfall-runoff processes of hydrology was needed for many different reasons, such as limited range of hydrological measurement techniques and limited range of measurements were space and time [41]. Therefore, it was necessary to develop a means of extrapolating from those available measurements in space and time to ungauged catchments and into the future to assess the likely impact of future hydrological changes.

Beven stated that many rainfall-runoff models are carried out purely for research purposes as a means of enhancing knowledge about hydrological systems. He added that other types of models are developed and employed as tools for simulation and prediction aiming ultimately to allow decision makers to improve decision making about hydrological problems [41].

2.5.3. Types of Hydrological Models

1) **Lumped models**:

Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response was evaluated only at the outlet, without explicitly accounting for the response of individual sub basins. Parameters of lumped models often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism.

The impact of spatial variability of model parameters was evaluated by using certain procedures for calculating effective values for the entire basin. The most commonly employed procedure was an area-weighted average. If the interest was primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models [42].

2) **Semi-distributed models**:

Parameters of semi-distributed models were partially allowed to vary in space by dividing the basin into a number of smaller sub-basins. There were two main types of semi-distributed models: 1) kinematic wave theory models (KW models, such as HEC-HMS), and 2) probability distributed models (PD models, such as TOPMODEL). The KW models were simplified versions of the surface and/or subsurface flow equations of physically based hydrologic models [28]. In the PD models spatial resolution was accounted for by using probability distributions of input parameters across the basin.

3) **Distributed models**:

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

2.5.4. SWAT Model, Development and Interface

SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time [43]. 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, weather, erosion, plant growth, nutrients, pesticides, land management, and stream routing.

The program was provided with an interface in Arc GIS 10.3 for the delineation of watershed hydrologic features and storage, as well as the organization and manipulation of the related spatial and tabular data. SWAT requires specific information about weather, soil properties, land use land cover, topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement/yiel d, crop growth, nutrient cycling, were directly modeled by SWAT using this input data.

2.5.5. Theoretical Description of SWAT

The large scale spatial heterogeneity of the study area was represented by dividing the watershed into sub basins. Each sub basin was further discredited into a series of HRUs that have unique soil-land use combinations. Soil water content, surface runoff, nutrient cycles, sediment yield, crop growth and management practices were simulated at each HRU and then aggregated for the sub basin by a weighted average [44].

SWAT model was a river basin scale, continuous time and spatially distributed physically based model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in complex catchments with varying soils, land use and management conditions over long periods of time [45].

Surface runoff from daily rainfall was estimated using a modified SCS curve number method, which estimates the amount of runoff based on local land use, soil type, and antecedent moisture condition. Peak runoff predictions are based on a modification of the Rational Formula [46]. The watershed concentration time was estimated using Manning's formula, considering both overland and channel flow.

The soil profile was subdivided into multiple layers that support soil water processes including infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. The soil percolation component of SWAT uses a water storage capacity technique to predict flow through each soil layer in the root zone. Sediment yield in SWAT was estimated with the modified soil loss equation (MUSLE) developed.

The sediment routing model consists of two components operating simultaneously: deposition and degradation. The deposition in the channel and flood plain from the sub-watershed to the watershed outlet is based on the sediment particle settling velocity [24]. The depth of fall through a reach was the product of settling velocity and the reach travel time. The delivery ratio was estimated for each particle size as a linear function of fall velocity, travel time, and flow depth. Degradation in the channel is based on Bagnold's stream power concept [4].

2.5.6. Hydrological Component of SWAT

Estimation or simulation of hydrology of a watershed was done in two separate components phases. The first phase was land phase of the hydrologic cycle that controls the water movement in the land and determines the water, sediment, nutrient and pesticide amount that could be loaded into the main stream.

Hydrological components simulated in land phase of the hydrological cycle were canopy storage, infiltration, redistribution, and evapotranspiration, lateral subsurface flow, surface runoff, ponds and tributary channels return flow. The second component phase was routing phase of the hydrological cycle in which the water was routed in the channels network of the watershed, carrying the sediment, nutrients and pesticides to the outlet.

In the land phase of the hydrologic cycle, SWAT simulates the hydrological cycle based on the water balance equation 2.1.

$$S_{wt} = S_{wo} + \sum \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

Where S_{wt} was the final soil water content (mm), Swo was the initial soil water content for day is (mm), t was the time (days), R_{day} is the day precipitation (mm), Q_{surf} is the surface runoff (mm), Ea is the evapotranspiration (mm), W_{seep} was the seepage from the bottom soil layer (mm) and Q_{gw} was the groundwater flow on day I (mm).

2.5.7 Sediment Component of SWAT

SWAT computes erosion caused by rainfall and runoff with the Modified Universal Soil Loss Equation (MUSLE) [44]. This method has high powerful than Universal Soil Loss Equation (USLE) to compute sediment yield.

2.5.8 Sediment Properties

Sediment was fragmental material, primarily formed by the physical and chemical disintegration of rocks from the earth's crust. Such particles range in size from large boulders to colloidal size fragments and vary in shape from rounded to angular. They also vary in specific gravity and mineral composition, the predominant material being quartz.

Once the sediment particles are detached, they may either be transported by gravity, wind or/and water. When the transporting agent is water, it is called fluvial or marine sediment transport. The process of moving and removing from their original source is called erosion. In a channel**,** the water flow erodes the available material in the banks and/ or the stream bed until the flow is loaded with as much sediment particles as the energy of the stream will allow it to carry.

Usually, three modes of particle motion are distinguished:

- ✓ Rolling and/ or sliding particle motion,
- ✓ Saltation or hopping particle motion,
- ✓ Suspended particle motion.

When the value of the bed-shear velocity just exceeds the critical value for initiation of motion, ***bed material*** particles will be rolling and/or sliding in continuous contact with the bed. For increasing values of the bed-shear velocity the particles will be moving along the bed by more or less regular jumps, which are called saltations.

The transport of particles by rolling, sliding and saltating is called bed-load transport, while the suspended particles are transport as suspended load transport**.** The suspended load may also include the fine silt particles brought into suspension from the catchment area rather than from streambed material (bed material load) and is called the wash load.

Classification and definitions in accordance with the ISO-standards (ISO 4363) are given:

Bed material: The material, the particle sizes of which are found in appreciable quantities in that part of the bed that is affected by transport.

Bed material load: The part of the total sediment transport which consists of the bed material.

Suspended load: The part of the total sediment transport which is maintained in suspension by turbulence in the flowing water for considerable periods of time without contact with the stream bed. It moves with practically the same velocity as that of the flowing water.

Bed load: The sediment in almost continuous contact with the bed, carried forward by rolling, sliding or hopping.

Wash load: That part of the suspended load which is composed of particle sizes smaller than those found in appreciable quantities in the bed material. It is in near-permanent suspension and, therefore, is transported through the stream without deposition.

2.5.9. Sediment Transport Modes

According to the mechanisms of transport, the total sediment load can be subdivided by source or by mode of transport. For source; the total load is split between the bed material load and wash load. The bed material load is derived from the river bed and is typically sand-sized or gravel-sized. The wash load consists of sediment that has been flushed into the river from upload source and is sufficiently fine-grained that the river is always able to carry it in suspension.

For mode of transport, the total sediment transport is divided into suspended load transport and bed load transport. The suspended load transport is dispersed in the flow by turbulence and is carried for considerable distance without touching the bed. The bed load transport is typically coarse sediment moving in almost continuous contract with the bed by rolling, sliding, or saltating under the tractive force exerted by the water flow [47].

2.5.10. Sediment Transport Equations

Erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss Equation (MUSLE) [43]. USLE predicts average annual gross erosion as a function of rainfall energy. In MUSLE, the rainfall energy factor is replaced with a runoff factor. This improves the sediment yield prediction, eliminates the need for delivery ratios, and allows the equation to be applied to individual storm events.

Sediment yield prediction is improved because runoff is a function of antecedent moisture condition as well as rainfall energy. Delivery rations (the sediment yield at any point along the channel divided by the source erosion above that point) are required by the USLE because the rainfall factor represents energy used in detachment only. Delivery ratios are not needed with MUSLE because the runoff factor represents energy used in detaching and transporting sediment.

A) Modified Universal Soil Loss Equation (MUSLE)

$$Sed = 11.8\left(Q_{surf} * Q_{peak} * Area\ hru\right)^{0.56} * K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * CFGR \ldots 2.2$$

Where Sed is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm/ha), $Q_{peak.}$ is the peak runoff rate (m^3/s), area.hu is the area of the HRU (ha), K_{USLE} is the USLE soil erodibility factor, C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor and CFRG is the coarse fragment factor.

B) Sediment Channel Routing

The SWAT model applies Bagnold's (1977) stream power concept as modified by Williams (1980) for sediment routing (Bagnold, 1977); (Williams, 1980). The routing of sediment involves channel deposition and re-entrainment, and bed degradation. The continuity equation is applied to volumes and concentrations of inflow and outflow. Bed degradation is adjusted with USLE soil erodibility and cover factors, and deposition depends on particle fall velocity.

Flow rate (qch) and Velocity (Vch) in a channel,

The rate and velocity of flow in a channel is calculated by using Manning's equation:

$$q_{ch} = \frac{A_{ch} * R_{ch}^{\frac{2}{3}} * slp_{ch}^{\frac{2}{3}}}{n} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 2.3$$

$$V_{ch} = \frac{R_{ch}^{\frac{2}{3}} * slp_{ch}^{\frac{2}{3}}}{n} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 2.4$$

where, q_{ch} is the rate of flow in the channel (m^3/s), A_{ch} is the cross-sectional area of flow in the channel (m^2), R_{ch} is the hydraulic radius for a given depth of flow (m), slp_{ch} is the slope along the channel length (m/m), n is Manning's "n" coefficient for the channel, and V_{ch} is the flow velocity (m/s).

SWAT calculates the peak runoff rate using the peak channel velocity (Vpk), and the peak flow rate (q_{pk}). These two important factors of the sediment transport are given by the following equations 2.5 and 2.6:

Peak channel flow velocity, Vpk

$$V_{pk} = \frac{q_{pk}}{A_{ch}} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 2.5$$

Peak flow rate, qch.pk

$$q_{ch\ .pk} = \frac{C * I * A}{3.6} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 2.6$$

Where C is runoff coefficient, I is the rainfall intensity (mrn/hr), A is the subbasin area (krn^2) and 3.6 is a unit conversion factor.

Peak flow velocity (qpk) is affected by the uncertainty in channel dimensions (slope, length, width and depth) estimated from the 30m DEM. Peak flow can be calibrated using an adjustment factor for peak flow, PRF, using

$$q_{pk} = PRF * \ q_{ch} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 2.7$$

PRF = is the peak rate adjustment factor.

Once these two factors are known, the maximum amount of sediment that can be transported from a reach segment is calculated using equation 2.8:

$$Sed_{max} = SPCON * V_{pk\ .SPEXP} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .2.8$$

Where: - SPCON, is a coefficient for the max amount of sediment that can be re-entrained, as defined by the user, - SPEXP is used to calculate sediment re-entrained during channel sediment routing.

C) Sediment Deposition

Sediment deposition occurs when the initial concentration of sediment in the reach (Sedi) is more than the maximum amount of sediment transported to the reach (Sedmx). Under this circumstance, the net amount of sediment deposited is calculated by equation 2.9:

$$Sed_{dep} = (Sed_i - Sed_{max}) * V_{ch} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .2.9$$

Where Vch is the volume of water in the reach segment

D) Sediment re-entrained

If Sedi < Sedmx degradation is the dominant process in the reach segment, and the net amount of sediment re-entrained is calculated by equation 2.10:

$$Sed_{re} = (Sed_{max} - Sed_i) * \mathrm{Vch} * \mathrm{Kch} * \mathrm{Cch} \dots\dots\dots\dots\dots\dots\dots . \dots\dots\dots\dots\dots .2.10$$

Where Kch is the channel erodibility factor (cm/hr/Pa), and Cch is the channel cover factor.

Once the amount of deposition and degradation has been calculated, the final amount of sediment in the reach is determined by equation 2.11:

$$Sed_{susp} = Sed_i - Sed_{dep} + Sed_{deg} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 2.11$$

Where Sed_{deg} is sediment degradation

2.6. Surface Runoff

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. When water is initially applied to a dry soil, the application rate and infiltration rates may be similar. However, the infiltration rate will decrease as the soil becomes wetter.

When the application rate is higher than the infiltration rate, surface depressions begin to fill. If the application rate continues to be higher than the infiltration rate once all surface depressions have filled, surface runoff will commence.

1) Methods of Surface Runoff Calculations

SWAT uses two methods for surface runoff calculation: (1) SCS curve number method, and (2) Green-Ampt infiltration method. The SCS curve number performs better than Green-Ampt method. In addition, Green-Ampt infiltration method requires hourly precipitation data, and flow routing at hourly time step which makes the model computationally demanding for long-term simulations.

Therefore, SCS curve Number method is used in most cases. Curve Number for antecedent moisture condition II (CN2) are adjusted for sub watershed slope in the model, and these values are updated on daily time step based on soil moisture conditions in the root zone.

A) Runoff volume

The SCS runoff equation is an empirical model that came into common use in the 1950s. It was the product of more than 20 years of studies involving rainfall-runoff relationships from small rural watersheds across the U.S. The model was developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types [48].

The SCS curve number equation is (SCS, 1972).

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \quad \ldots 2.12$$

Where Q_{surf} is the accumulated runoff or rainfall excess (mm H_2O), R_{day} is the rainfall depth for the day (mm H_2O),

Ia is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H_2O), and *S* is the retention parameter (mm H_2O). The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined in equation 2.13:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad \ldots 2.13$$

Where: *CN* is the curve number for the day. The initial abstractions, *Ia*, is commonly approximated as 0.2*S* and equation 2.13 becomes

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \quad \ldots 2.14$$

Runoff will only occur when $R_{day} > Ia$.

B) Peak Runoff Rate

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

The rational method is widely used in the design of ditches, channels and storm water control. The rational method is based on the assumption that if a rainfall of intensity i begins at time t=0 and continues indefinitely, the rate of runoff will increase until the time of concentration, tc, when the entire sub basin area is contributing to flow at the outlet.

The rational formula in equation 2.15

$$q_{peak} = \frac{C.i.Area}{3.6} \quad \ldots 2.15$$

2.7. Soil Hydrologic Groups

The U.S. Natural Resource Conservation Service (NRCS) classifies soils into four hydrologic groups based on infiltration characteristics of the soils. Soil properties that influence runoff potential are those that impact the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozen. These properties are depth to seasonally high water table, saturated hydraulic conductivity, and depth to a very slowly permeable layer. Soil may be placed in one of four groups, A, B, C, and D, or three dual classes, A/D, B/D, and C/D.

Definitions of the classes are:

A: (Low runoff potential). The soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels and have a high rate of water transmission.

B: The soils have a moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep to deep, moderately well-drained to well-drained soils that have moderately fine to moderately coarse textures and have a moderate rate of water transmission.

C: The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission

D: (High runoff potential). The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have a high swelling potential, soils that have a permanent water table, soils that have a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material.

Antecedent Soil Moisture Condition

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 the equations 2.16 and 2.17:

$$CN_1 = CN_2 - \frac{20\,.(100 - CN_2)}{(100 - CN_2.exp[0.00673.(100 - CN_2)])} \quad \dots\dots 2.16$$

$$CN_3 = CN_2\,.exp[0.00673.(100 - CN_2)] \quad \dots\dots 2.17$$

Where CN_1 is the moisture condition I curve number, CN_2 is the moisture condition II curve number, and CN_3 is the moisture condition III curve number.

The retention parameter varies with soil profile water content according to equation 2.18:

$$S = S_{max} \cdot \left(1 - \frac{S_w}{[S_w + exp(w_1 - w_2 \cdot S_w)]}\right) \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 2.18$$

Where S is the retention parameter for a given moisture content (mm), $Smax$ is the maximum value the retention parameter can achieve 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 H_2O), and w_1 and w_2 are shape coefficients. The maximum retention parameter value, $Smax$, is calculated by solving equation above using CN_1.

The shape coefficients are determined by solving equation above assuming that

1) The retention parameter for moisture condition I curve number corresponds to wilting point soil profile water content,

2) The retention parameter for moisture condition III curve number corresponds to field capacity soil profile water content, and

3) The soil has a curve number of 99 (S = 2.54) when completely saturated.

$$W_1 = ln\left[\frac{FC}{1 - S_3 . \ S_{max}{}^{-1}} - FC\right] + W_2 . FC \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 2.19$$

$$W_2 = \frac{\left(ln\left[\frac{FC}{1 - S_3 . S_{max}{}^{-1}} - FC\right] - ln\left[\frac{FC}{1 - 2.54 \, . S_{max}{}^{-1}} - FC\right] - SAT\right)}{(SAT - FC)} \dots \dots \dots \dots 2.20$$

Where w_1 is the first shape coefficient, w_2 is the second shape coefficient, FC is the amount of water in the soil profile at field capacity (mm H_2O), S_3 is the retention parameter for the moisture condition III curve number, $Smax$ is the retention parameter for the moisture condition I curve number, SAT is the amount of water in the soil profile when completely saturated (mm H_2O), and 2.54 is the retention parameter value for a curve number of 99 and curve number (CN) is given by equation 2.21

$$CN = \frac{25{,}400}{(S + 254)} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 2.21$$

3. METHODOLOGY AND MATERIAL

3.1. Study area

The Fincha watershed is located in the Horro Guduru Wollegga Zone, Oromia Regional State, Ethiopia, between latitudes 9°9′53″ N to 10°1′00″ N and longitudes 37°00′25″ E to 37°33′17″ E shown in figure 3.1.The watershed covers an area of 2,619 km^2 and covers parts of six districts-namely, Jimma Geneti, Horro, AbbayChomen, AbaboGuduru, Guduru, and Jimma Rare. The watershed is bordered on the north by the Blue Nile River (also called Abbay River in Ethiopia), on the east by the Guder River Basin, on the south by Awash River Basin, and on the west by Diddessa River Basin

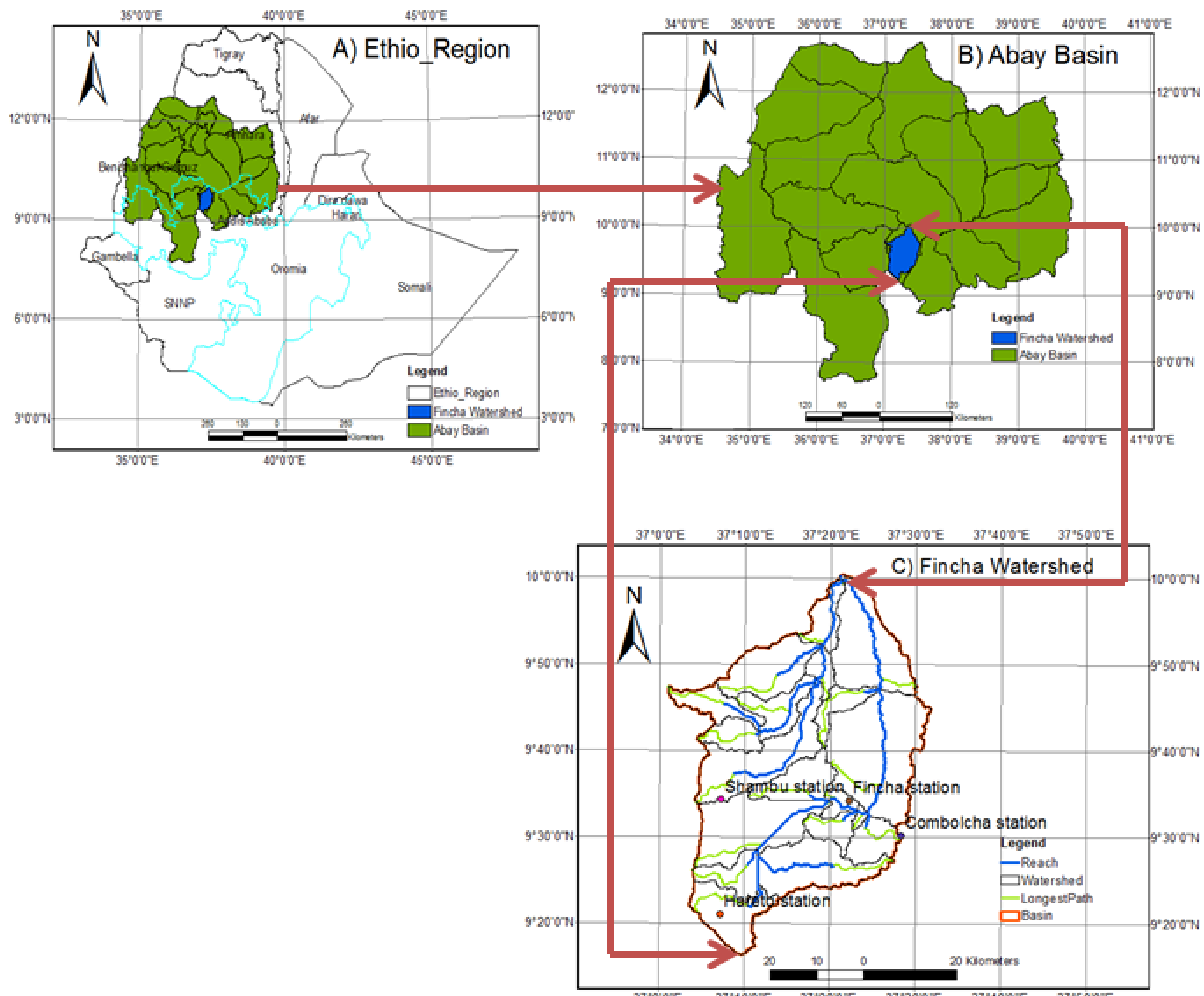

Figure 3.1: Map of the study area

The climate of the Fincha watershed is tropical highland monsoon with an average annual rainfall of 1,763.6 mm and mean monthly temperature of the area varies from 14.6 to 17.7 °C. Most of the rain falls during the months of June to September with peaks occurring during July to August and it is virtually somewhat dry from November through to April. As the watershed is located in a high rainfall area, it receives frequent torrential showers and frequent flash floods during the rainy season.

The major landform of the watershed includes flat to gently sloping, undulating plains, hills and mountains based on classified slope of the catchment. The elevation of the catchment were varied from 902 m to 317 m ams and western part of the watershed is characterized by highly rugged, mountainous and rolled topography with steep slopes and the lower part is characterized by a valley floor with flat to gentle slopes from digital elevation model result.

A) Fincha Reservoir

In Fincha watershed there was no significant water body except stream flow before the construction of the Fincha hydro reservoir dam in 1973. Originally, it was swamp area used as grazing land and was fed by numerous streams and intermittent rivers arising from a chain of mountainous plateaus. This was evidenced from the 1957 aerial photos interpretation by Bezuayehu that showed only traces of river courses [22].

The reservoir was created by backing water into Fincha and Chomen swamps after the construction of the Dam and the area under the water body has been increasing year after year. The interpretation of the 1980 aerial photo indicated that about 151.1 km^2 was under water body. Moreover, the volume of the reservoir also increased following the diversion of Amarti River into Fincha reservoir in 1987, which provide an annual runoff of about 138.8 mm to the reservoir. Currently the water body covers an area of about 405 km^2 [22].

3.2. Instruments used

The main tools that have been used in this study for data collection, preparation and analysis were Arc VIEW GIS version 10.3, Arc SWAT 2012, SWAT CUP 2012, map window, PCPSTAT, dew02.exe, angstrom and Microsoft excel.

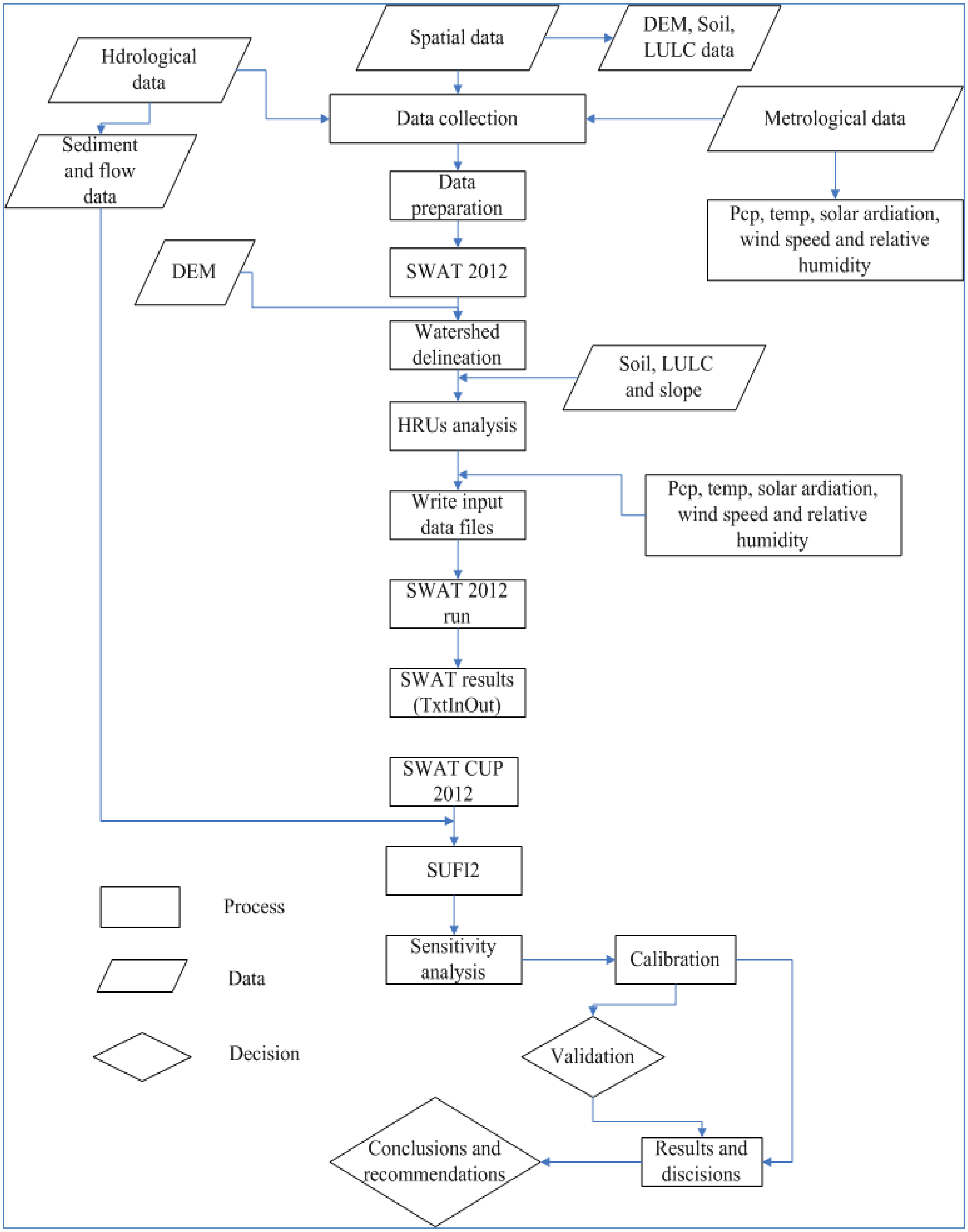

Figure 3.2: General framework of Methodology used

3.3. Data sources and data collection process

This process includes both secondary data (desk) and primary data (field investigation) for the gathering of important data in order to achieve the thesis objectives. It comprises the methods employed to achieve the theme.

The deskwork includes literature review on modeling journals, books, and previous work, collection of topographic map, soil data, land use/land cover data, Digital model (DEM), meteorological data, hydrological data and make ready computer code that help for modeling like Arc SWAT 2012, Arc GIS 10.3 since they were compatible to each other.

Generally, the main data sources were Ministry of Water, Irrigation and Electricity, Ethiopian Mapping Agency and National Meteorological Agency and shown in table 3.1.

Table 3.1 Description of data used and major data sources in this study

S. No	Data type	Data format	Description	Source
1	DEM	Grid	30 m X 30 m grid DEM for Fincha watershed delineation process	MoWIEoE
2	LULC data	Grid/ shape file	The land use data that contains crop, specific digital layers, suitable in GIS and SWAT	MoWIEoE
3	Soil data	Grid/ shape file	Soil types and physical properties of Fincha watershed for SWAT model	MoWIEoE
4	Weather data	text	Daily (pcp, max and min. temp, solar radiations, wind speed and relative humidity)	ENMA
5	Hydrological data	text	Stream flow and sediment data	MoWIEoE

3.4. Model inputs and their Preparation

The Arc SWAT Arc GIS extension was graphical user interface for the SWAT (Soil and Water Assessment Tool) model and requires detailed spatial (GIS input) and metrological inp ut data, as a physical model [27]. Daily meteorological data (precipitation, max and min temp erature, solar radiations, relative humidity and wind speed) spatial data (DEM in grid form, a nd use/cover map in shape file, stream network layers and a soil data in shape file) and hydr ological data (sediment data and river discharge data) were required. These data were essential for runoff computation, sediment yield estimation, calibration and validation purposes of stream flow and sediment yield.

3.4.1. Weather generator

The weather generator is one of the main components of the SWAT model. It helps to estimate the values of the missed data for the climatic parameters of the study area. The missed values of climate elements like rainfall, temperature, wind speed, relative humidity and solar radiation were generated by the weather generator components.

In this study, one weather generator station (Shambu station) was selected because it was a principal station that consists of all metrological data type. Monthly statistical values for weather generator were prepared from daily data values using pcpSTAT (for precipitation), dew02.exe (for maximum and minimum average temperature with average relative humidity), excel using pivot table for the rest data in order to generate daily missed datum values for rest stations.

The weather generator component requires statistical parameters, such as a standard deviation for the maximum and minimum temperature, a standard deviation for precipitation, daily precipitation, average daily solar radiation, average amount of precipitation falling in a month, skew coefficient of precipitations, probability of wet day followed by dry day, probability of wet day followed by wet day, average dew point temperature and maximum half hour rainfall.

3.4.2. Metrological Data

The metrological data required for model were daily precipitation, maximum and minimum air temperature, solar radiation, wind speed, and relative humidity. If any of these data were not available, which was very likely, SWAT can generate missed data using weather generat or. Monthly average weather simulation data required by the SWAT model to generate daily values from monthly values.

These data were collected from ENMA for the period of 25 years from 1990-2014 G.C. In this study the selected four metrological stations were Combolcha, Fincha, Hareto and Shambu. Their coordinates and geographical locations were presented in table 3.2 and shown in figure 3.3 respectively.

Table 3.2 coordinates of climate station

Station Name	XPR	YPR	Longitude	Latitude	Elevation
Combolcha	322344	1050758	37.4727	9.50233	2341
Fincha	321143	1058294	37.3703	9.57	2248
Hareto	293529	1034098	37.12	9.35	2260
Shambu	293789	1058566	37.1212	9.5712	2460

Where: XPR is X coordinate in defined projection

YPR is Y coordinate in defined projection

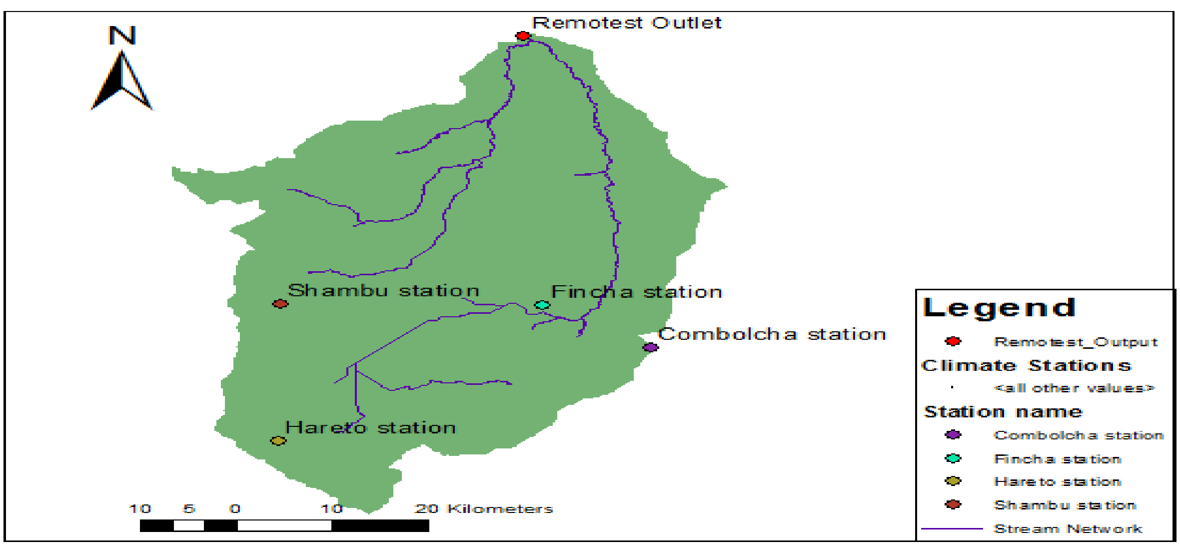

Figure 3.3: Location of climate station in Fincha watershed

I) Filling missed data

Before checking consistency of data and data preparation, some missed data should be filled using different methods. Missed data for precipitations were filled using XLSTAT 2015 from nearest neighborhood stations depending on their correlation coefficients and linear regression method for all stations (Combolcha, Fincha, Hareto and Shambu).

For stream flow and maximum and minimum temperatures, mean imputation method was used to fill missed data based on their correlation coefficient. For wind speed, relative humidity and solar radiations, weather generator was used to generate missed data of non-principal stations.

II) Consistency of filled data

To keep the precision and accuracy of data for the model, consistency of data have been approved. Consistency of filled data was checked using double mass curve before data preparation was started and presented in figure 3.4 and figure 3.5 for precipitation and temper ature respectively.

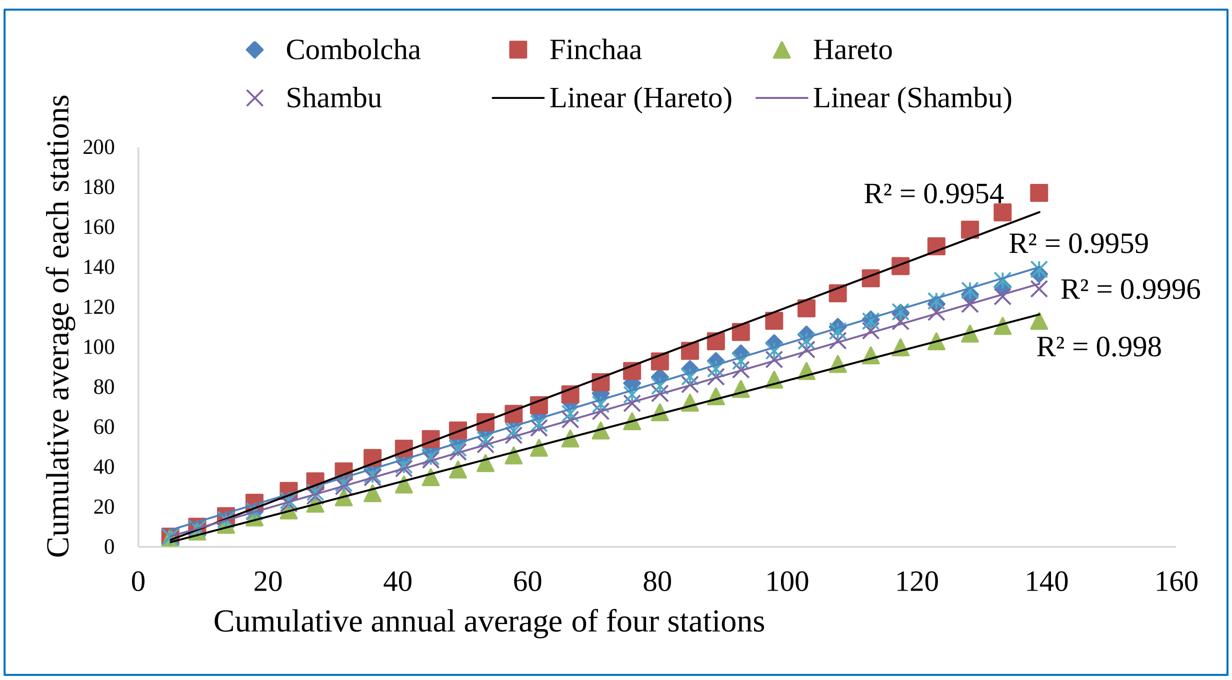

Figure 3.4: Double mass curve precipitation

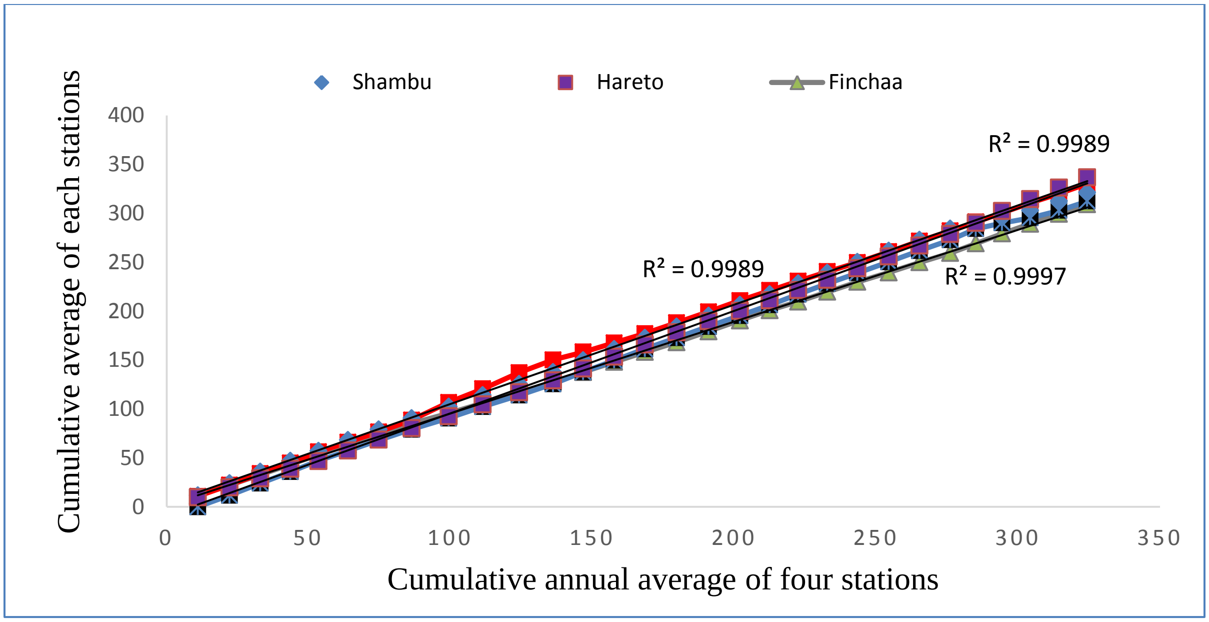

Figure 3.5: Double mass curve of temperature

III) Data preparations

After missed data were filled and their consistencies were checked, data were prepared according to their compatibilities for the model. Daily precipitation and temperature of all gauged stations (Shambu, Fincha, Combolcha, and Hareto) were prepared in text format.

Solar radiation, relative humidity, and wind speed data were available only for principal station (Shambu station) and prepared in text format. But, sunshine hour of Shambu station was converted into solar radiation using angstrom. The spatial data land use/cover and soil data were prepared in shape file format and DEM was prepared in grid form.

3.4.3. Spatial Data

Spatial data was also the main input of Arc SWAT model. The main spatial data required were digital elevation model (DEM) of Fincha watershed, land use land cover (LULC) information and soil information.

A) Digital elevation model

DEM was the main inputs of SWAT model. It helps in understanding the flow behavior and flow pattern. Topography of the catchment was defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution.

A digital elevation model was needed for raster-based hydrological analysis in Arc GIS. A 30m by 30m DEM resolution was extracted from original Ethiopia of DEM.

This DEM was used to delineate the boundary of the watershed and analyze the drainage patterns of the land surface terrain. Terrain parameters such as slope gradient and slope lengt h, and stream network characteristic such as channel slope, length and width were derived fro m the DEM. Location of Fincha DEM in Abbay and extracted Fincha DEM from Abbay DE M were shown figure 3.6 and figure 3.7 respectively

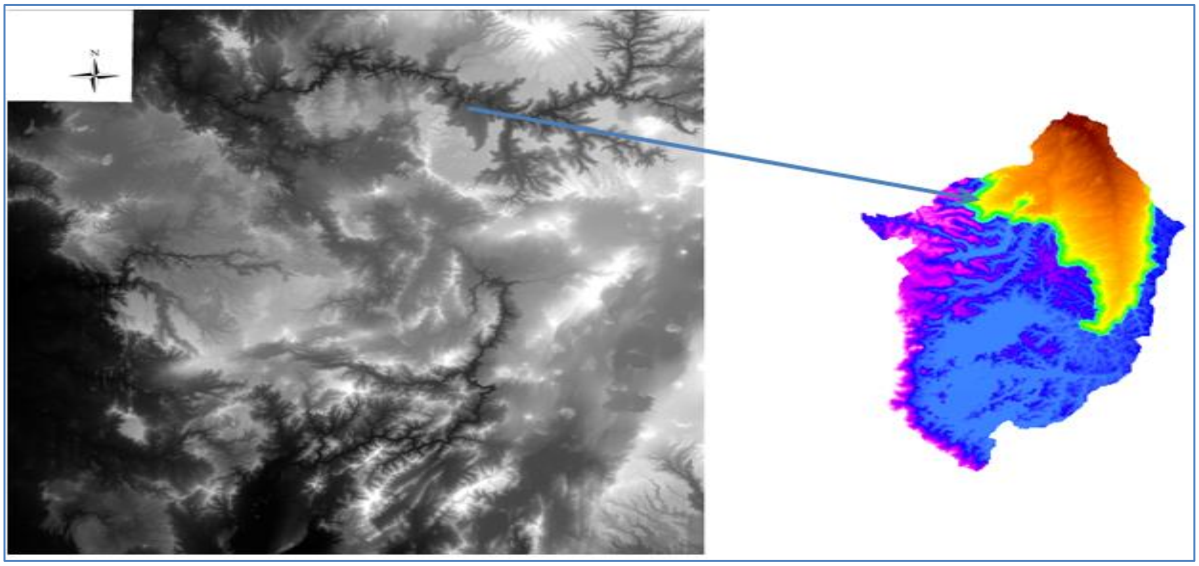

Figure 3.6: Fincha DEM from Abbay DEM

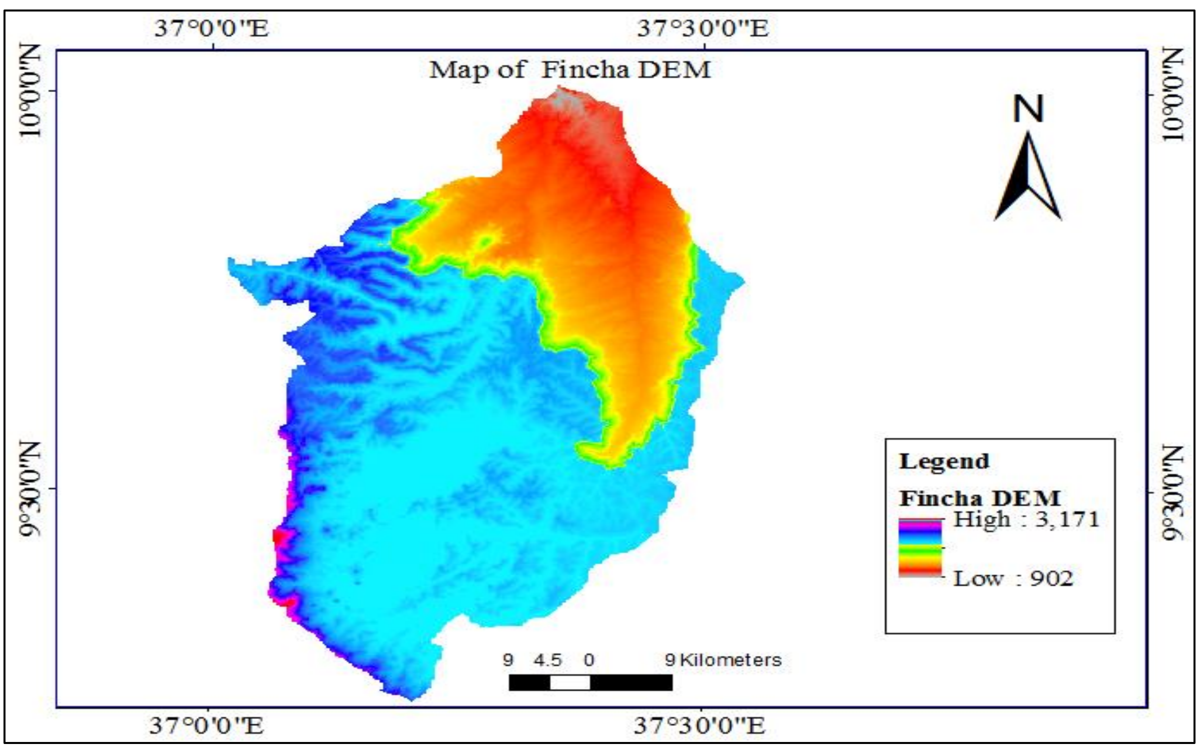

Figure 3.7: DEM of Fincha watershed

B) Land use/cover data

The land use/cover of an area was one of the most important factors that affect soil erosion, runoff, sediment and evapotranspiration in a watershed during simulation [49]. The land use map of the study area was obtained from the Ministry of Water, Irrigation and Electricity of Ethiopia.

The land use map of Ethiopia and Fincha basin were overlaid and Fincha LULCs were clipped. Clipped Fincha land use land cover map was projected to UTM zone 37, projection area of Ethiopia and nine major land use land cover classes of the study area were identified. These land use land cover were bush land, dominantly cultivated, moderately cultivated, irrigated land, grass land, water bodies, swampy area, urban and woodland and shown in figure 3.8.

Arc SWAT does not take these land use land cover directly. Therefore a predefined of land uses land cover by coding was required. They were coded by four letter codes and linked to SWAT land use databases and presented in table 3.3. The coded LULC were prepared in text format followed by the guide line on data preparation for SWAT model and were loaded into Arc SWAT model through lookup table.

Table 3.3 LULC types in the study area and their redefinition according to SWAT Code

Original Land use land cover	Redefined land use according to SWAT database	Attribute code	SWAT code
Bush land	Bush land/shrub land	10	GRNB
Dominantly cultivated	Agricultural land row crops	20	AGRR
Moderately cultivated	Agricultural land –Generic	30	AGRL
Irrigated land	Corn	40	CORN
Grass land	Range-Grasses	50	GRNE
Water bodies	Water	60	WATR
Swamp area	Swampy	70	WETN
Urban	Urban	80	URBN
Woodland open	Forest-mixed	90	FRST

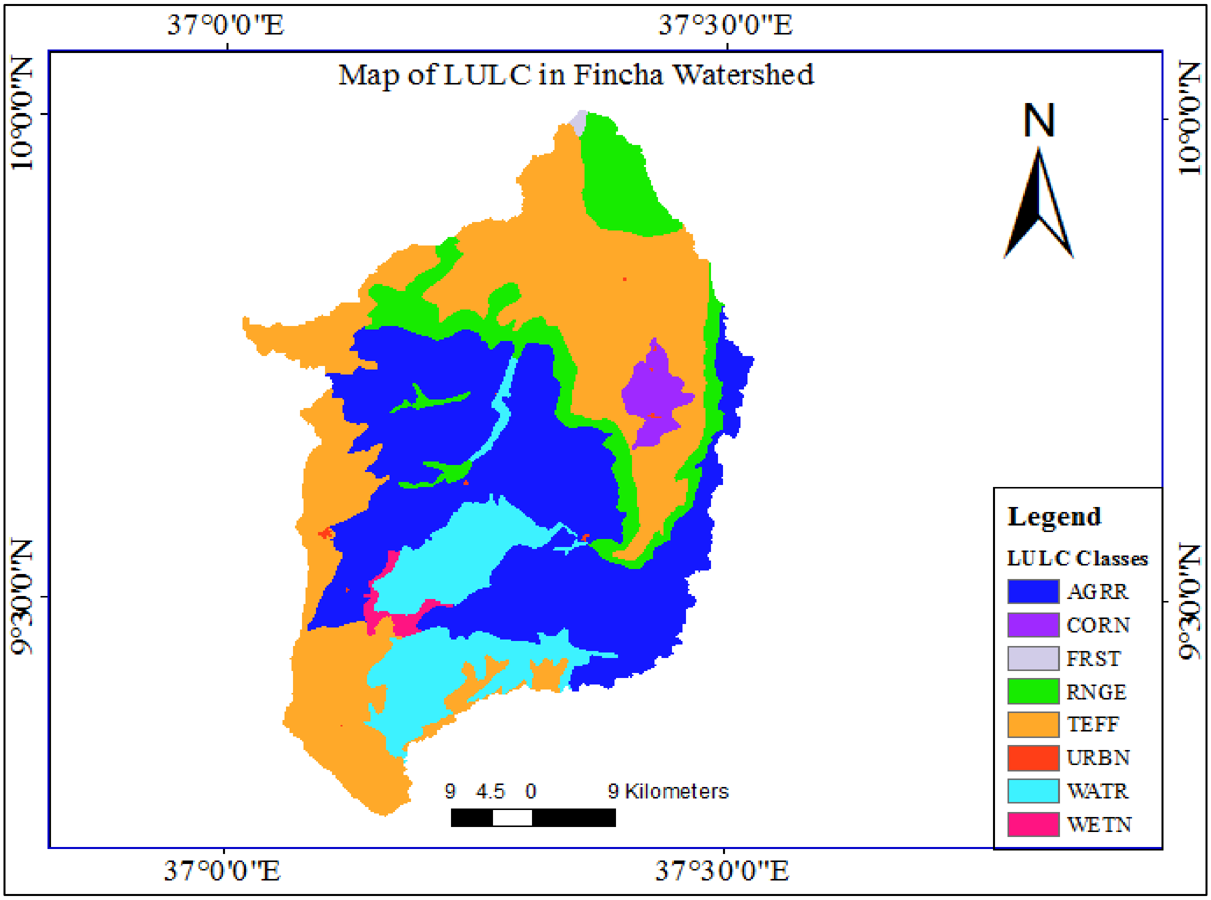

Figure 3.8: Major land use classes in Fincha watershed

C) Soil data

Arc SWAT model require soil data to provide both the distribution of the soil type in the watershed and the various parameters describing the soils hydrological and textural properties. The soil textural and physicochemical properties required by the SWAT model include soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for each soil type. Soli data were obtained from soil map of Ethiopia Ministry of Water, Irrigation and Electricity of Ethiopia.

Fincha basin was overlaid with soil map and clipped. Clipped Fincha soil map was projected to UTM zone 37, projection area of Ethiopia and nine major soil types were obtained and shown in figure 3.9. These major soils were chromic luvisols, chromic vertisols, dystric cambisols, eutric cambisols, eutric nitosols, eutric regosols, haplic phaeozems, humic cambisols and water.

These soil data should be prepared as a map in text format and then linked to a customized soil database designed by the user since they were not included in the existing SWAT soil database. It was difficult to get directly all of the soil information from SWAT soil database.

Therefore, map window was integrated with SWAT soil database in order to obtain the necessary soil information in this study as supportive tool but not as a source of soil data. Based on soil information from map window, majority of soils in the watershed were classified under hydrological group C and covers around 55.56% of the catchment. Also, large portion of the watershed was characterized by clay soils.

These soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture and have a slow rate of water transmission. Most parts of these soil leads runoff since infiltration is inversely proportional with surface runoff when become wetted

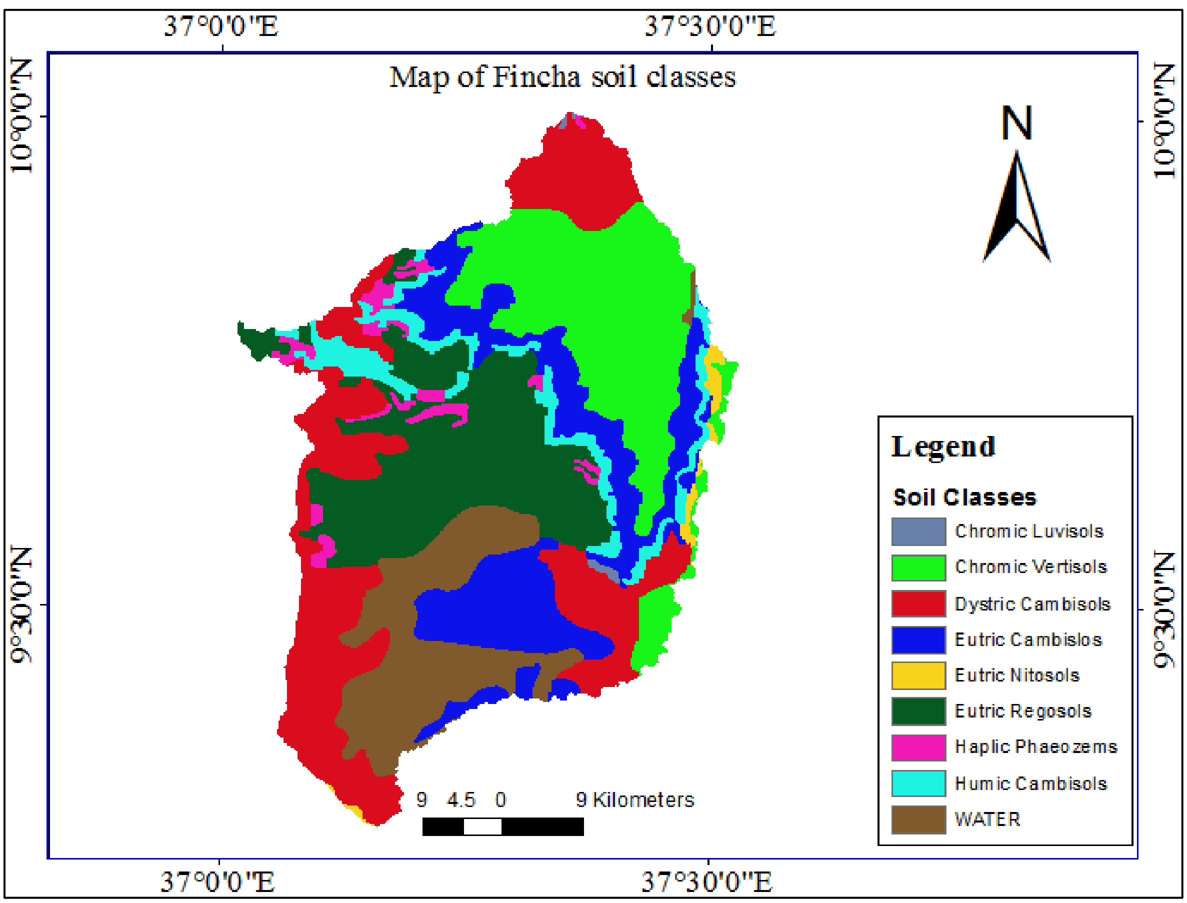

Figure 3.9: Major soil classes of Fincha watershed

3.4.4. Hydrological Data

The main hydrological data required for this study were daily observed stream flow and sediment concentration data. These data were important for sensitivity analysis, calibration and validation processes at outlet of the watershed or point of interest using SWAT CUP 2012 model. Daily observed stream flows for a period of twenty five years, from 1990 to 2014 were obtained from the Hydrology Department of the MoWIEoE

But, measured sediment data in Fincha watershed were limited. Therefore, it was difficult to calibrate and validate sediment yield using these data and developing rating curve was the last option. Based on these data, rating curve was developed from power function of rating curve formula and used to generate sediment yield as a function of measured discharge.

$$Q_s = a * Q_f{}^b \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \; 3.1$$

Where: Qs = suspended sediment loading in mg/L, Q_f = water flow rate (m^3/s), a and b are constants. These constants were determined by using least square regression method to fit a straight line through the scatter points of daily recorded flow and sediment concentration. The developed rating curve was expressed in figure 3.10 and Summary of input models were shown in figure 3

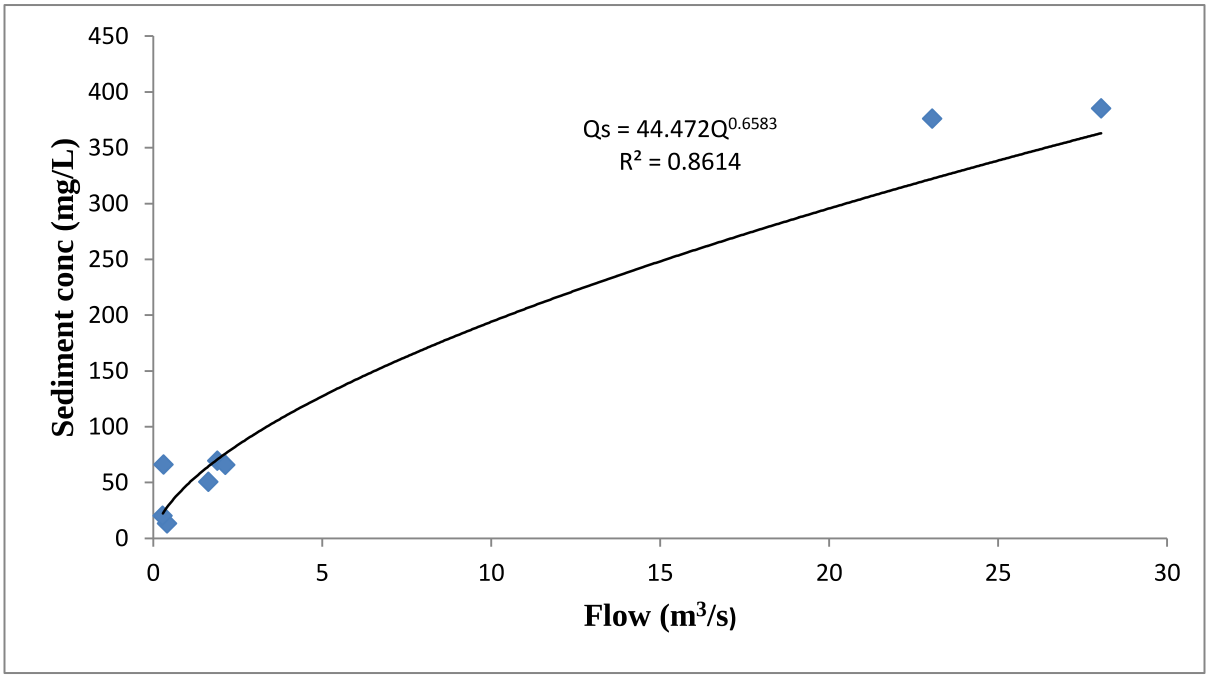

Figure 3.10: Developed rating curve of Fincha watershed

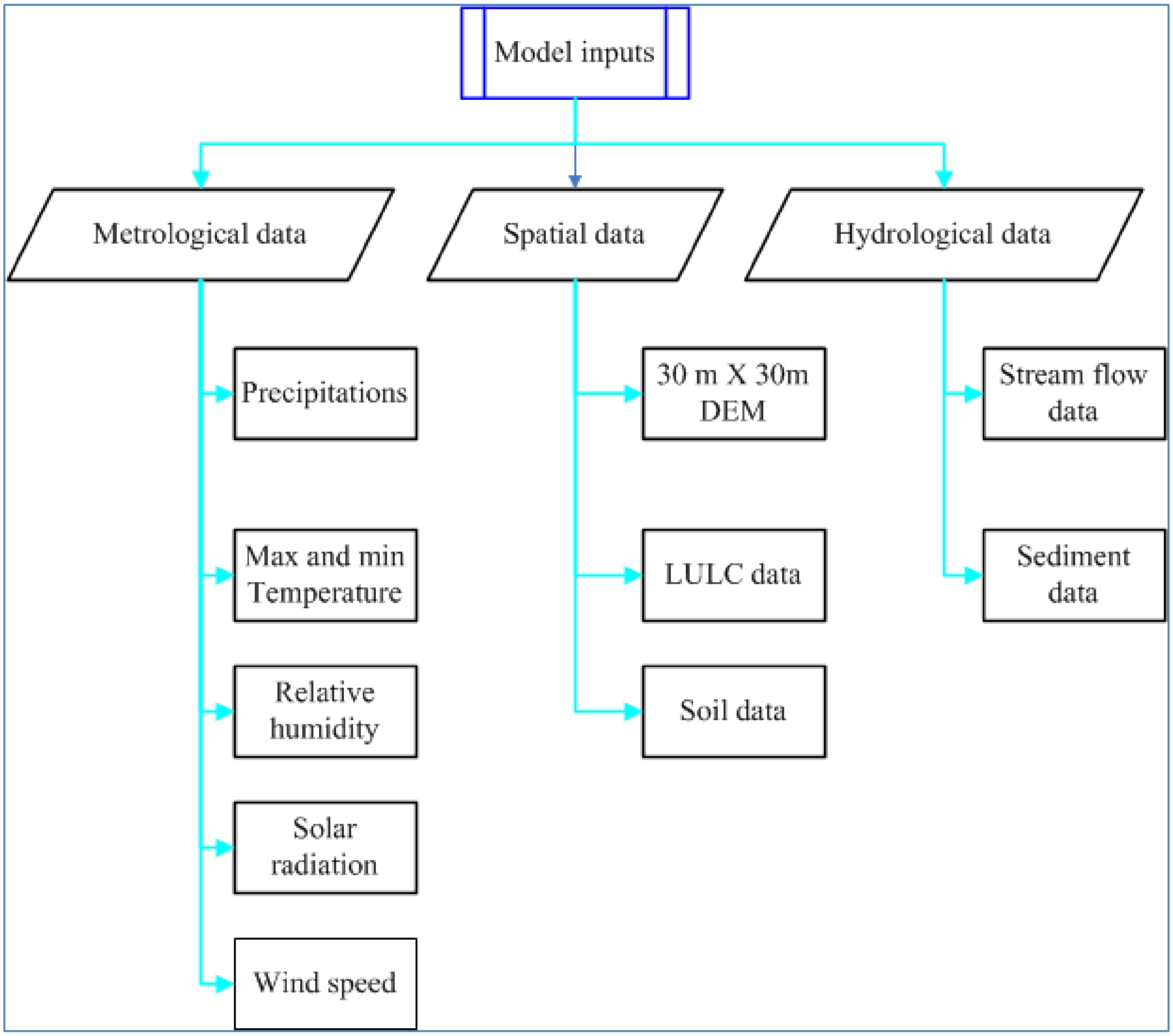

Figure 3.11: Summary of SWAT model inputs

3.5. Model Setup

3.5.1. Watershed Delineation process

The Arc SWAT requires model setup and parameterization of the model. Watershed was automatically delineated using Digital Elevation Model (DEM) as input data. Automatically delineated the watershed was classified into several hydrologically connected sub watersheds After the DEM grid loaded and the stream networks superimposed, the DEM map grid was prepared to remove the non-draining zones. The initial stream network and sub-basin outlets were also defined based on drainage area threshold approach.

In order to delineate the required watershed, Arc Map was opened to create an empty document and Arc SWAT toolbar was loaded in the map document after its installation. The tool functions were divided into five sections, namely DEM setup, stream definition, outlet and inlet definition, watershed outlet(s) selection and definition. The flow chart of these steps and final delineated Fincha watershed were shown in figure 3.12 and in figure 3.13 respectively.

A) Project Setup

The first step in watershed delineation using Arc SWAT Arc GIS was to set up SWAT project.

Then the SWAT project geodatabase, raster storage geodatabase and the SWAT parameter geodatabase automatically get a name and stored in the created folder. A 30m by 30m resolution grid DEM was loaded from the disk into SWAT model ArcGIS interface and the unit was adjusted from DEM projection setup box to reflect the real situation.

B) Stream Definition

There are two ways to define the watershed and stream network. The firs method was based on introducing threshold area, while another method based on pre-defined watershed without changing the pre-defined. The threshold area defines the drainage area required to form the beginning of a stream. Introducing threshold method was used to fix the number of sub basin and HRUs during watershed delineation in this study. Next, flow direction and accumulation needs to be calculated. Stream definition defines the stream network and sub basins outlets.

C) Outlet and inlet definition

There are different options to define outlet and inlet. These options were (1) to change the threshold area and rerun the stream and outlet definition routine, (2) to add outlet points by importing a table that contains the locations, (3) add outlet points manually, and (4) to remove outlet points. Inlets represent any point source loading into the study area or the inlets of drainage into the watershed from an upstream area.

One or more outlet locations can be selected to define the boundary of the main watershed. But, in this study, one outlet at the downstream edge of the masked area was selected to represent outlet the whole watershed.

D) Calculations of sub basin parameters

Sub basin parameters were calculated in order to estimate the basic watershed characteristics from the DEM. The results of the calculations were stored as additional fields in the streams and sub basins theme database files and automatic watershed delineation process was finalized

E) Final watershed delineation

From the steps A-D, final watershed was obtained. This delineated watershed resulted with different sub basins, outlets, riches, longest path, basin and stream networks. It indicates the direction of flow based on divide line and shows where these streams can be collected at low land. The general over flow chart which shows automatic watershed delineation process was shown in figure 3.12 and delineated watershed was depicted in figure 3.13.

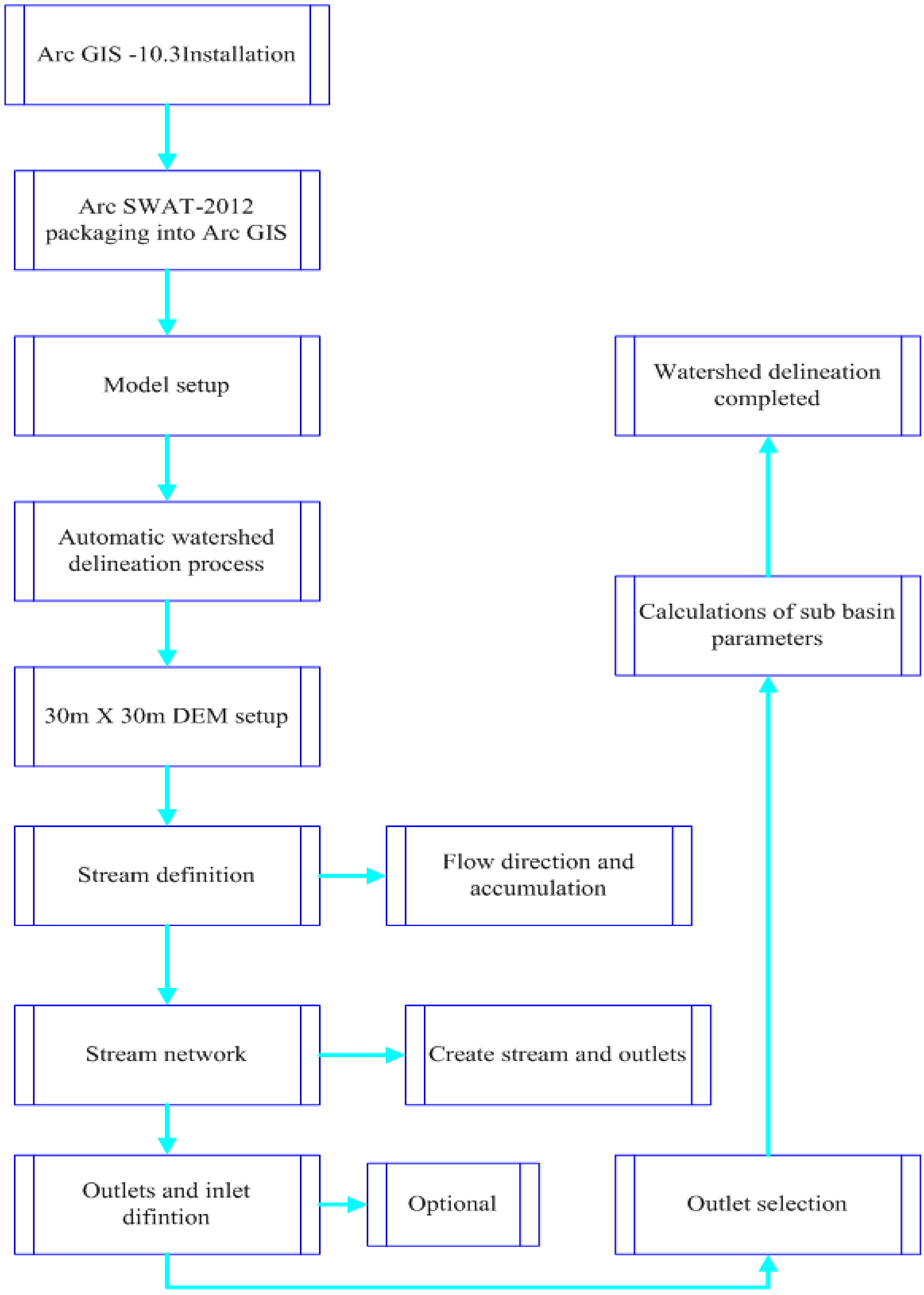

Figure 3.12: Flow chart of watershed delineation process

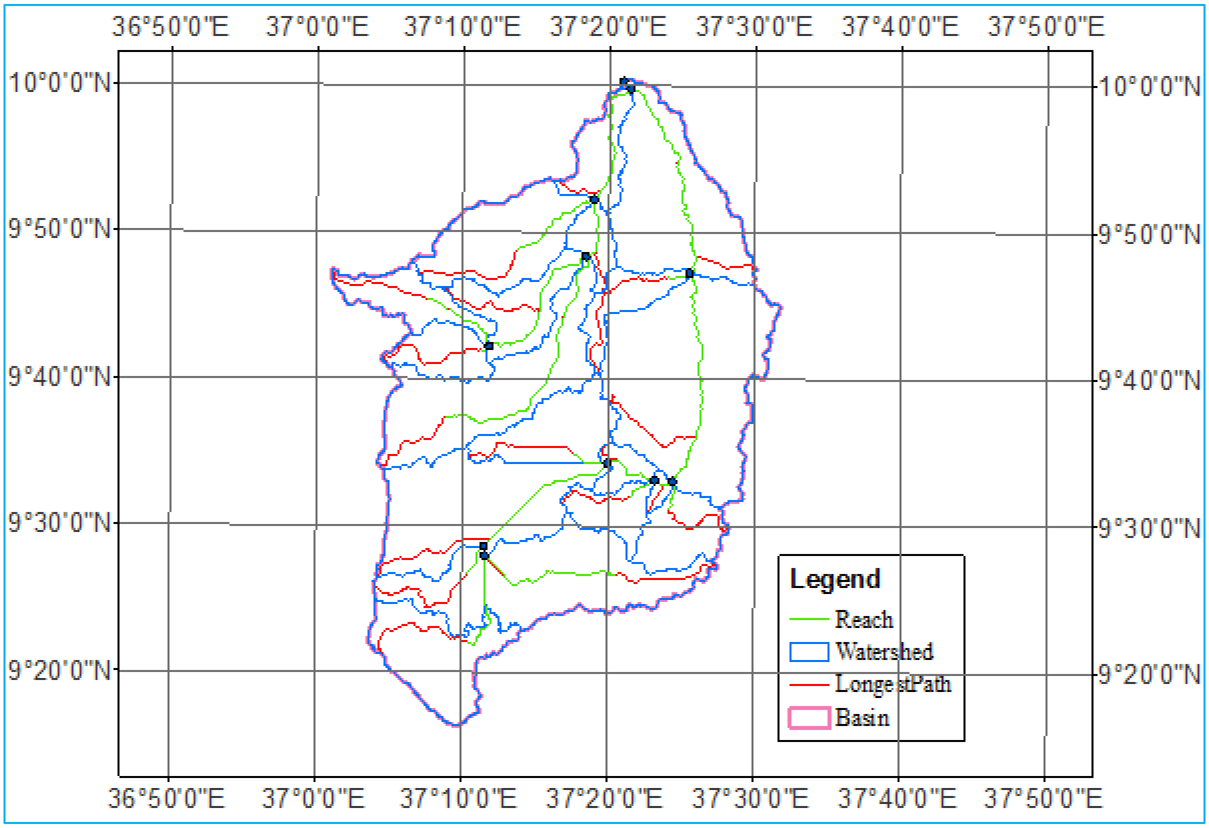

Figure 3.13: Delineated watershed and sub-basins of Fincha watershed

3.6. HRU Analysis

For analysis of HRUs, the SWAT model requires land use/cover, soil and slope layers and their threshold inputs. HRU was the basic simulation unit in SWAT model which was defined as a lumped land area comprised of a uniform land use land cover, soil type and uniform slope. HRUs enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils.

Runoff and sediment yield were predicted separately for each HRU and routed to obtain the total runoff for the total watershed. This increases the accuracy in runoff and sediment yield prediction that provides a much better physical description of the water balance rather than prediction from the whole catchment at once. The land use and the soil data was projected in shape file format and loaded into the SWAT interface to determine the area and hydrologic parameters of each land-soil category simulated within each sub-watershed.

Land use/cover of the catchment was imported from a mask and successfully 100% overlapped. The land use/land covers were loaded into the SWAT model through look up table that related to crop SWAT database. Calculation of the area covered by each land use/cover and reclassification were done alone. Similarly, the soil informations were loaded from mask and have been successfully 100% overlapped.

The layer in the map was linked to the user soil database information by loading each soil through look-up table and reclassification was applied. The slope of the catchment were classified into four multiple classes 0-3%, 3-6%, 6-9% and above 9% based on the DEM data used during the watershed delineation and the topography of the catchment and shown in figure 3.14.

Most of the catchment area has greater than 9% slope that covers about 56.43% of the total catchment area and slope (6-9) accounts about 15.82% and the slope (0-3) that accounts 15.03% of the catchment. After the reclassification of the land use, soil and slope have been finished, overlay operation was performed by creating HRUs features and full HRUs were created. The last step in the HRU analysis was the HRU analysis report. This part was used to read the reports on land use, soils and slope or on final HRU definitions and it was optional.

The next step in the HRU analysis was the HRU definition. There were different options under HRU definition. In this study, multiple HRU distribution was selected for each sub-watershed. In multiple HRU definition, a threshold level was used to eliminate minor land uses/cover, soils and slope classes in each sub-basin. In defining HRUs, the minor land use/land cover, slope and soil types were ignored by setting a threshold of 10 %, to avoid unnecessary large number of HRUs in the analysis [49].

Land uses, soils and slopes which cover less than the threshold level were eliminated. After the elimination process, the area above threshold was so that 100% used as the land area in the sub-basin have been modeled. The threshold level was a lower boundary and set as a function of the project goal and amount of detail required.

According to SWAT user manual, it is better to use a larger number of sub-basins than larger number of HRUs in a sub-basin and a maximum of 10 HRUs in a sub-basin was recommended [27]. So, based on the criteria, 10% threshold level was used for all.

Summary of HRUs analysis shown in table 3.4 for land use land cover, table 3.5 for soil and table 3.6 for slope classifications respectively

Table 3.4 Major land use/cover classes in Fincha watershed

S. No	Land use/cover category	SWAT code	Coverage Area (Km2)	Watershed area (%)
1	Bush land	RNGB	55.79	2.13
2	Dominantly cultivated	AGRR	985.52	36.599
3	Moderately cultivated	AGRL	763.12	29.138
4	Irrigated land	CORN	50.72	1.94
5	Grass land	RNGE	278.67	10.64
6	Water bodies	WATR	298.67	11.42
7	Swamp area	WETN	66.34	2.533
8	Urban	URBN	40.33	1.54
9	Woodland open	FRST	106.33	4.06
		Total	2,619	100

Table 3.5 Soil distribution in Fincha watershed

S. No	Soil category	Soil name from Map window	Coverage Area (Km2)	Watershed area (%)
1	Chromic Luvisols	Lc13_1a_127	2.6	0.1
2	Chromic Vertisols	Vc23-30-262	528.36	20.17
3	Dystric Cambisols	Bd31-2c-11	620.65	23.17
4	Eutric Cambisols	Be8-3c-24	426.27	16.28
5	Eutric Nitosols	Ne20-3b-160	21.82	0.83
6	Eutric Regosols	Re59-2c-246	545.18	20.82
7	Haplic Phaeozems	Hh23-3a-6524	34.84	1.33
8	Humic Cambisols	Bh12-3c-31	132.97	5.08
9	Water	WATER-6997	306.38	11.7
		Total	2,619	100

Table 3.6 Slope classes in Fincha watershed

S.No	Slope class (%)	Covered Area (Km^2)	Watershed area (%)
1	0-3	393.66	15.03
2	3-6	414.31	15.82
3	6-9	333.17	12.72
4	>9	1,477.92	56.43
Total		2,619	100%

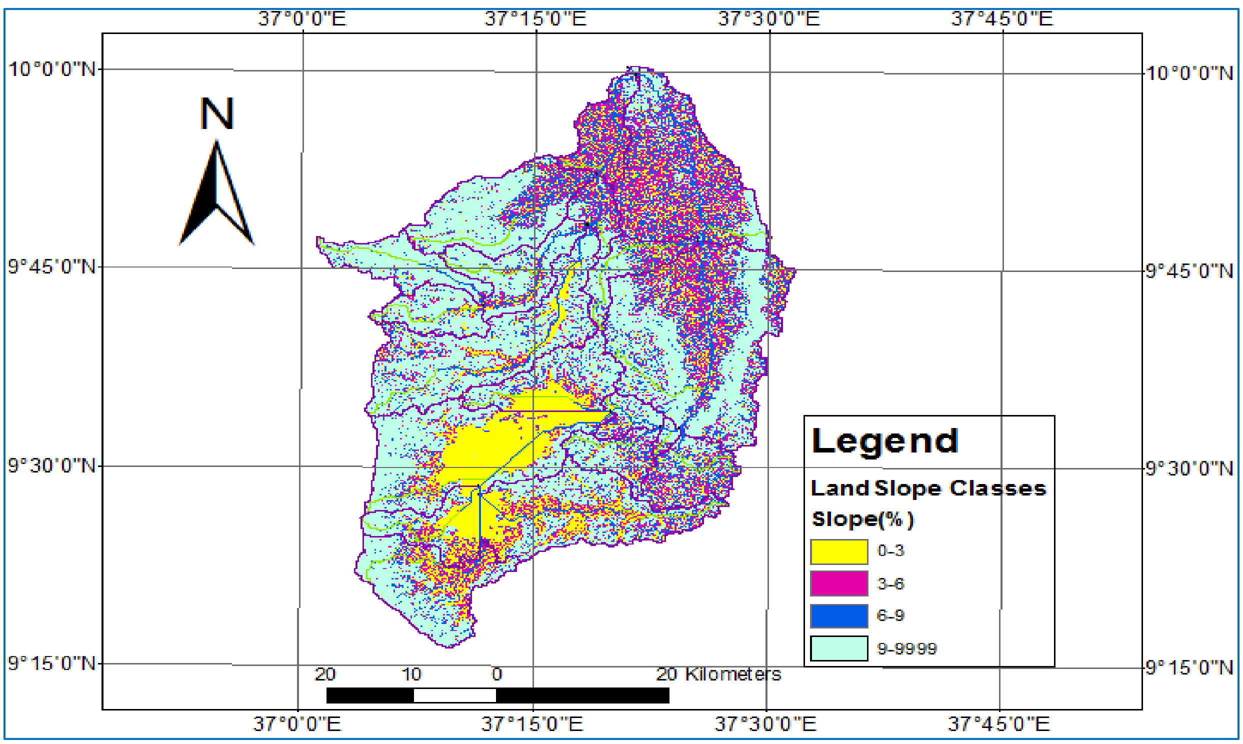

Figure 3.14: Slope classes of Fincha watershed

3.7. Write input tables

In this processes, each gauged daily weather prepared data (precipitation, maximum and mini mum temperature, solar radiation, wind speed and relative humidity) were loaded into the Arc SWAT model. These gauged data have been used to run the model and obtain the required results in order to answer the objectives of the study.

One weather generator (Shambu station) with weather parameters was defined and loaded into Arc SWAT model in order to generate missed datum for the rest stations since it was the principal station which consist all weather data. The HRU distribution was done to build up the input database files to complete generated data and to check the status of input file generation.

3.8. SWAT model Simulation

At the end, SWAT model was simulated for a period of 25 years from 1990-2014 G.C by considering the first two years as warm up period for the model. This warm up period was number of years to skip output and used to initiate model for well run. After the model simulation run was completed, 21 sub basins and 205 HRUs were created. This indicated that 205 HRUs divided by 21 sub basins that resulted with 9.76 HRUs per sub basin which was less than 10 HRUs per sub basin and it was satisfactory.

3.9. SWAT CUP 2012

SWAT CUP 2012 was generic interface developed for Arc SWAT model. It was used for parameter sensitivity analysis, calibration and validation process. SWAT CUP was used to reduce model uncertainty by removing some probable sources of modeling and calibration errors.

The main function of an interface was to provide a link between the input/output values through text file format (TxtInOut) from scenarios of the SWAT simulation. An automated model calibration requires that the uncertain model parameters were systematically changed, the model was run, and the required outputs (corresponding to measured data) were extracted from the model output files.

Uncertainty analysis was defined as the process of quantifying the level of confidence in a given model simulation output based on: (1) the quality and amount of measured data available, (2) the absence of measured data due to the lack of monitoring in certain locations, (3) the lack of knowledge about some physical processes and operational procedures, (4) the approximate nature of the mathematical equations used to simulate processes, and (5) the quality of the model sensitivity analysis and calibration.

SWAT CUP 2012 consists of five packaged programs in it. These programs were SUFI2, GLUE, Parasol, MCMC, and PSO. In this study, SUFI2 was used to identify sensitive parameters, calibration and validation values. This program was selected because of its applicability. It was powerful to quickly identify which parameters were most sensitive within a reasonable time, number of iterations when compared with the rest programs [50].

In SUFI2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data. The degree to which all uncertainties were accounted for quantified by a measure referred to as the P-factor, which was the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU) [51].

Another measure quantifying the strength of a calibration/uncertainty analysis was the R-factor, which was the average thickness of the 95PPU band divided by the standard deviation of the measured data. Theoretically, the value for P-factor ranges between 0 and 100%, while that of R-factor ranges between 0 and infinity. A P-factor of 1 and R-factor of zero was a simulation that exactly corresponds to measured data. Hence, often a balance must be reached between the two.

When acceptable values of R-factor and P-factor were reached, then the parameter uncertainties were the desired parameter ranges. Further goodness of fit can be quantified by the R^2 and/or Nash-Sutcliff (E_{NS}) coefficient between the observed and the final best simulation. A schematic of the linkage between SWAT and SUFI2 was illustrated in Figure 3.15.

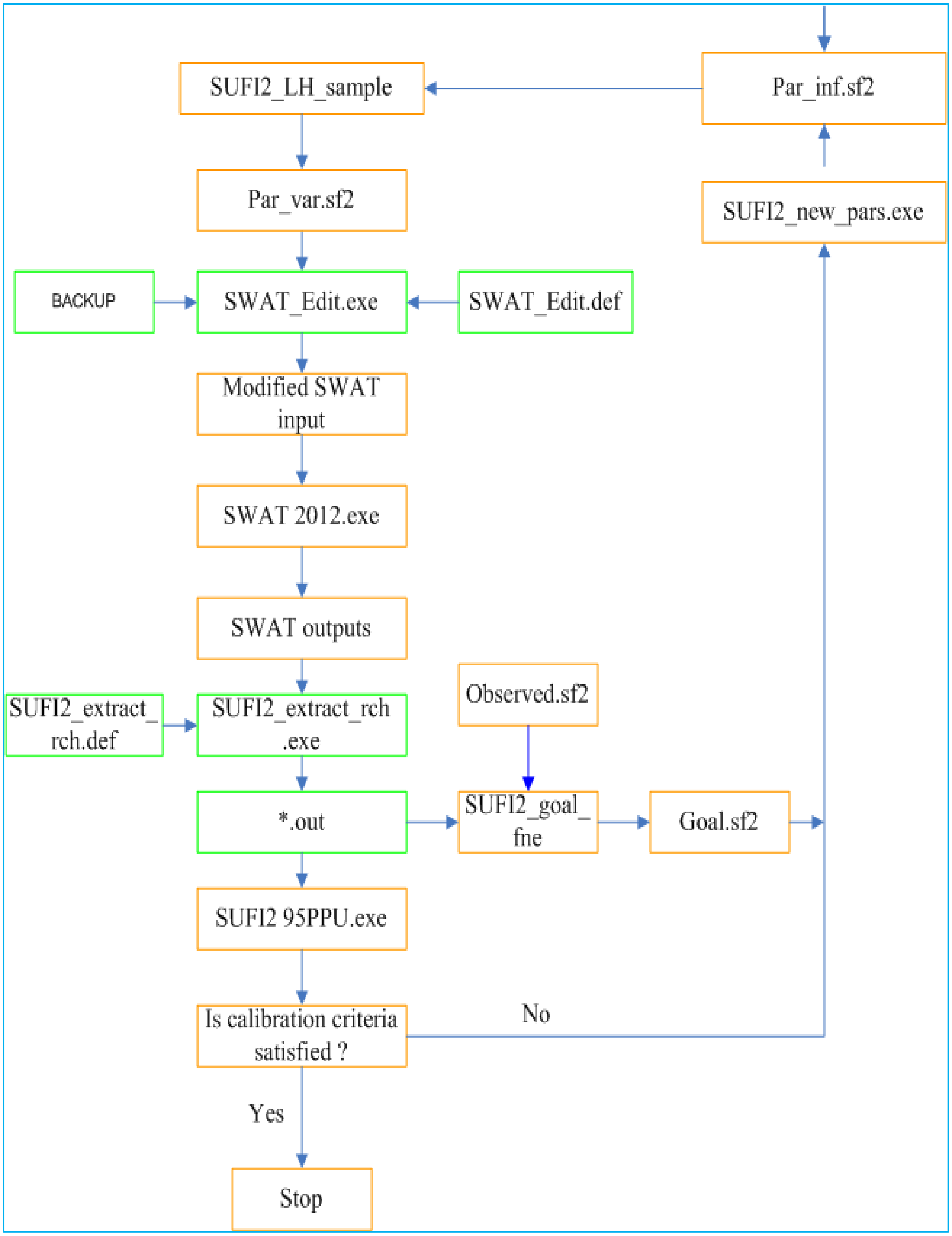

Figure 3.15: A schematic of the linkage between SWAT and SUFI2 [52].

3.10. Sensitivity analysis

SWAT was complexes model with many parameters that makes manual calibration difficult. Hence, sensitivity analysis was performed to limit the number of optimized parameters to obtain a good fit between the simulated and measured data. It can be done by one-at a time or global sensitivity analysis. One-at time method is identifying one parameter by considering the rest parameters as constant while global method was by considering the whole parameters to be under change during sensitivity analysis.

Sensitivity analysis helps to determine the relative ranking of which parameters most affect the output variance due to input variability which reduces uncertainty and provides parameter estimation guidance for the calibration step of the model [52]. SWAT CUP 2012 was used to perform sensitivity analysis and provides recommended ranges of parameter changes. This SWAT CUP 2012 ranks sensitivity parameters based on t-stat and p-value. The largest the absolute values of t-stat and the smallest p-values were the most sensitive and the most significant parameter respectively.

3.11. Calibration/Validation Procedures

The general procedures for calibration and validation according to SWAT user manual:

1st step: Hydrology (stream flow) calibration and validation- this was the first and foremost value that should be calibrated and validated before another values were calibrated and validated.

2nd step: Sediment calibration and validation – sediment should be calibrated and validated next hydrology as user manual recommends. In this study, measured sediment data were limited and not available for both calibration and validation. Due to this, rating curve was developed from the existing sediment and flow data. Using developed rating curve, sediment yield was generated and the comparison between observed, generated sediment by rating curve and simulated sediment yield by SWAT model was discussed after the stream flow was calibrated and validated.

3rd step: Water quality calibration and validation- water quality (nitrogen, phosphorus, pesticides, DO, bacteria) calibration and validation process is the last procedure. But this step is not the objective of this study.

3.12. Model calibration

Calibration is a process of model testing with known input and output used to adjust or estimate factors either by multiplying, adding or replacing with the desired value. The SWAT model includes a large number of parameters that describe the different hydrological conditions and characteristics across the watershed. Proper model calibration was important in hydrologic modeling studies to reduce uncertainty in model simulations.

There are three calibration approaches widely used by the scientific community. These are the manual calibration, automatic calibration, and a combination of the two. Manual calibration is the most widely used approach. However, it is tedious, time consuming, and success of it depends on the experience of the modeler and knowledge of the watershed being modeled [53]. Automatic calibration involves the use of a search algorithm to determine best-fit parameters. It was desirable as it was less subjective and due to extensive search of parameter, possibilities can give results better than if done manually.

The manual calibration approach helps to compare the measured and simulated values, and then to use the expert judgment to determine which variable to adjust, how much to adjust them, and ultimately assess when reasonable results have been obtained. The auto-calibration technique was used to obtain an optimal fit of process parameters which was based on a multi-objective calibration and incorporates the Shuffled Complex Evolution Method algorithms [17].

During the calibration process, model parameters were subjected to adjustments, in order to obtain model results that correspond better to the measured datasets. The hydrological components of the model were calibrated sequentially until the average simulated and measured values were in close agreement. The procedure for calibrating the model for runoff and sediment yields is shown in Figure below 3.16.

3.13. Model Validation process

Validation was a process of comparison of model results with an independent data set without further adjustment with different period and data value from the calibration. In the validation process, the model was operated with input parameters set during the calibration process and the results were compared against an independent set of observed data to evaluate the performance of model prediction.

3.14. Evaluation of model performance

Mean, standard deviation, coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (E_{NS}) are used to evaluate model prediction. The R^2 value is an indicator of strength of the relationship between the observed and simulated values and ranges from 0 to 1, with a value of 0 indicating no correlation and a value of 1 representing that the predicted dispersion equals the measured dispersion [29].

The prediction efficiency (RE) indicates the model's ability to describe the probability distribution of the observed results. If the R^2, E_{NS}, and RE values were less than or very close to zero, the model prediction is considered unacceptable or poor. If the values were one, then the model prediction was perfect. In this study, during both calibration and validation periods, the goodness-of-fit between the simulated and measured stream flow were evaluated using the coefficient of determination (R^2) and the Nash-Sutcliffe coefficient of efficiency (E_{NS}) [30].

E_{NS} was used to assess the predictive power of hydrological models and indicates how well the plot of the observed versus simulated values fit the 1:1 line. The closer the model efficiency is to 1, the more accurate the model. An acceptable calibration result of $R^2 > 0.6$ and E_{NS} values should exceed 0.5 in order for the model results to be judged as satisfactory for hydrological and sediment evaluations performed on a monthly time step. These values were also considered in the current study as adequate statistical values for accepting calibration results [29].

A p-factor, r-factor and percent bias measures the average tendency are additional factors. Percent bias measures the average tendency of the simulated data to be larger or smaller than the observations. The optimum value is zero, where low magnitude values indicate better simulations. Positive values indicate model underestimation and negative values indicate model over estimation. The R^2 and E_{NS} were defined by the equations 3.1 and 3.2 respectively:

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

$$R^2 = \frac{\left(\sum_{i=1}^{n}(O_i - \bar{O})\left(P_i - \overline{P}\right)\right)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2 \sum_{i=1}^{n}\left(P_i - \overline{P}\right)^2} \quad \text{………………………………………………………….3.2}$$

Where E_{NS}, R^2, Oi, Pi, $\bar{O}$, $\overline{P}$ and n are the Nash-Sutcliffe efficiency of the model, coefficient of determination, observed, predicted, the average observed , average predicted values and number of observations during the simulation period respectively. Calibration procedure for surface runoff and sediment is shown in figure 3.16.

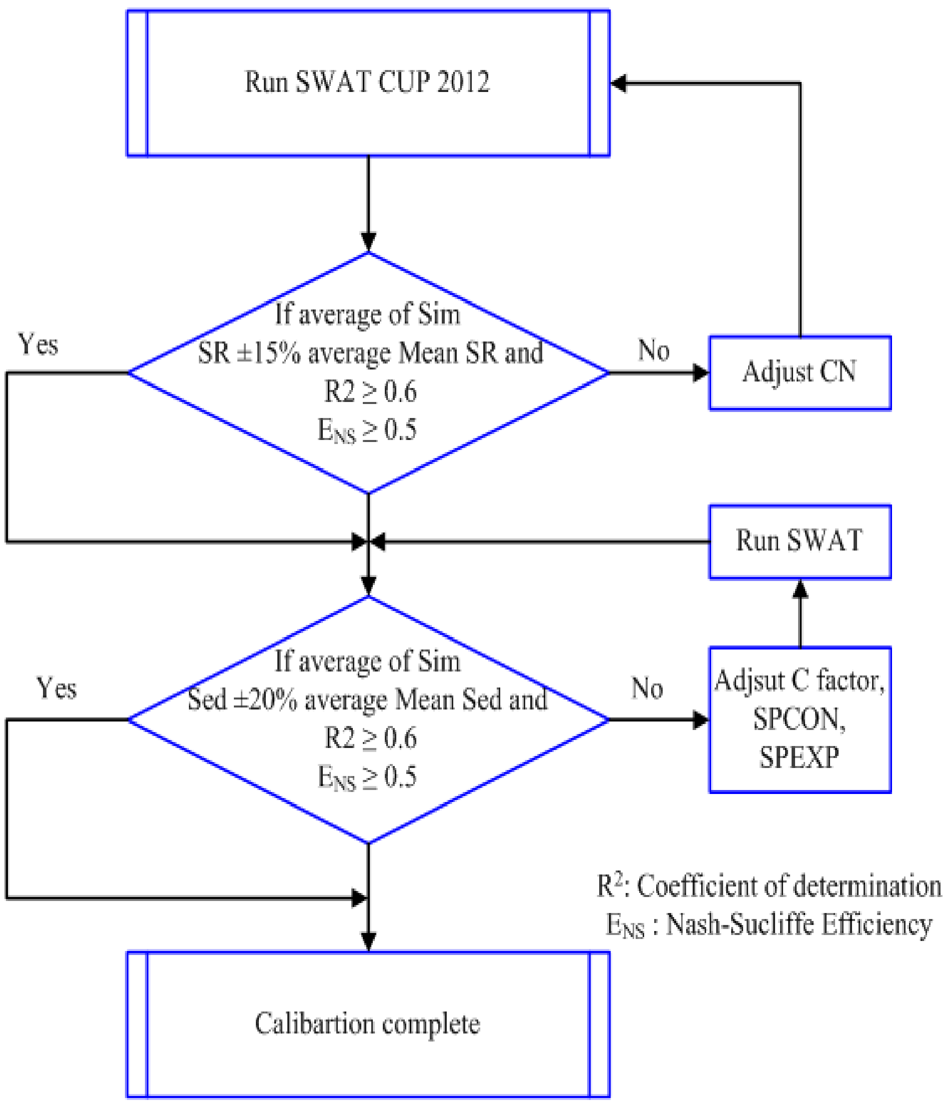

Figure 3.16: Calibration procedures for flow/runoff and sediment yields in the SWAT CUP model [53].

4. RESULTS AND DISCUSSION

4.1. Sensitivity analysis

Delineated Fincha watershed covers total area of 2,619Km^2 that consists of large number of stream flow and sediment parameters in SWAT input data. These parameters should be reduced to minimize over parameterizations during calibration using SUFI2 uncertainty program which is the package of SWAT CUP 2012 technique and used to identify most sensitive parameters.

Most sensitive parameters were determined by global sensitivity analysis. Twenty seven stream flow parameters were considered for model parameterization sensitivity analysis and only ten of them were effective for monthly flow simulation analysis. The descriptions, upper and lower boundary of the stream flow parameters were shown in Annex.

They were ranked based on the values of t-stat (the larger absolute values) and p-value (the smaller the p-value) from most sensitive and most significance to least sensitive and least significant respectively (table 4.1). The most sensitive paramteres for stream flow up to four ranks were CN2, GW_DELAY, SLSUBBSN and ALPHA_BNK.

Table 4.1 Ranked parameters for stream flow calibration uncertainties of Fincha watershed

		Global sensitivity		
S.No	SWAT Input Parameter	t_stat	P_value	Rank
1	CN2.mgt	-15.36596	0.00000	1
2	GW_DELAY.gw	-8.91245	0.00000	2
3	SLSUBBSN.hru	-4.27224	0.00003	3
4	ALPHA_BNK.rte	-3.03717	0.002495	4
5	CH_K2.rte	1.74481	0.081547	5
6	CH_N2.rte	1.63902	0.10175	6
7	SURLAG.bsn	1.06582	0.28695	7
8	SOL_K. sol	1.03595	0.300655	8
9	GW_REVAP.gw	0.76129	0.446795	9
10	ALPHA_BF.gw	0.73993	0.459642	10

4.2. Stream flow calibration

The stream flow calibration has been done for a period of eight years from 2000-2008 based on monthly values by considering one year for warm up period. The model was automatically calibrated using SWAT CUP 2012; SUFI2 based on the selected 10 most sensitive parameters at outlet of the watershed where there was available recorded data.

The values of coefficient of determination, R^2 and Nash-Sutcliffe, E_{NS} has been computed from monthly observed and simulated flows for model testing. The computed values of R^2 and E_{NS} during calibration were 0.81 and 0.76 respectively. These values indicated that, there was good agreement between simulated and observed stream flow on monthly basis with the selected sensitive parameters. The results of P-factor and R-factor during calibration were 0.73 and 0.77 respectively which are closer to each other.

The comparison between observed and simulated discharges during the calibration period was shown in figure 4.1. The time series data of the observed and simulated flows on monthly basis was plotted for visual comparison to explore the similarity within the peak values resulting from the procedures of SUFI2. The scatter plot of monthly stream flow that shows a well-fitting between observed and simulated values for calibration (figure 4.2).

From the calibration periods, the model over estimate peak monthly flow in 2000, 2002, 2003, 2007 and underestimate the peak monthly flow during 2001, 2004, 2005, 2006 and in the last three years of the simulation periods. But, the graph was almost smooth from 2002-2006 indicated that observed and simulated stream flow were well matched. The green colour indicate the predicted percentage of uncertainty (95PPU) which shows the closeness of agreement between the measured and the observed flow with 95% good fit.

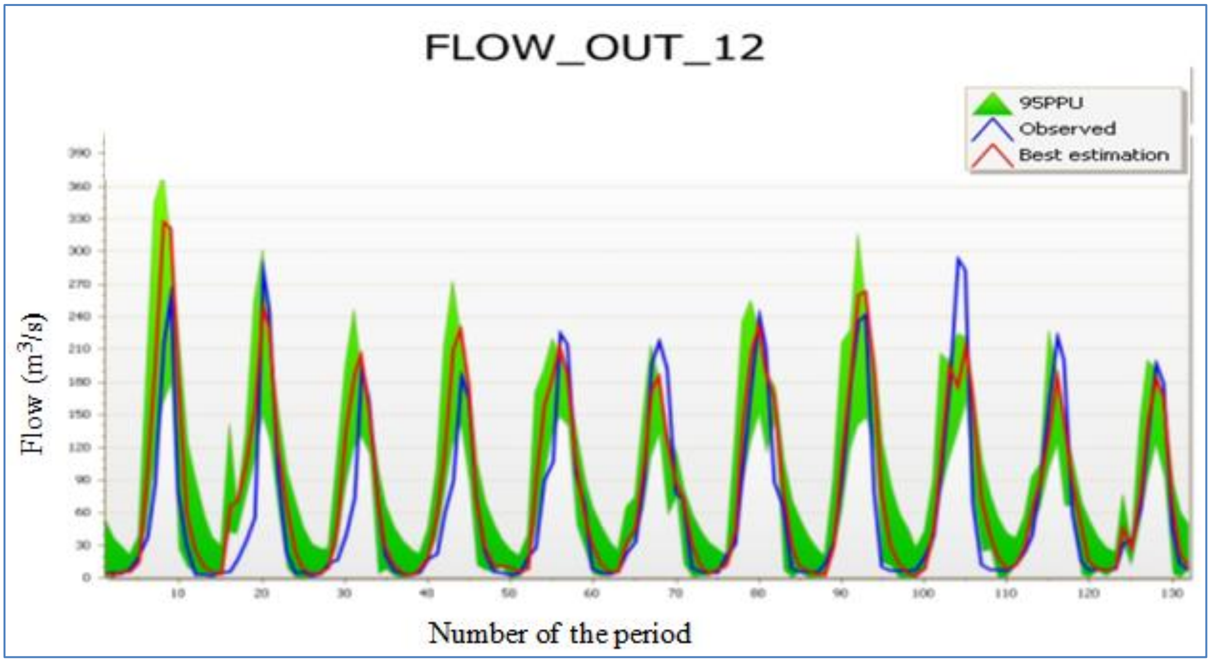

Figure 4.1: 95PPU, observed and simulated monthly stream flow of Fincha watershed during calibration period 2000–2008

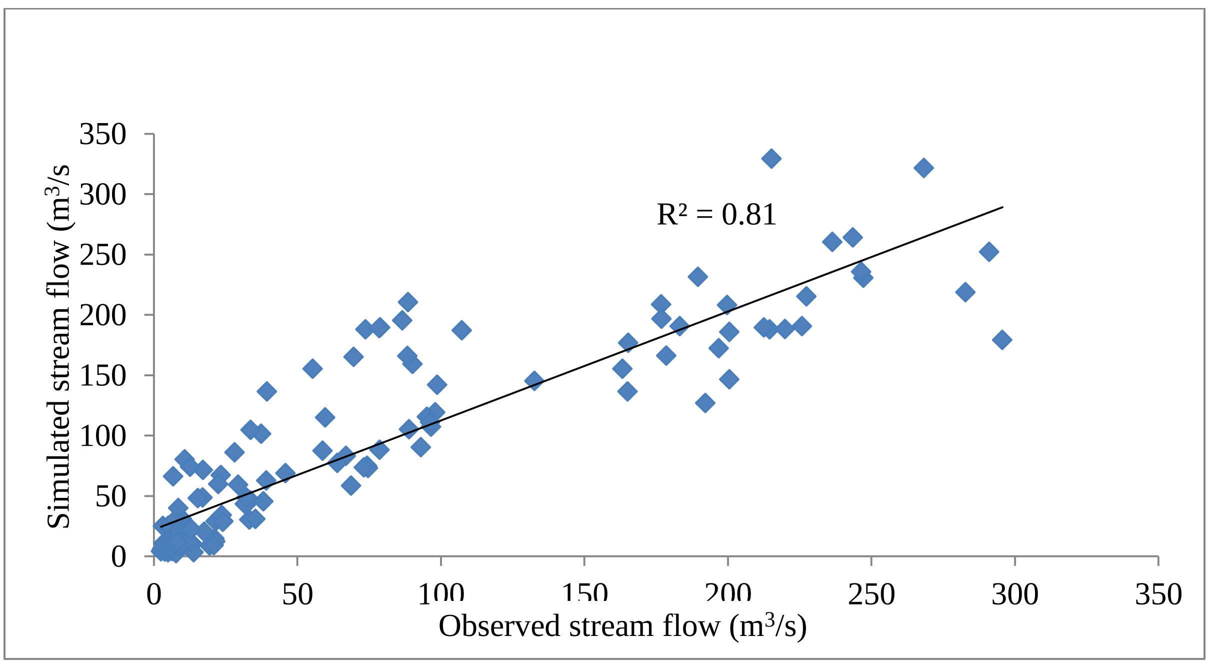

Figure 4.2: Scatter plot of observed vs. simulated stream flow of Fincha watershed during calibration from 2000 – 2008

4.3. Stream flow validation

The calibrated model parameters of Fincha watershed can be transferable to stream flow validation model parameter since the model performance criteria during calibration, R^2 and E_{NS} were satisfied. Validation process has been performed for a period of five years from 2009-2014 based on monthly values by providing one year for warm up period. The model was operated with the same input parameters set during the calibration process without further adjustment and the results were compared to the remaining observational data to evaluate the model prediction capability

The results of coefficient of determination, R^2 and Nash-Sutcliffe, E_{NS} during validation model were 0.78 and 0.74 respectively. These values indicate that simulated stream flow matched well with observed values and the model can predict stream flow in Fincha watershed for the remaining data and for the feature. Time series plots and statistical measures were used to verify model predictions. Graphical visualization of observed and simulated stream flow and its scatter plot for validation were presented in figure 4.3 and figure 4.4 respectively.

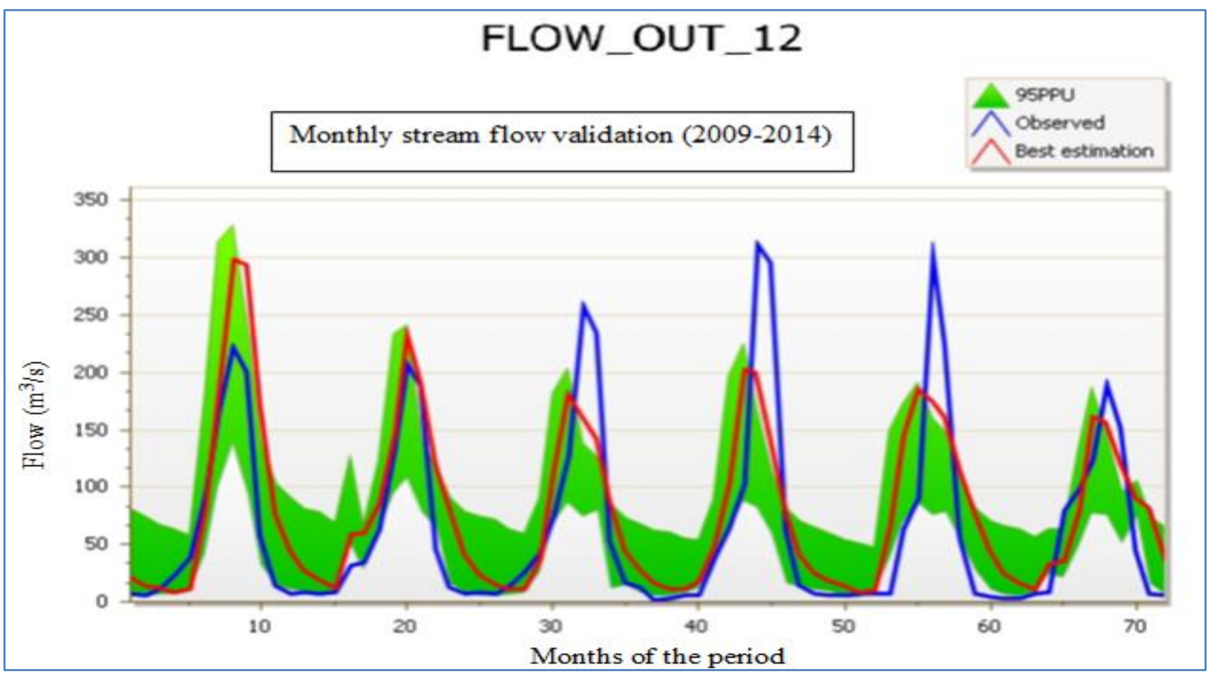

Figure 4.3: 95PPU, observed and simulated monthly stream flow of Fincha watershed during validation period 2009–2014

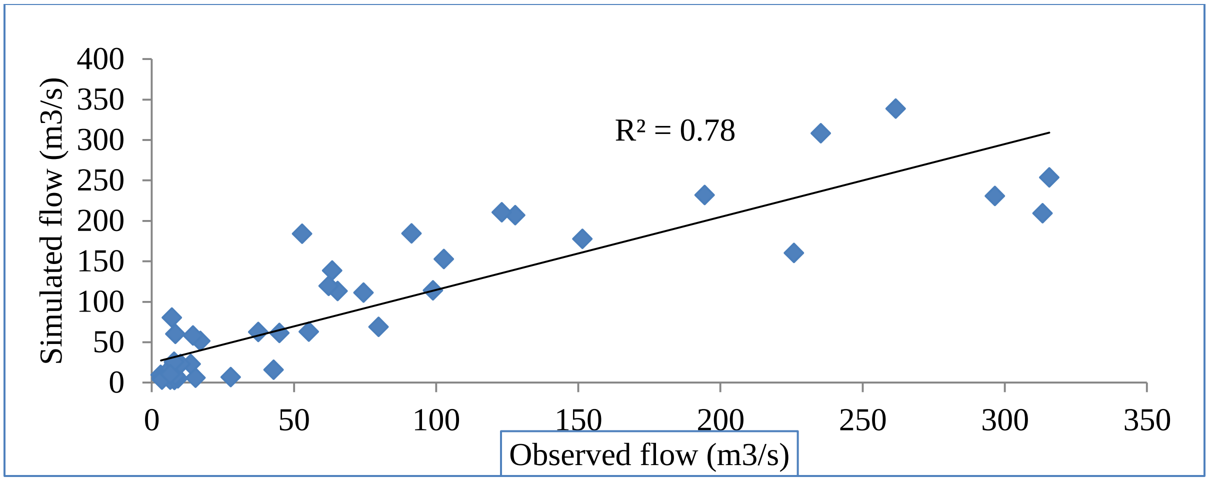

Figure 4.4: Scatter plot of observed vs. simulated stream flow of Fincha watershed for validation from 2009 – 2014

4.4. Evaluation of model performance

Based on the results of R^2 and E_{NS} during calibration and validation, the model was evaluated and summarized in table 4.2. From the value of percent bias in table 4.2, the model under estimate in some years since the value is positive. But, based on the results of R^2 and E_{NS}, SWAT model has good capacity to predict stream flow for the remaining data and for the feature in Fincha watershed since the performance criteria was satisfied.

Table 4.2 Summary of calibrated and validated performance criteria's for stream flow of Fincha watershed

Performance criteria'	Calibration from (2000-2008)		Validation from (2009-2014)	
R^2	0.81		0.78	
E_{NS}	0.76		0.74	
P_factor	0.73		0.77	
r_factor	0.85		0.87	
PBIAS	36.1		47.2	
	Observed flow (m^3/s)	Simulated flow (m^3/s)	Observed flow (m^3/s)	Simulated flo w (m^3/s)
	7,499.39	9,491.15	4,958.19	5,815.03

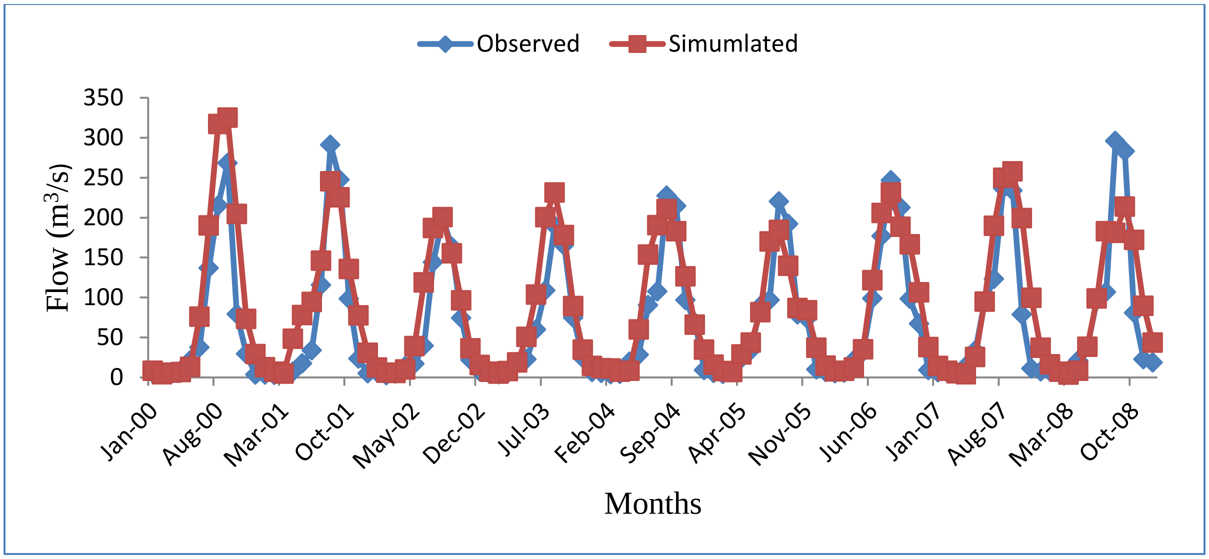

Figure 4.5 Comparison of observed and simulated stream flow during calibration 2000-20008

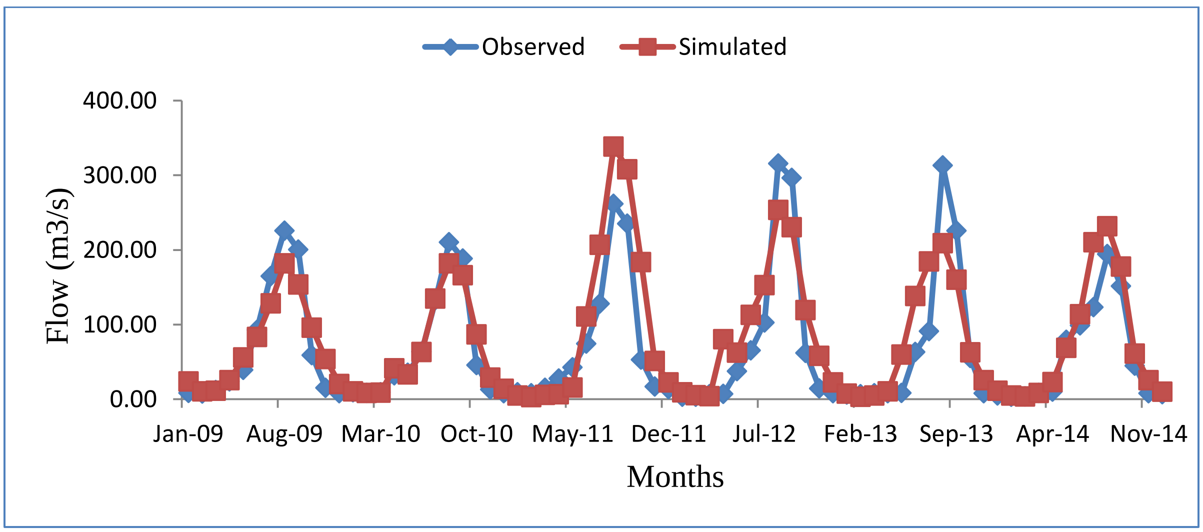

Figure 4.6 Comparison of observed and simulated stream flow during validation 2009-20014

A) Comparison of stream flow/runoff sensitive parameters in this study with other research papers

Concerning with stream flow analysis of sensitivity parameters, most researchers were concluded that curve number was most sensitive parameter. Research papers that agree with this idea were:

Micheale Berhane (2015) studied on Runoff and Sediment Yield Estimation in Western part of Ziway Lake Watershed, Central Ethiopia, Gebremicael.Y *et al.*, (2016) studied on Trend analysis of runoff and sediment fluxes in the Upper Blue Nile basin, Mohammad E. (2016) studied on Annual Runoff and Sediment in Duhok Reservoir Watershed Using SWAT.

Gebremicael.Y *et al.,* (2016) studied on Trend analysis of runoff and sediment fluxes in the Upper Blue Nile basin,

Mohammad E. (2016) studied on Annual Runoff and Sediment in Duhok Reservoir Watershed Using SWAT.

Therefore, these researchers agreed with the idea that curve number was the most sensitive stream flow/runoff parameter when compared with the rest parameter. Also, according to this study the most sensitive stream flow/runoff was curve number. This indicated that, to check good agreement between observed stream flow and simulated values based on model performance criteria, the first parameter to be adjusted is curve number.

So, after sensitive parameters were adjusted during calibration period and the performance criteria were met, most researchers agreed that model has good capacity to predict runoff since it was satisfactory in most cases. Also, in this study, the SWAT model was good model predictor for runoff prediction because of good agreement between observed and simulated in general.

4.5. Relationship between rain fall and surface runoff

Rain fall and surface runoff have direct relationship in most cases. This means as rain fall increases, surface runoff also increases and as rain fall decreases, runoff also decreases. But, their relationship was based on different factors such as magnitude of rain fall or rain fall intensity, characteristics land use land cover, soil type, soil properties, average slope of sub basin, topography, climatic conditions and duration of rain fall.

According to study rainy season starts from June through September and high rain fall was occurred July to August that results with high surface runoff. As duration and magnitude of rain fall increase, surface runoff also increase since soil moisture become saturated but depends on soil type. In this study, the relationship between rain fall and surface runoff was presented in figure 4.7. Also, the from the scatter plot in figure 4.8, formation of surface runoff was highly dependent on amount of rain fall since coefficient of determination, R^2 from linear relationship between rain fall and surface runoff is 0.99.

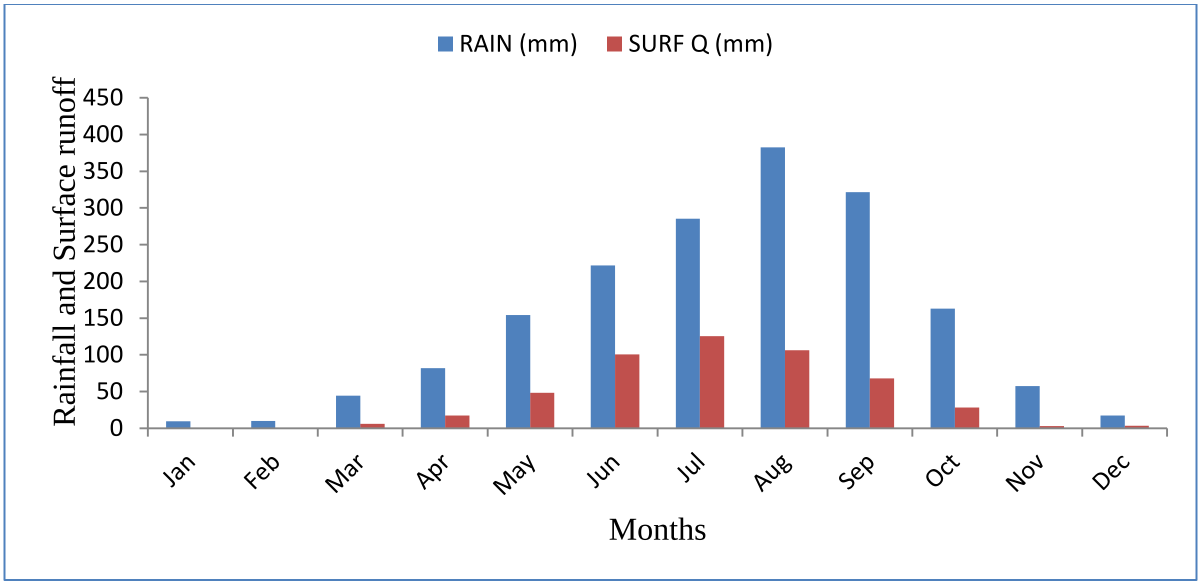

Figure 4.7: Relationship between monthly rain fall and surface runoff

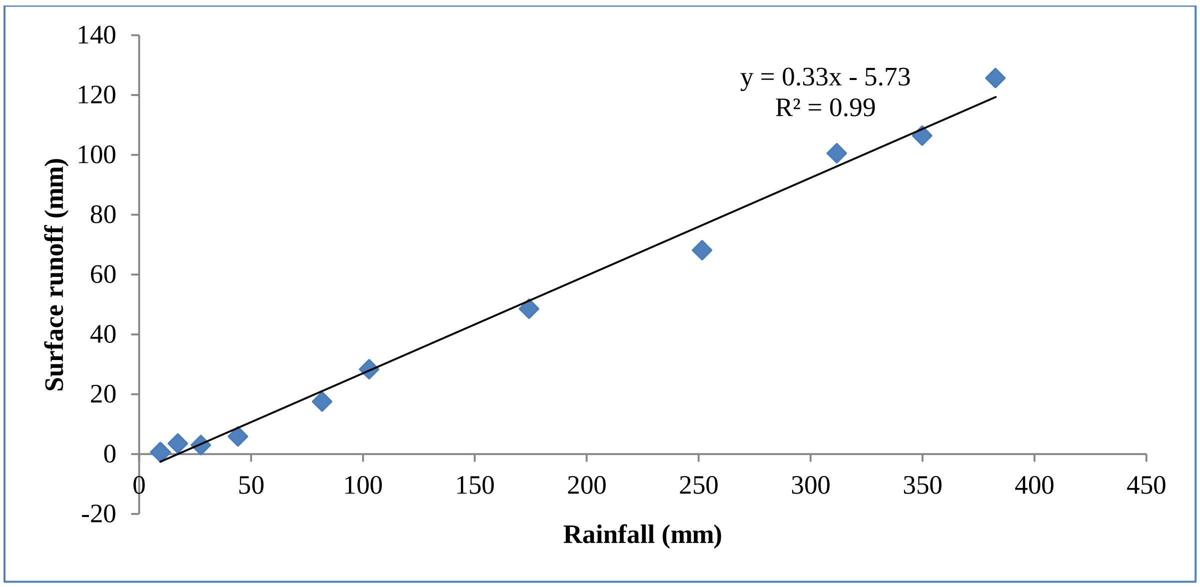

Figure 4.8: The scatter relation between monthly rainfall depth and surface runoff.

4.6. Surface runoff discussion at sub basin level

Discussing surface runoff at sub basin level was important since in order to identify which parts of catchment were under high runoff. Not all sub basins of the catchment generate uniform surface runoff since they have different LULC, soil types and the slopes. Even in each sub basin, there are lots of HRUs that gave different values of surface runoff.

The highest and lowest runoff were generated from sub basins (4, 5) and (8. 11) with the value was 567.4 mm and 10 mm respectively. So, based on these two values, surface runoff control mechanism should be applied on sub basins 4 and 5 before applying for sub basins 8 and 11.

The spatial distributions of average surface runoff over sub basins were classified into four classes based on the obtained results and presented in table 4.3 and figure 4.9. The first class was from sub basins 2, 4, 5, 13, 14 and 16 that ranges from 347.1 mm to 567.4 mm. The second class was from sub basins 1, 3, 6, 9, 15 and 17 that range from 216.9 mm to 347.1 mm. The third class was from sub basins 7, 10, 12 and 20 that range from 161.4mm to 216.9mm. The last class was from sub basins 8, 11, 18, 19 and 21 that range from 10 mm to 161.4 mm.

An average annual surface runoff generated from all sub basins was 242.7 mm in depth and 6.9 X 10^5 m^3 in volume. Sub basins 2, 4, 5, 13, 14 and 16 were high surface runoff that covers 35.06 % of the watershed when compared to the rest sub basins. These problems may due to topography, soil properties, land use land covers, poor watershed managements, etc.

It was necessary to know the spatial distributions of average surface runoff over sub basin to determine which part of the catchment was under high runoff that can lead for the formations of soil erosion. So, based on the spatial distributions of average surface runoff, the stakeholders should take appropriate decisions in order to control soil erosion problems and watershed management practices for present and for features.

Table 4.3. Statistical surface runoff classifications and percentage area they cover

Surface runoff (mm)	Sub basins	Area ratio (%)
10 - 161.4	8, 11, 18, 19 and 21	17.46
161.4 - 216.9	7, 10, 12 and 20	22.79
216.9 - 347.1	1, 3, 6, 9, 15 and 17	24.7
347.1 - 576.4	2, 4, 5, 13, 14 and 16	35.06

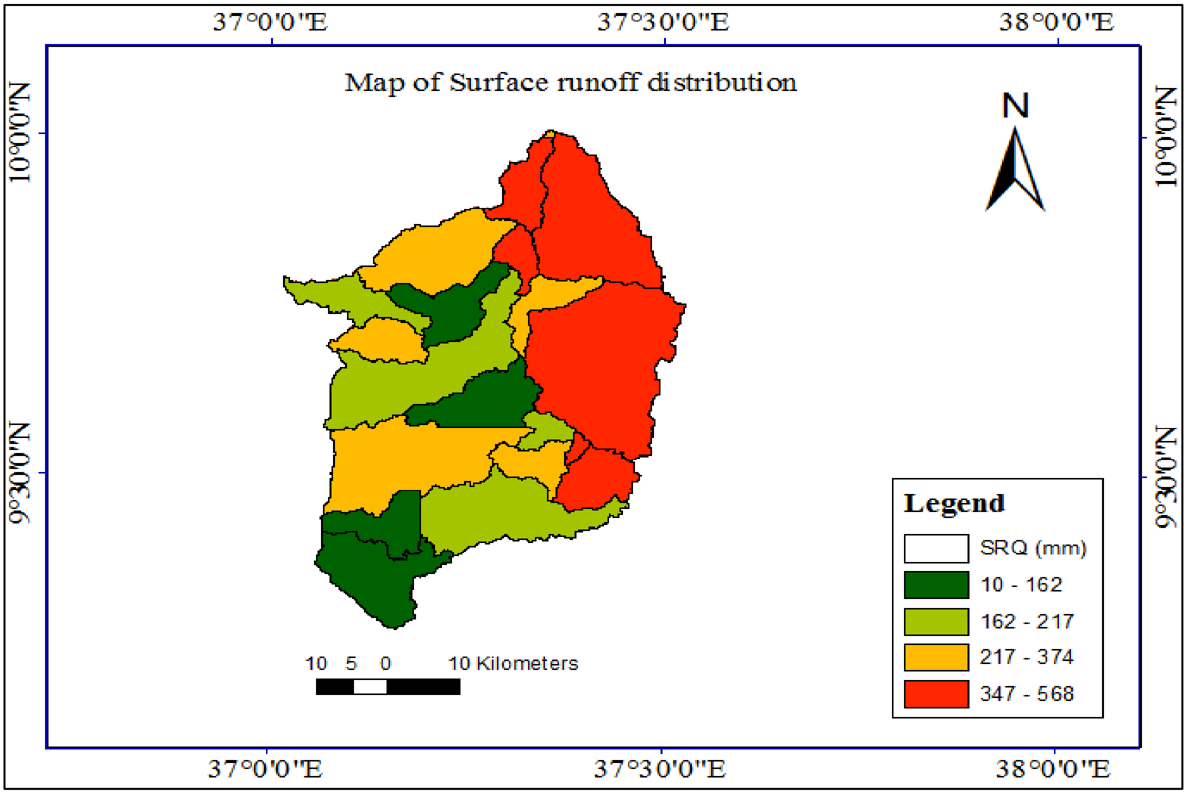

Figure 4.9 Spatial distributions of average surface runoff over sub basins

4.7. Relationship between rain fall, surface runoff and Sediment yield

Rain fall and surface runoff have direct impact on the formation of sediment yield. Their impact were based on different factors such as magnitude of rain fall or rain fall intensity, characteristics land use land cover, soil type, soil properties, average slope of sub basin, topography, climatic conditions and duration of rain fall.

As duration and magnitude of rain fall increase, surface runoff also increase and sediment yield also increased but it depends on soil type. As sediment yield from the catchment increased due an increment of surface runoff, soil losses it's fertility that can affect agricultural outputs. As sediment yield to the Fincha hydropower increased, the capacity of the reservoir decreased due to saltations.

This indicates that the water bodies became polluted and flooding may occur due overtopping which can affect the communities and the environment located at downstream of the dam. Therefore, good controlling mechanisms should be applied to protect Fincha hydropower reservoir, the communities and the environment. The relationship between rain fall, surface runoff and sediment yields was presented in figure 4.10.

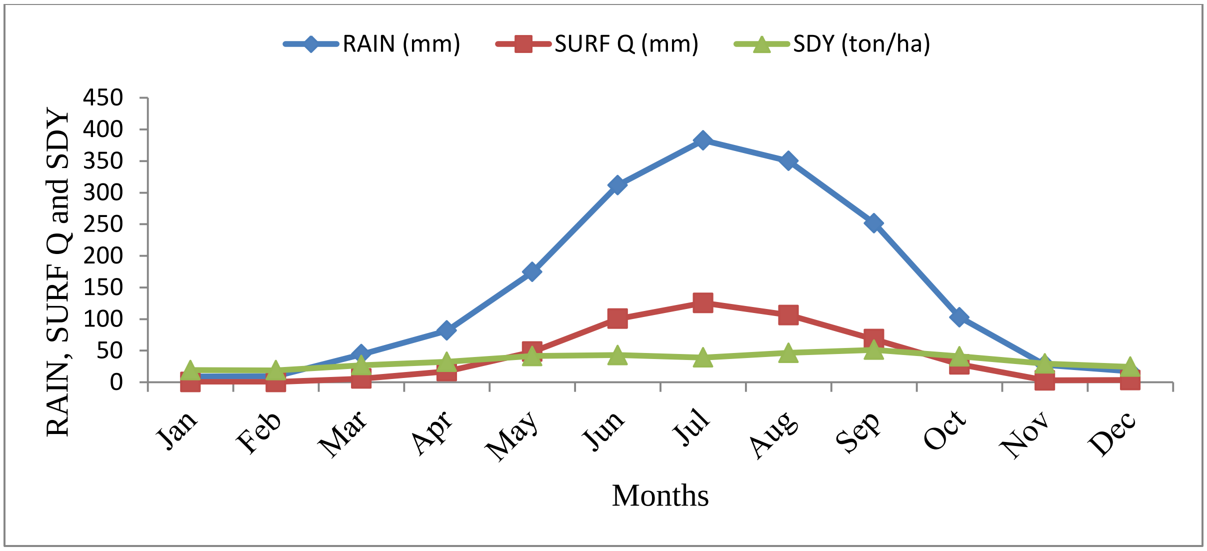

Figure 4.10: Relationship among rainfall, surface runoff and sediment yield based on average monthly basin values

Sediment was transported from point of detachment to outlet as a function of surface runoff. Not all detached from original location reach the remotest outlet as a function of surface runoff. Depending on size of detached soil and characteristics of the catchment, some of them were remain in before reaching the outlet of the watershed.

The relationship between surface runoff and sediment yields have been checked by time series plot in figure 4.11 and by scatter plot of annual surface runoff and annual sediment yield in figure 4.12. Therefore, controlling runoff formation was indirectly minimizing soil erosion, managing amount of sediment yielded from the catchment and reducing sediment deposition into the reservoir.

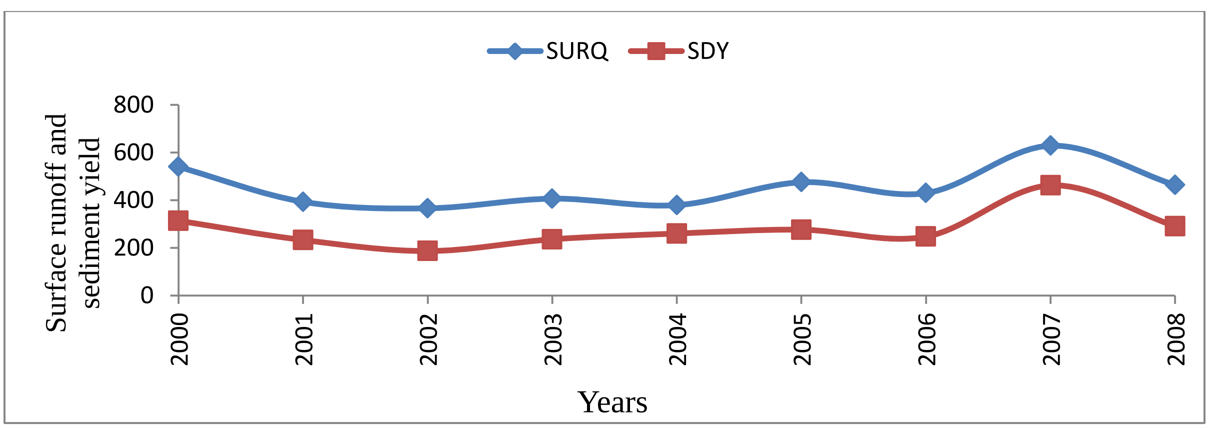

Figure 4.11: Time series plot of surface runoff and sediment yield from 2000-2008

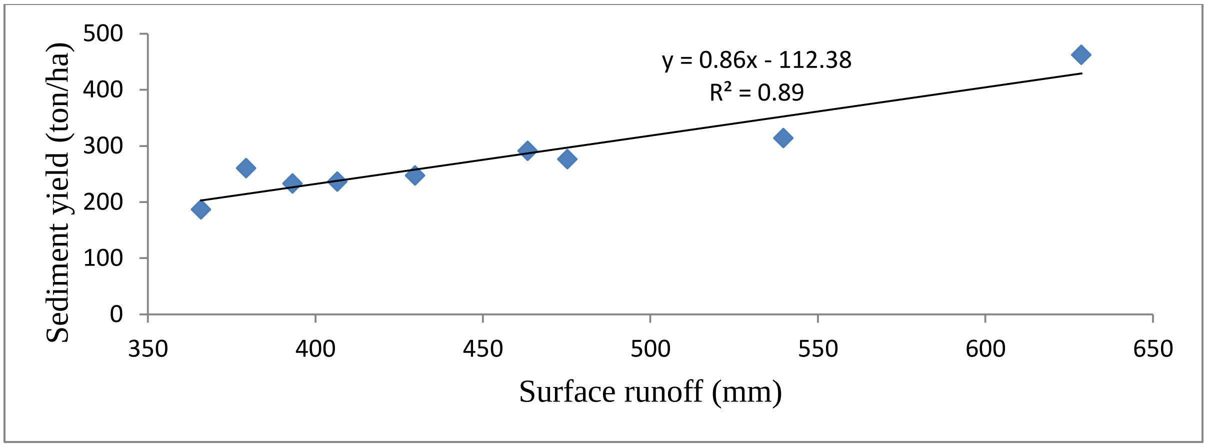

Figure 4.12: Scatter plot of annual surface runoff and annual sediment yield 2000-2008

Annual percentage distribution of surface runoff and sediment yield over sub basins were shown by pie charts in figure 4.13 (a) and (b) respectively. From annual percentage distribution, the highest and lowest percentage of surface runoff was occurred in 2007 (15.4%) and in 2002 (9.29%) respectively.

Similarly, the maximum and minimum percentage of sediment yield was occurred in 2007 (18.44%) and in 2002 (7.44%) respectively. Predicted percentage spatial distributions of both surface runoff and sediment yields were an input raw data for Fincha watershed management practices, environmental protection, water pollution reduction, minimize their impacts on aquatic life and Fincha hydropower reservoir protection. Based on these trends, responsible person (stakeholders), farmers, government and decision makers can check and recheck watershed management practiced in these years and can find the solution for the feature.

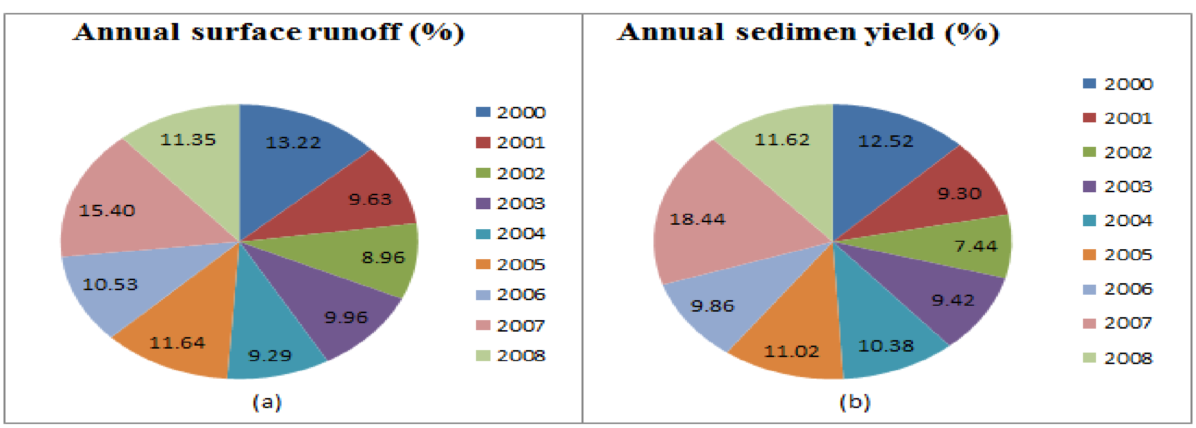

Figure 4.13: Annual percentage distributions of surface runoff (a) and sediment yield (b)

4.8. Sensitivity analysis, calibration and validation of Sediment yield

The measured sediment data in Fincha watershed were limited. So, it was difficult to determine sediment sensitive parameters, calibration and validation process with limited data. Daily sediment yield was generated using developed rating curve and compared with the predicted sediment yield from SWAT output after the stream flow was calibrated. When generated sediment yield was compared with simulated sediment yield from 2000-2008, most simulated values were much higher than that of generated sediment concentration by rating curve.

That means rating curve under estimate due to different factors such as limited data since as number of data decrease, accuracy and precisions also decrease and vice versa. Another factor was computations of constants, coefficient and exponent constant from scatter point data using least square regression technique. The model over estimate when compared with generated values.

Also, it was over predicted when compared with the limited observed sediment data. These problems were not the problems of the model rather than the problems of availabilities of measured data since the model has good simulation capacity for sediment yield based on the results of different research paper when there were available measured data.

4.8.1 Reviewed research papers of other researchers on Runoff and Sediment yield estimation using SWAT model with available measured sediment data were:

1) Mohammad E. (2016) studied on Annual Runoff and Sediment in Duhok Reservoir Watershed Using SWAT

The researcher came up with the results of R^2 = 0.94 and E_{NS} = 0.73 indicated that SWAT model was good predictor model.

2) Kaleab Habte (2013) studied on Runoff and Sediment Modeling Using SWAT in Gumera Catchment, Ethiopia

In his study, the computed values of R^2 and E_{NS} were 0.61 and 0.60, for calibration and R^2 and E_{NS} 0.84 and 0.83, during validation respectively.

The researcher concluded that model performance evaluation reasonably satisfied and the SWAT model was capable of predicting runoff and sediment yields from Gumera catchment.

3) Micheale Berhane (November 2014) studied on Runoff and Sediment Yield Estimation for Western part of Ziway Lake Watershed, Central Ethiopia

The researcher conclude that, there was good agreement between simulated and measured sediment that demonstrated by correlation coefficient (R^2) = 0.87, Nash-Sutcliffe model efficiency (E_{NS}) = 0.62 respectively during calibration.

Since the measured data was not available on sediment yield, only the modeled data has been used to identify the impact of adjusting a parameter value on some measure of simulated sediment output. Accordingly, most sensitive parameters ranked 1 to 7 were re-entrainment parameter for channel sediment routing (SPCON), channel cover factor (CH_COV), USLE support practice factor (USE_P), USLE land cover factor(USLE_C), channel erodibility factor (CH_EROD), CH_K2 and exponent of re-entrainment parameter for channel sediment routing (SPEXP) respectively

4.9. Sediment yield discussion at HRUs of sub basin level

The assessment of the spatial variability of sediment yield at HRU and sub basin level was useful to control environmental impacts, watershed management planning and reservoir protection. From SWAT model simulation outputs, 21 sub basins and 205 HRUs were created. Based on sub basin level sediment yield from each sub basin was not uniform since their HRUs were different.

The highest and lowest average sediment yield were generated from sub basin 11 and sub basins (19, 21) with their corresponding values were 64.7 ton/ha and 0.3 ton/ha respectively. This indicates sub basin 11 was under high soil erosion and the most prone area of Fincha watershed at sub basin level when compared with the rest sub basins. Therefore, this part of the watershed was the highest prone area from 21 sub basins in Fincha watershed and requires first management practices to minimize soil erosion.

To identify the vulnerable area of the catchment, it is important to see the spatial distributions of sediment rate over the watershed. So, accordingly soil erosion rate were classified into four classes based on the result obtained and classifications of erosion rates in the Ethiopian high lands.

The first class was from sub-basins 1, 11 and 14 that cover an area of 13,100 ha (5 %) and ranges from 50.6 to 64.7ton/ha/yr. The second class was from sub-basins 3, 7, 8, 9, 12, 13, 15, 16, 17 and 20 covers area of catchment 154,200 ha (59 %) and ranges from 22.4 to 50.6 ton/ha/yr.

The third class was from sub-basins 4, 5, 6, and 10, that covers area of 63,467 ha (24.24 %) and ranges from 11.7 to 22.4 ton/ha/yr. The last classification was from sub-basins 2, 18, 19 and 21 covers an area of 31,200 ha (12 %) and having soil erosion ranges 0.3 to 11.7 ton/ha/yr. From the spatial distributions of soil loss rate classes, sub basins 1, 11 and 14 were the most prone areas of the catchment by comparing with the rest classes.

Since these sub basins have sediment yield above 50 ton/ ha/yr, it indicates there was high sediment yield from the watershed to Fincha hydropower. Based on the spatial distributions of soil losses, the stakeholders should plan and implement best watershed management practices in order to protect the environment, minimize water pollution, minimize sediment impact on Fincha hydropower reservoir, protect aquatic animals, etc. The statistical data of the soil loss class and corresponding area ratios and the spatial distributions were presented in table 4.4 and shown in figure 4.14 respectively. The average annual sediment yield from total sub basins was 25.7 ton/ha.

Table 4.4 Statistical data of the soil class and their corresponding coverage areas

Soil loss rate (ton/ha/yr.)	Sub basins	Area (Km^2)	Area ratio (%)
0.3-11.7	2, 18,19,21	312	12
11.7-22.4	4, 5, 6, 10	635	24
22.4 -50.6	3, 7, 8, 9, 12, 13, 15, 16, 17, 20	1542	59
50.6 -64.7	1, 11, 14	131	5
	Total	2,619	100

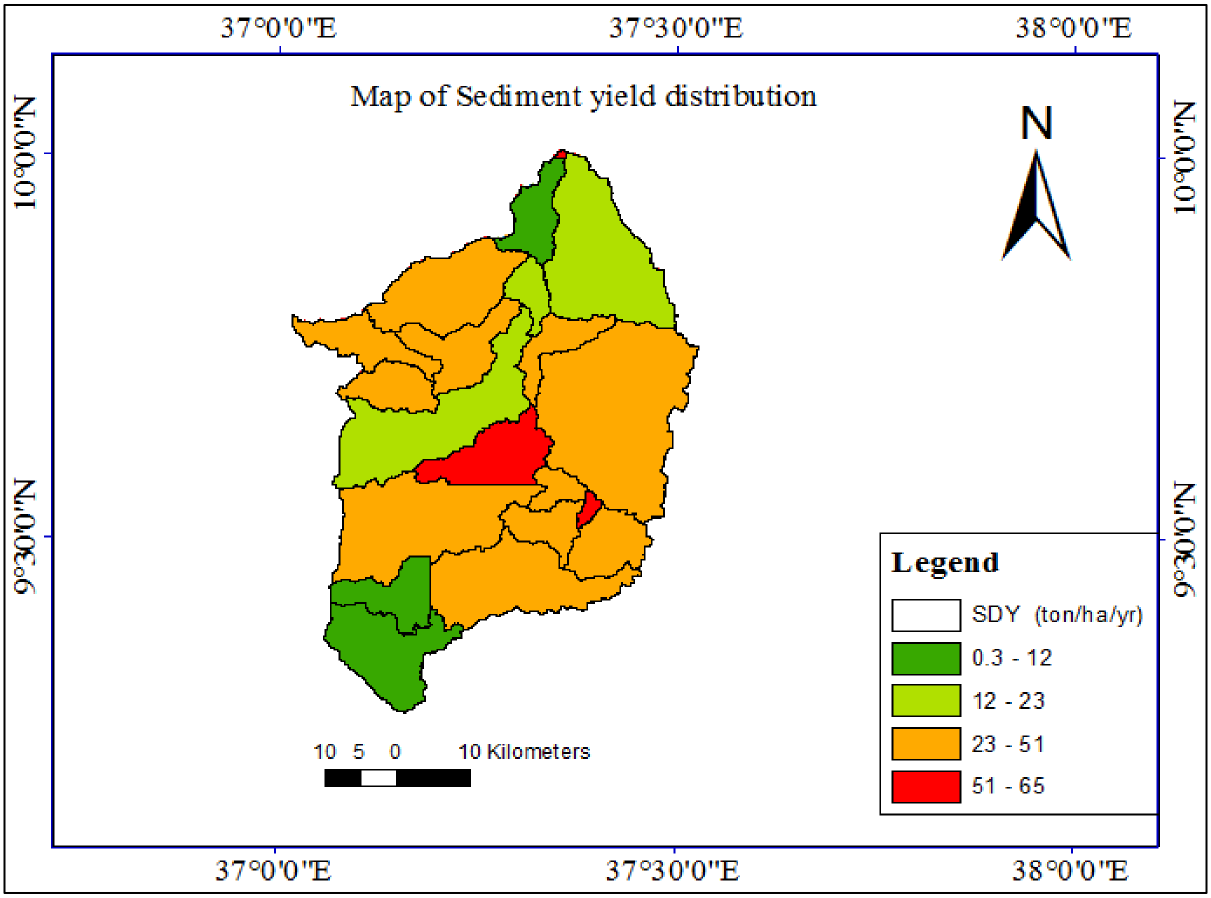

Figure 4.14: Sub basin based spatial distributions of sediment yield in Fincha watershed

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The SWAT model was simulated for twenty five years from 1990 to 2014. The simulated model gave twenty one sub basins, two hundred five HRUs, catchment size of 2,619 Km^2 and other results used as an input data in SWAT CUP. From the HRUs results, there were nine land use land cover and nine major soil types were obtained. SUFI2, uncertainty analysis in SWAT CUP was used to analyze stream flow sensitivity analysis, stream flow calibration and stream flow validation.

Parameters sensitivity analysis for stream flow was performed using SUFI2 and ten most sensitive parameters have been selected based on the largest absolute value of t-stat and the smallest p value (the most sensitive and most significant). The stream flow calibration has be en done for a period of eight years from 2000 to 2008 based on monthly values by considerin g one year for warm up period.

The values of coefficient of determination, R^2 and Nash-Sutcliffe, E_{NS} during calibration were 0.81 and 0.76 respectively. This shows that there was good agreement between observed and simulated stream flow data. The model was validated based on monthly stream flow data for a period of five years from 2009 to 2014 without further parameter adjustment by considering one year for warm up period. The values of coefficient of determination, R^2 and Nash-Sutcliffe, E_{NS} during validations were 0.78 and 0.74 respectively.

The model was also evaluated using performance evaluation criteria, R^2 and E_{NS} both during calibration and validation. The values of these criteria were satisfied in both cases and indicated that the SWAT model has the capacity to predict the remaining hydrological data and for the feature in Fincha watershed and in other catchments in general.

Average annual surface runoff depth and average annual surface runoff volume, 242.9 mm and 6.9 X 10^5 m^3 were generated respectively. The highest and lowest runoffs generated from sub basins (4, 5) and (8, 11) with values 567.4 mm and 10 mm respectively. From the spatial distributions at sub basin level, sub basins 2, 4, 5, 13, 14 and 16 were under high surface runoff.

For sediment yield available data was limited for calibration and validation process. Therefore, rating curve was developed and simulated sediment yields were compared with sediment yield generated by rating curve. For sensitivity analysis of sediment yield, only the simulated data has been used to identify the impact of value on some measure of simulated sediment output. Sediment yield was analyzed in detail using surface runoff as a function and at sub basin level.

The average annual sediment yield from total sub basins was 25.7 ton/ha. Based on rate of soil erosion classifications, sub basins 1, 11 and 14 were under high sediment yield with the values of 50.6 - 64.7 ton/ha/yr when compared with rest sub basins. These parts were the most vulnerable areas of Fincha watershed based on the spatial distributions of sediment yield at sub basin level.

Therefore, first priority should be given for sub basins they were under high soil erosion problems. So, soil conservation activities, re-afforestation and afforestation, proper land use, planning and implementations of best watershed management practice should be applied first in these sub basins and implement in all sub basins of Fincha watershed for the feature.

Generally, the main purposes of the study were to estimate amount of runoff and sediment yielded from Fincha watershed. These two outputs indicate whether the catchment was under normal conditions or not. The outcomes were used as raw data for feature investigations since they have significant impacts on soil compositions, environment, water quality, aquatic ecosystems, Fincha hydropower reservoir due to siltation problems, on communities that live in the catchment and downstream of the dam due flooding when the depositions of sediment exceeds the recommend values and when river bank become over flow.

Therefore, any researcher or concerned bodies who want to do research on Fincha watershed can use the results of the study as an input data. It will be the main indicator for water quality analysis, watershed management and soil conservations using different techniques. Also, maybe I will continue on this topic by modifying the tittle concerned with water quality analysis, best watershed management practice for the feature using the output of this thesis as an input data.

5.2. Recommendations

Starting from data availability up to results, there are different recommendations:

- ✓ In order to analysis well runoff and sediment yield in Fincha watershed and others, all important data should be recorded well accordingly.
- ✓ Training should be given for staff of hydrology department on the purposes of the research since they were not opened to give available data.
- ✓ All responsible bodies should control soil erosion and apply best watershed management practices.
- ✓ Afforestation and re-afforestation should be adapted in the catchment
- ✓ Using natural fertilizer (compost) is best option rather than using chemical fertilizers which consist of high chemical that causes for the formation of water quality problems.
- ✓ Shifting of grazing, crop rotations, using solar energy, appropriate cultivation should be applied.
- ✓ To determine the characteristics of different watershed, SWAT model has a capacity to predict the past, current and features situation in a simple way. Therefore, researchers can use this model to identify the conditions of any catchment since it was important for watershed management practices.

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ANNEX

Annex 1

Table1. Simulation details of SWAT model set-up

General details	
Simulation length (years)	25
Warm up period (years)	2
Hydrological response units (HRUs)	205
Sub-basins	21
Precipitation method	Measured
Output time step	Monthly
Watershed area (Km^2)	2,619
Hydrology (water balance ratio)	
Stream flow/precipitation	0.71
Base flow/total flow	0.59
Surface run-off/total flow	0.41
Percolation/precipitation	0.38
Deep recharge/ precipitation	0.02
ET/ precipitation	0.24
Hydrological parameters	
Average curve number	82.73
ET and transpiration	417.3
Precipitation	1,763.6
Surface run-off	512.85
Lateral flow	128.48
Return flow	617.97
Percolation to shallow aquifer	662.65
Revaporation from shallow aquifer	11
Recharge to deep aquifer	33.13

Table 2. Average monthly basin water budget values

Month	Rain (mm)	SURFQ (mm)	LAT Q (mm)	Water yield (mm)	ET (mm)	PET (mm)
1	9.45	0.59	0.88	16.01	19.45	62.54
2	9.76	0.42	0.73	6.81	19.12	63.39
3	44.2	5.91	2.91	13.95	27.12	70.55
4	81.78	17.92	5.26	32.62	32.5	69.66
5	174.36	49.32	11.31	80.82	41.49	72.62
6	311.76	101.51	21.41	167.71	43.12	62.62
7	350.35	126.08	27.98	243.02	39.24	51.15
8	382.71	107.22	26.10	255.56	46.93	60.45
9	251.68	68.83	19.48	213.52	52.2	10.69
10	102.87	28.61	8.61	146.96	41.67	69.65
11	27.60	3.01	2.53	73.68	29.85	59.94
12	17.32	3.41	1.29	41.68	24.38	58.77
Max	382.71	126.08	27.98	255.29	52.2	72.8
Min	9.45	0.42	0.73	6.81	19.12	10.69
Total	1763.49	507.58	128.49	1,292.34	373.95	712.33

Table 3. Selected input parameters for stream flow calibration of Fincha watershed based on monthly values

S. No	Stream flow parameters	Description of stream flow parameters	Min value	Max Value	Fitted value
1	CN2.mgt	SCS runoff curve number for moisture condition II	-0.2	0.2	0.18
2	ALPHA_BF.gw	Base flow alpha factor	0	1	0.11
4	GW_DELAY.gw	Ground water delay time	30	450	286.2
5	GW_REVAP.gw	Ground water revaporation coeff.	0.02	0.2	0.083
6	CH_N2.rte	Manning roughness for channel	0	0.3	0.255
7	CH_K2.rte	Effective hydraulic conductivity	5	130	33.75
8	ALPHA_BNK.rte	Base flow alpha factor for bank storage	0	1	0.05
9	SOL_K.sol	Soil hydraulic conductivity	-0.8	0.8	-0.656
10	SURLAG.gw	Surface runoff lag time	0	10	7.1