Runoff and Sediment Yield Modeling

(The Case of Kessie Watershed)

M.Sc. Thesis

By

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ADDIS ABABA UNIVERSITY

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A Thesis Presented To the School of the Graduate Study

Of Addis Ababa Institute of Technology

In Partial Fulfillment of the Requirements for the Degree of

Master of Science in Hydraulic Engineering.

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DECLARATION

I hereby declare that I am the sole author of this thesis and have not been presented and will not be presented for any degree in any university.

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CERTIFICATION

The undersigned certify that he has read the thesis entitled: **Runoff and Sediment Yield Modeling, (The Case of Kessie Watershed)** and hereby recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science.

Dr. Bayou Chane (Advisor)

Date

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ABSTRACT

Soil erosion is a major problem causing land degradation in most watersheds of Ethiopia. The Kessie watershed which found on the north east of Blue Nile Basin of Ethiopia is most affected areas by soil erosion, sediment transport and land degradation.

Sediment yield (the amount of sediment exported by a basin over a period of time) model evaluated in this paper is the Soil and Water Assessment Tool (SWAT). SWAT in this paper used to model soil erosion, identify soil erosion prone areas and assess factors that most contribute to soil loss on Kessie watershed.

The delineated watershed has divided into 23 sub basins, Model calibration and validation was done at Kessie station. The study found satisfactory agreement between daily observed and simulated sediment concentrations based on the values for coefficient of determination (r^2) and Nash–Sutcliffe model efficiency (ENS), i.e. (0.773 & 0.81 for R^2 and 0.71 & 0.72 for NSE, values for calibration and validation respectively).

The annual average measured suspended sediment generated from the sediment rating curve was 14.71 ton/ha/yr. and the simulated annual average sediment yield by SWAT model was 16.69 t/ha/yr. Out of the total 23 sub basin 12 sub-basins produce average annual sediment yields above 12 ton/ha/yr. and the highest loading is from North Gojjam and Beshilo Sub basins. The result has shown that 35.49 % of the watershed has exceeded the tolerable range, 23.54 % of the watershed is exposed in high erosion and sediment yield and about 40 % of the watershed is in moderate and low level.

Key Words: Kessie Watershed, GIS, SWAT, Remote Sensing, Soil loss, Sediment Yield.

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LIST OF ABBREVIATIONS

AAU	Addis Ababa University
Alpha_Bf	Base Flow alpha factor
°C	Degree Celsius
Bm^3	Billion cubic meters
CN	Curve number
D	Diameter
DEM	Digital Elevation Model
E	East direction
ET	Evapotranspiration
Esco	Soil evaporation compensation factor
FAO	Food and Agricultural Organization
GIS	Geographical Information System
GW_Q	Ground water flow (mm)
ha	Hectare
HRU	Hydrological Response Unit
ITCZ	Inter Tropical Convergence Zone
Km	kilometer
Km^2	Square kilometer
m	Meter
M	Million (Mega)
m.a.s.l	Mean above sea level
m^3	Unit of volume, cubic meter
m^3/s	Unit of discharge, cubic meter per second
mg/L	Milligram per liter

Mton/day	Million tons per day
mm	Millimeter
MoWRE	Ministry of Water Resources of Ethiopia
MT	Million tons
MUSLE	Modified Universal Soil Losses Equation,
N	North direction
NA	Not available
Perc	Percolation (mm)
PET	Potential Evapotranspiration
Precip	precipitation (mm)
Q	Symbol for discharge
RUSLE	Revised Universal Soil Loss Equation,
SCS	Soil Conservation Service
SI	International Unit system
Sol_Awc	Soil available water capacity
SW	Shallow water flow (mm)
SWAT	Soil and Water Assessment Tool
SWR_Q	Surface runoff (mm)
T/ha/m	Ton per hectare per month
T/ha/yr.	Tons per hectare per year
t/year	Unit of sediment yield in terms of weight, tons per year
ton	Tons
WLRC	water and land resource center
USLE	Universal Soil Loss Equation,

1. INTRODUCTION

1.1 GENERAL BACKGROUND

High population pressure, poor land-use planning, over-dependency on agriculture as a source of livelihoods and extreme dependence on natural resources are inducing deforestation, overgrazing, expansion of agriculture to marginal lands and steep slopes, declining agricultural productivity and degradation of the environment. Poor agricultural and other practices affect run-off characteristics resulting in increased erosion and siltation and reduced water quality (Awulachew et al., 2008). FAO estimates an annual loss of over 1.9 billion tons of soil from the Ethiopian Highlands. Only approximately 122 million tones reach the Ethiopia border (Ahmed and Ismail, 2008). Erosion from the land surface occurs in the form of sheet erosion, rill and inter-rill erosion, or gully erosion, part of which is delivered to rivers. This, together with deposition of erosion from in-stream beds and banks of rivers, constitutes the sediment load in the river (Awulachew et al., 2008). Ethiopian plateau is the main source of the sediment in the Blue Nile system. The main area of sheet erosion is within the Ethiopian Highlands.

These problems are more distinct in the Blue Nile basin the main tributary of the River Nile. Rapid population increase led to fast land-use change from forest to agricultural land, and as associated with steep terrain, these changes has resulted in severe soil erosion over the Upper Blue Nile (Nyssen, et al., 2004). The soil erosion and sediment transport processes have affected the whole Blue Nile basin negatively even though it was nutrient-rich sediment source (Nixon, 2002). The upper Blue Nile is losing fertile topsoil, exacerbating impacts of dry spells and drought, a common incident in the area. While, the reservoirs and irrigation canal in the lower Blue Nile are seriously affected by sediment deposition, leading to significant reduction of reservoirs storage capacities, and excessive de-silting costs of irrigation canals.

Due to an increase in crop lands and other the land use of the basin changes dynamically, understanding these watershed hydrology will enable local governments and policy makers to articulate and implement effective and appropriate response strategies to minimize the undesirable effects of future land use/cover change or modifications. Given that impacts of land use/cover change are the result of complex interactions between diverse site specific factors and offsite conditions, standardized types of responses will rarely be adequate. General statements about land & water interactions need to be continuously questioned to determine whether they represent the best available information and whose interests they support in decision-making processes (FAO, 2002).

In this study, on one hand, the erosion characteristics of KESSIE watershed has been assessed. Factors that most contribute to soil loss within the catchment have been identified. Remotely sensed data has been integrated with SWAT model to determine the spatially distributed soil loss map of the catchment. The study area has been classified into erosion prone areas based on land use and slope of the catchment and parts of the catchment that most feed have been identified.

On the other hand, different management intervention scenarios by SWAT model has developed for the watershed which helps to reduce land degradation, increase vegetation cover, and increases the productivity of the watershed area in addition to this the study intends to calibrate, validate and check the applicability of physical based model (SWAT) for the study catchment. There are two basic advantages using hydrological models instead of relying only on collected data. In the first place models can be used to understand the processes that are difficult to measure due to the complexity of temporal and/or spatial scale. Secondly, a model can be used to study the effect of changes in land cover, water management or climate (Kite and Droogers, 2001).

Therefore, to address the above situation, watershed management is one of the most important approaches, which helps to reduce land degradation, increase vegetation cover, and increases the productivity of the watershed area.

1.2 STATEMENT OF THE PROBLEM

Sediment in the Blue Nile Basin is mainly originated from the Ethiopian Highlands, Presence of steep and long slopes is among the major factors for intensive erosion. The kessie watershed which is found in the east side of the Blue Nile Basin embraces most of the steep and long slopes of the basin, which makes the basin hot spot for soil erosion. Fast population growth and high density of livestock's spare those forest lands to crop lands also cultivation on long and steep slopes are conducted without effective protective measures which makes the watershed susceptible to soil erosion.

The above explanation makes Kessie watershed main contributor of sediment to the basin, therefore analyzing the impact of different contributing parameters for the cause will help different stake holder to work in reduction of land degradation, increase vegetation cover and the productivity of the watershed area.

1.3 OBJECTIVES

The main objective of this research is to model Sediment yield loading for Kessie watershed and to develop management intervention scenarios by using SWAT Model.

The specific objectives of the studies are:

- ✓ To calibrate, validate and check the applicability of physical based model (SWAT) for the study catchment.
- ✓ To characterize the runoff from catchment and associated sediment yield.
- ✓ To assess and evaluate the spatial variability of sediment yield in the watershed and identify priority hot spot areas.
- ✓ Assess the impact of different catchment management interventions on runoff and sediment yield
- ✓ To develop appropriate runoff and sediment yield reduction scenarios (needs time and rough investigation of the existing conservation measure).

1.4 ORGANIZATION OF THE THESIS

The study was carried out based on the literature reviews and available data of the study area. This are the chapter included in the study with content overview.

Chapter 1 introduces the background of the study, explained the problem and presents the objectives of the study.

Chapter 2 briefly describes the study area topography, climate, hydrology, geology and different Basin parameters.

Chapter 3 briefly presents the available literature reviews on sediment yield, on physically based model SWAT and on different sediment management strategies.

Chapter 4 explains the conceptual frame work of the study and analyze the hydro metrological data's additionally SWAT model setup and inputs will briefly presented.

Chapter 5 result of the model and brief discussion about the model output will be presented.

Chapter 6 recaps conclusions and recommendations.

2. THE STUDY AREA

2.1 DESCRIPTION OF THE STUDY AREA

2.1.1 Location

The Blue Nile (Abbay) basin lies in the western part of Ethiopia between 70° 45' - 12° 45' N and 34° 05' - 39° 45' E. It is the largest in terms of volume of discharge, second largest in terms of area from 12 major river basins in Ethiopia. The river contributes over 50 % of the long-term river flow of the Main Nile (Conway, 2000). The basin covers an area of 200,000 km^2 having 16 sub basins. The headwaters of the river are situated in the mountains surrounding Lake Tana, which has a natural elevation of 1,785 m a.m.s.l. and commands a catchment area of 15,320 km^2.

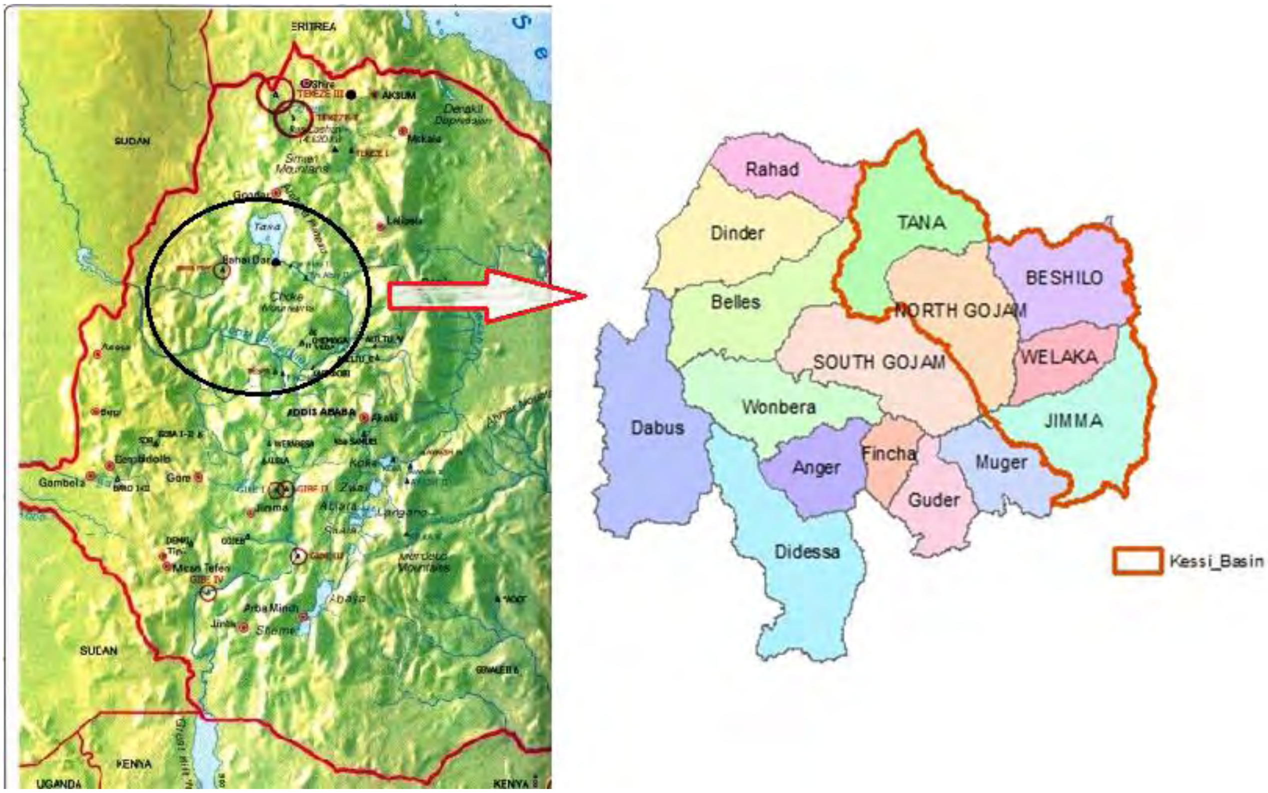


Figure 2.1: Abbay basin and Kessie watershed.

Kessie watershed locates with in the Blue Nile basin which lies between 36°43’55’’ to 39°49’12’’ E long and 9°12’18’’ to 12°45’20’’N lat, this watershed covers 5 sub basins out of the 16 sub basins of Blue Nile which are BASHILO, NORTH GOJAM, TANA, WELAKA & JIMMA, those sub basins contribute 25% of Abbay basin i.e. covering 64,229.81km^2 area with a total perimeter of 2,160 Km.

2.1.2 Physiography

The Blue Nile Basin is characterized by very broken and hilly plateau with grassy uplands, swamp valleys and scattered trees (Sutcliffe and Parks, 1999). The highland plateau has been deeply incised by the Blue Nile and its tributaries and has the general slope to the northwest (Conway, 1997). The slope of the catchment ranges from as steep as 45% in the Eastern part of the area to 0% in Sudan border with an average of about 4%. The elevation of the basin ranges from less than 400 m a.m.s.l. in Sudan to 4,261 m a.m.s.l at the top of highlands in the east.

The elevation of Kessie watershed ranges from 4,261 m a.m.s.l to 1,011 m a.m.s.l. at the outlet and the slope of the catchement ranges from 0% to 40%, having an average of 4%.

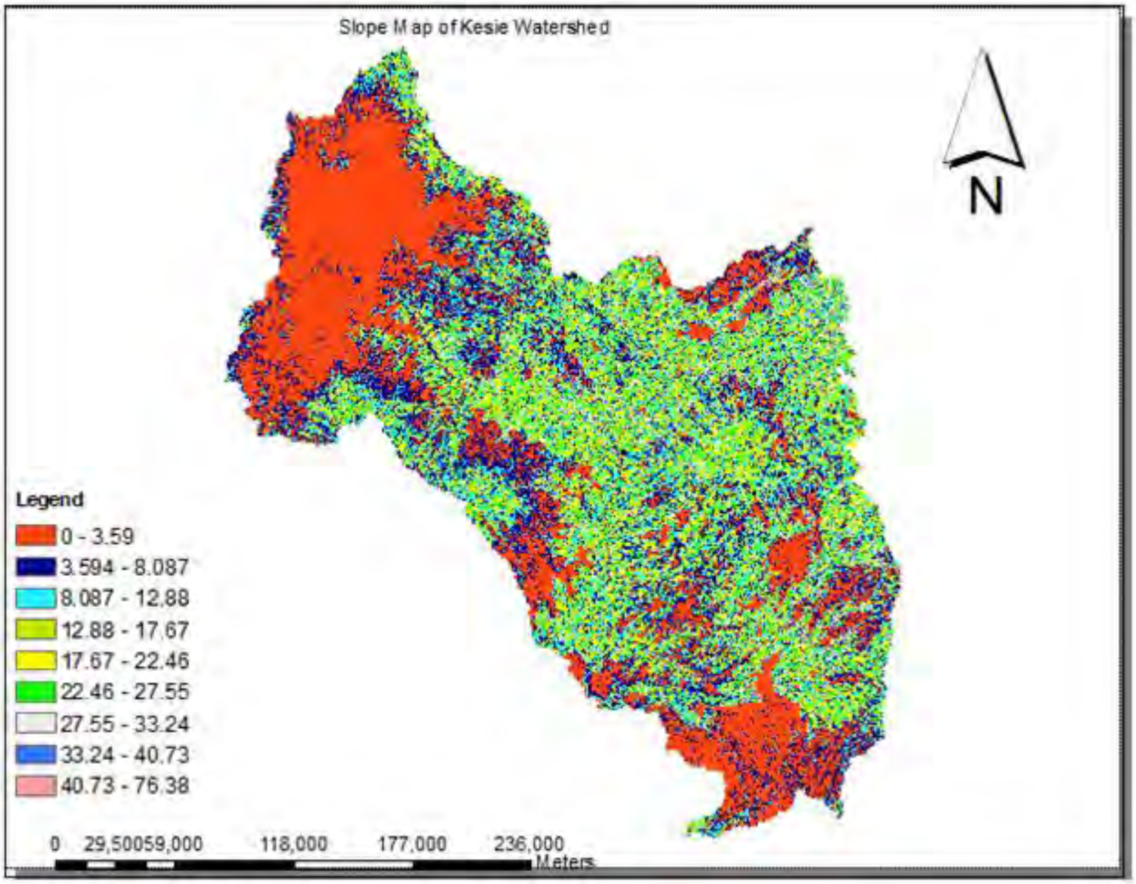


Figure 2.2: Slope map of Kessie watershed.

2.1.3 Climate and Hydrology

In Ethiopia the seasons are classified based on rainfall regime. The monthly rainfall variation and the mean annual rainfall pattern for the selected stations demonstrate that there are mainly four rainfall regimes in Ethiopia (Tesfaye, 1986 and Abebe, 1987). These four rainfall regimes are Mono-modal (single maxima), Bimodal Type – 1(quasi – double maxima), Bimodal Type-2 (double maxima) and Diffused pattern. The study area has a rainfall season which is a bimodal type.

The climate in the Blue Nile is governed by the seasonal migration of Inter Tropical Convergence Zone from south to north and back. Mean annual precipitation ranges from about 2000 mm in Ethiopian highlands to less than 200 mm in Sudan (Hydrosult, et al., 2007). Within the highlands of the wet season lasts four months from June to September.

The mean annual temperature of the area is around 15 to 23 °C with maximum daily temperature of 44 °C in May and minimum daily temperature of 10 °C in January. The spatial distribution of temperature highly depends on altitude. In the highlands the mean annual temperature ranges from 6 to 9 °C and 23 to 26 °C in the low lands of the area, near the border (Hydrosult, et al., 2007).

2.1.4 Land use and land cover

Land use refers to the actual economic activity for which the land is used whereas land cover refers to the cover of the earth’s surface. Land use can be seen as the ultimate expression of everything else that is going on in the basin. According to water and land resource center (WLRC), around half of the watershed is covered with cultivated land which is mostly covered by teff, sorghum, wheat, barley and agricultural land. The remaining half covers by Bare Land 10.29%, grass land 6.5%, shrub land 5.8%, mixed forest 4.42%, deciduous forest 3.59%, water 4.81%, while built up and artificial areas accounted for 0.33% of the total area. The remaining 0.45% being wet land.

The land use of the study area can be categorized mainly as agricultural, pastoral, savannah, forest, bush, bare-land and water bodies. The information contained in the land use map tells how the different uses of the surface are distributed inside the area under study. Though land cover changes from time to time there is no comprehensive data to show change in land use and land cover of the basin.

2.1.5 Soil

The Upper Blue Nile basin is mainly formed from clay and clay-loam soil type, but the riverbed has a loam and sandy-loam type of soil. The predominant soils are generally characterized as vertisols, luvisols, and leptisols (Easton, et al. 2010). Soil profiles in the highlands are characterized by permeable soils, underlain by bedrock at depth. Soils are generally deeper at lower reaches of the basin while soil depth is less in the steeper slopes. Based on the FAO soil classification, part of the basin is dominated by the Eutric Vertisols. The part of the basin in Ethiopia is mainly dominated by Umbric Nitosols in the south eastern part and Lithic Leptisols in the north eastern part (Awulachew and Yilma, 2009).

The study area mainly dominated by vertisols, luvisols, and leptisols in combination with three diagnostic horizon modifiers: eutric, chromic and hapic.

2.1.6 Geology

The geology of the basin signifies different formations such as Basalt, Alluvium, Lacustrine deposit, Sand stone, Granite and Marble. The highlands of the basin are composed of basic rocks, mainly basalts and the lowlands composed basement complex rocks as well as metamorphic rocks, such as gneiss and marble (Awulachew, et al. 2008).

3. LITERATURE REVIEW

3.1 GENERAL

The hydrology of Nile basin has been studied from many perspectives. Several studies concerned with the long-term climatologic trends and especially precipitation (Conway, 2000; Yilma and Demarce, 1995 and Sutcliffe and Parks, 1999). Other studies relate the effect of climate change and spatial variability of precipitation to stream flow; (Conway and Hulme, 1993) and developing water balance model for water resource management (Conway, 1997; Kebede and Travi, 2006) and for sensitivity analysis of lake level and outflows.

Water is the most vital resource to support all forms of life on earth. It will remain essential for mankind survival and the future development of the world. Water is not evenly distributed over the world by season or location, i.e. global fresh water distribution is neither uniform in space nor in time. Some parts of the world are prone to drought making water scarce and precious commodity, while in other parts of the world it appears in raging torrents causing floods and loss of life and property. The last 50 years have seen remarkable developments in water resources and in particular agriculture, industry, and domestic consumption. Massive developments in hydraulic infrastructures have put water at the service of people. On the other hand, while the world population grew from 2.5 billion in 1950 to 6.5 billion today, the irrigated area doubled and water withdrawals tripled. Moreover, the Nile Basin with its majority situated in dry and semi-dry region is facing a similar fate of high water demand if not worse. The Nile River Basin covers 10.3% of the African continent area. It is the sixth largest Basin in the world area-wide encompassing most of the northeastern Africa and incorporating ten countries in total (Burundi, D. R. Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda), with a combined population of about 325 million, about 170 million of them live within the boundaries of the Nile Basin.

Sediment in the Nile is mainly originating from the Ethiopian Highlands with large quantities of eroded soil. This stems from frequently alternating dry–wet seasons coupled with agricultural over-utilization, overgrazing, wood cutting to sustain livelihood and housing. These are resulting in deforestation and loosening of the soil surface thus facilitating and accelerating water erosion. Therefore, it leads to land degradation in the upper land and loss of reservoir's capacities, flooding, blockage of hydropower inlets, irrigation canal's sedimentation and water quality degradation. The latter collectively summarizes the negative impacts of soil erosion from the Ethiopian.

Watershed management strategies are critical to efficiently utilize the natural resources base while maintaining environmental quality. Of the many resources at risk in the Ethiopian Highlands soil and water are arguably the most critical, as nearly 80% of the population depends on subsistence agriculture. One process that threatens the resource base is soil erosion. The Ethiopian Highlands provide nearly 85% of flow in the main stem of Nile in Egypt, and support 80% of the Ethiopian population (Swain, 1997). Thus it is critical to understand the processes and sources impacting water quantity, quality and, most importantly erosive losses and sedimentation mechanisms that threaten both agricultural productivity (Constable, 1984) and the considerable infrastructure in downstream countries, including Sudan and Egypt. Ethiopia has abundant yet underutilized water resource potential, and 3.7 million hectare of potentially irrigable land that can be used to improve agricultural production and productivity (Awulachew et al., 2007; MoWR, 2002). However, agricultural productivity in Ethiopia lags other, similar, regions, which is attributed to unsustainable environmental degradation mainly from erosion and loss of soil fertility (Grunwald and Norton, 2000). Therefore, understanding the hydrological processes of different parts of the basin is crucial to water and land resource management. Soil erosion by water represents a major threat to the long-term productivity of agriculture in the Ethiopian Highlands where the estimated soil erosion rates range from as low as 16 t ha−1 y−1 (Gizawchew, 1995) to as much as 300 t ha−1 y−1 (Hurni, 1993; Herweg and Stillhardt, 1999).

Ethiopia, often referred to as the water tower of East Africa, is dominated by mountainous topography, and the rainfall-runoff processes on the mountainous slopes are the source of the surface water for much of Ethiopia (Derib, 2009), and thus, understanding the rainfall-runoff processes is critical to controlling erosion and enhancing agricultural productivity. The majority of the sedimentation of rivers in the basin occurs during the early period of the rainy season and peaks of sediment are consistently measured before peaks of discharge for a given rainy season (Steenhuis et al.2009).

Soil loss from a watershed can be estimated based on an understanding of the underlying hydrological processes, climatic conditions, landforms, land management, and soil factors. Assessing and mitigating soil erosion at the basin level is complex both spatially and temporally. Hence, watershed models those are capable of capturing these complex processes in a dynamic manner can be used to provide an enhanced understanding of the relationship between hydrologic processes, erosion/sedimentation, and management options. There are many models that can continuously simulate stream flow, erosion/sedimentation, or nutrient loss from a watershed. However, most were developed in temperate climates and were never intended to be applied in monsoonal regions, like Ethiopia, with an extended dry period. In monsoonal climates a given rainfall volume at the onset of the monsoon produces a drastically different runoff volume than the same rainfall volume at the end of the monsoon (Lui et al., 2008). Steenhuis et al. (2009) and Lui et al. (2008) showed that the ratio of discharge to precipitation – evapotranspiration (Q/(P-ET)) increases with cumulative precipitation and consequently the watersheds behave differently depending on how much moisture is stored in the watershed, suggesting that saturation excess processes play an important role in the watershed runoff response.

One characteristic of Ethiopian Blue Nile hill slopes is that most have infiltration rates in excess of the rainfall intensity, thus most runoff is produced when the soil saturates (Ashagre, 2009) or from degraded, shallow soils. Indeed, data from Soil Conservation Reserve Program (SCRP) watersheds (Bayabil, 2009; Engda, 2009) show the probability of rainfall intensity exceeding the measured soil infiltration rate to be very low, only 7.8% of storm intensities exceeded the lowest measured infiltration rate. Of course defining sources of landscape erosion require knowledge of both where runoff is generated, and of how the landscape is managed (e.g., tillage, livestock, vegetative cover, etc.). Few models have been developed that can predict both the distributed runoff sources and the sedimentation dynamics in the Blue Nile.

There are many classification schemes of hydrologic models, based on the method of representation of the hydrologic cycle or a component of the hydrologic cycle (Cunderlik 2003). Hydrologic simulation models use mathematical equations to calculate results like runoff volume or peak flow.

3.2 Hydrological Modeling

Hydrological models are characterizations of the real world system. Modeling of the rainfall runoff processes of hydrology is needed for many different reasons the main reasons being limited range of hydrological measurement techniques and limited range of measurements in space and time Anderson, (M.J. & Burt, T.P). A watershed model simulates hydrologic processes in a more holistic approach compared to many other models which primarily focus on individual processes or multiple processes at relatively small-or field-scale without full incorporation of a watershed.

A watershed model simulates hydrologic processes in a more holistic approach compared to many other models which primarily focus on individual processes or multiple processes at relatively small-or field-scale without full incorporation of a watershed area. Watershed-scale modeling has emerged as an important scientific research and management tool, particularly in efforts to understand and control water pollution (Daniel et al.).

A model is physical or mathematical description of a physical system, including the interaction with its outside world, which can be used to simulate the effects of changes in the system itself or the changes in the condition imposed upon it. The primary features for distinguishing watershed-scale modeling approaches include the nature of the employed algorithms (empirical, conceptual, or physically-based), whether a stochastic or deterministic approach is used for model input or parameter specification, and whether the spatial representation is lumped or distributed

Watershed models can also be categorized as deterministic or stochastic depending on the techniques involved in the modeling process. Deterministic models are mathematical models in which outcomes are obtained through known relationships among states and events. Stochastic models will have most, if not all, of their inputs or parameters represented by statistical distributions which determine a range of outputs. Even though most models are deterministic in nature, stochastic models provide two important advantages. First, their conceptually simple framework makes it possible to describe heterogeneity when there are limited spatial or temporal details. Second, they provide decision makers with the ability to determine uncertainty-associated with prediction.

Empirical models consist of functions used to approximate or fit available data. Such models span arranges of complexity, from simple regression models to hydro informatics-based models which utilize Artificial Neural Net-works (ANNs), Fuzzy Logic, Genetic, and other algorithms

3.2.1 Selection of Hydrological Model

Each model type serves a purpose, and a particular model type may not categorically be considered more appropriate than others in all situations. Choice of a suitable model structure relies heavily on the function that the model needs to serve.

There are various criteria which can be used for choosing the right hydrological model for a specific problem. These criteria are always project dependent, since every project has its own specific requirements and needs. Further, some criteria are also user-depended (and therefore subjective). Among the various project-dependent selection criteria, there are four common, fundamental ones that must be always answered (Cunderlik):-

I. Required model outputs important to the project and therefore to be estimated by the model (Does the model predict the variables required by the project?).

II. Hydrologic processes that need to be modelled to estimate the desired outputs adequately (Is the model capable of simulating single-event or continuous Processes?)

III. Availability of input data (Can all the inputs required by the model be provided within the time and cost constraints of the project?).

IV. Price (Does the investment appear to be worthwhile for the objectives of the project?).

The selection of model were by considering the above criteria's with inclusive of availability of data, level of application, purpose, required accuracy, space and time scale, catchment area, simplicity, previous trends(studies) in the surrounding area & Ethiopia as a whole**.** Considering all the criteria's set above data driven model (Artificial Neural network) and physical based models (SWAT) were adopted for this study.

Reason for Selection of SWAT Model: SWAT model was selected due to the following reasons:-

i. It has been indicated and tested by different researcher and journal paper that the model is calibrated and simulated with satisfactory results on Abbay basin.

ii. It has been tested that the model has obvious advantage as a hydrological modeling tool that includes modularity, computational efficiency, ability to predict long-term impacts as a continuous model, and ability to use readily available global datasets, availability of a reliable user and developer support has contributed to its acceptance as one of the most widely adopted and applied hydrological models worldwide.

iii. The model simulates the major hydrological process in the watersheds, less demanding on input data, and it is readily and freely available.

iv. Specifically the model was tested for prediction of runoff and sediment yield in Abbay basin with satisfying results, since SWAT can be applied for the same land use /land cover and topographical conditions it will have good performance on Kessie basin too.

3.2.2 Description of selected model

Soil and Water Assessment Tool (SWAT)

SWAT is the acronym for Soil and Water Assessment Tool, a river basin, or watershed, scale model developed by the USDA Agricultural Research Service (ARS). 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.

The SWAT watershed model is one of the most recent models developed by the USDA-ARS to predict the impacts of land management practices on water, sediment and agricultural chemicals yields in watersheds with varying soils, land use and management practices over long periods of time (Neitsch et al.). The model is a physical based, semi-distributed, continuous time, and operating on daily time step. As a physical based model, SWAT uses Hydrological Response Units (HRUs) to describe spatial heterogeneity in terms of land use, soil types and slope with in a watershed.

In order to simulate hydrological processes in a watershed, SWAT divides the watershed in to sub watersheds based upon drainage areas of the tributaries. The sub watersheds are further divided in to smaller spatial modeling units known as HRUs, depending on land use and land cover, soil and slope characteristics.

The SWAT model uses two phases of hydrologic cycle; one for the land processes and the other for the channel processes:

A. .Land Phase Of Hydrologic Cycle

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{sur} - E_a - w_{seep} - Q_{gw}) \ldots\ldots\ldots\ldots\ldots\ldots . equation\ 3.1$$

Where: - SWt is the final soil water content (mm H2O), SW0 is the initial soil water content on day i (mm H2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H2O), Q_{surf} is the amount of surface runoff on day i (mm H2O), E_a is the amount of evapotranspiration on day i (mm H2O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H2O), and Q_{gw} is the amount of return flow on day i (mm H2O).

The subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases accuracy and gives a much better physical description of the water balance.

B. Hydrological Process Cycle

Once SWAT determines the loadings of water, sediment, nutrients and pesticides to the main channel, the loadings are routed through the stream network of the watershed using a command structure similar to that of HYMO (Williams, JR). In addition to keeping track of mass flow in the channel, SWAT models the transformation of chemicals in the stream and stream bed.

Erosion: Erosion and sediment yield are estimated for each HRU with the Modified Universal Soil Loss Equation (MUSLE) (Williams, JR et al.). While the USLE uses rainfall as an indicator of erosive energy, MUSLE uses the amount of runoff to simulate erosion and sediment yield. The substitution results in a number of benefits: the prediction accuracy of the model is increased, the need for a delivery ratio is eliminated, and single storm estimates of sediment yields can be calculated. The hydrology model supplies estimates of runoff volume and peak runoff rate which, with the sub basin area, are used to calculate the runoff erosive energy variable. The crop management factor is recalculated every day that runoff occurs. It is a function of above-ground biomass, residue on the soil surface, and the minimum C factor for the plant. Other factors of the erosion equation are evaluated as described by (Wischmeier, W.H et al.).

I. 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. SWAT provides two methods for estimating surface runoff: the SCS curve number procedure (Heber Green, W and Ampt, GA).

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 (Rallison, Robert E. et al.).

The SCS curve number equation:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \dots\dots\dots\dots\dots\dots\dots\dots \, equation \; 3.2$$

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

$$S = 25.4\left(\frac{100}{CN} - 10\right) \dots\dots\dots\dots\dots\dots\dots equation\ 3.3$$

Where CN is the curve number for the day and it is a function of land use, soil permeability and antecedent soil water condition.

Commonly I_a is approximated by 0.2S and the above equation can be rewrite as follow

$$\mathrm{Q_{sur}} = \frac{(\mathrm{R_{day-}}0.2S)^2}{R + 0.8S} \dots\dots\dots\dots\dots\dots\dots\dots. equation\ 3.4$$

Peak runoff rate: 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 for each HRU as follow:

$$Q_{peak} = \frac{\alpha_{tc} * Q_{sur} * A}{t_{conc}} \dots\dots\dots\dots\dots\dots\dots\dots equation\ 3.5$$

Where Q_{peak} is peak runoff rate (m^3/s), α_{tc} is the fraction of daily rainfall that occurs during the time of concentration, Q_{surf} is the surface runoff (mm); A is the sub-basin area (km^2), t_{conc} Time of concentration (hr.) and 3.6 is conversion factor

SWAT estimates the value of α_{tc} by using:

$$\alpha_{tc} = 1 - \exp[2 * t_{conc} * \ln(1 - \alpha_{0.5}) \dots\dots\dots\dots\dots\dots\dots\dots. equation\ 3.6$$

Where $\alpha_{0.5}$ is the fraction of daily rain falling in the half-hour highest intensity rainfall, t_{conc} is the time of concentration for the sub basin (hr.).

Time of Concentration: The time of concentration, t_{conc}, is a time within which the entire sub basin area is discharging at the outlet point. It is calculated by summing up both the overland flow time of the furthest point in the sub basin to reach a stream channel (t_{ov}) and the upstream channel flow time needed to reach the outlet point (t_{ch})and calculated by ..

$$t_{conc} = t_{ov} + t_{ch} \dots\dots\dots\dots\dots\dots\dots\dots.. equation\ 3.7$$

Overland flow time is defined as the time it takes for water to travel from the furthest point in the sub-basin to a stream channel. The overland flow time (t_{ov}) is computed by:-

$$t_{ov} = \frac{L_{slp}}{3600 * V_{ov}} \dots\dots\dots\dots\dots\dots\dots\dots\dots \; equation\ 3.8$$

Where: L_{slp} is the average sub basin slope length (m), V_{ov} is the overland flow velocity (m/s), and 3600 is a unit conversion factor.

The overland flow velocity for a unit width along the slope is calculated by using the Manning's equation:

$$V_{ov} = \frac{q_{ov} * 0.4 * slp}{n^{0.6}} \dots\dots\dots\dots\dots\dots\dots\dots. equation\ 3.9$$

Where: q_{ov} is the average overland flow rate (m^3/s), Slp is the average slope of the sub basin (m/m), and n is Manning's roughness coefficient of the sub basin

Channel flow time is computed as:

$$t_{ch} = \frac{L_c}{3.6 * V_c} \dots\dots\dots\dots\dots\dots\dots\dots. equation\ 3.10$$

Where: L_c is the average flow channel length (km), V_c is the average flow velocity (m/s), and 3.6 is a unit conversion factor.
The average flow channel length is calculated as:

$$L_c = \sqrt{L * L_{cem}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. equation\ 3.11$$

Where: L is the channel length from the furthest point to the sub basin outlet (km), and L_{cem} is the distance along the channel to the sub basin centroid (km).

Soil Water Percolation, Bypass Flow and Lateral Flow: Soil water may follow different paths of movement: vertically upward (plant uptake), vertically downward (percolation), or laterally-contributing to stream flow. The vertical movement as plant uptake removes the largest portion of water that enters the soil profile.

Percolation is the downward movement of water in the soil. SWAT calculates percolation for each soil layer in the profile. Water is allowed to percolate if only the water content exceeds the field capacity of that layer (Neitsch, S et al.).

Bypass flow is the vertical movement of free water along macro pores through unsaturated soil horizons. While simulating the bypass flow, SWAT calculates the crack volume of the soil matrix for each day of simulation by layer. On days in which precipitation events occur, infiltration and surface runoff are first calculated for the soil. Part of the surface runoff equivalent to the cracks volume enters the soil profile as bypass flow and the rest remains overland flow. Cracks are filled in accordance with their presence in the consecutive layers: those at the bottom layers are filled first (Neitsch, S et al.).

Lateral flow is common in areas with high hydraulic conductivities in surface layers and an impermeable or semi-permeable layer at a shallow depth. Rainfall will percolate vertically up to the impermeable layer and develops a saturated zone stored above this layer. This is called a perched water Table; which is the source of water for lateral subsurface flow. Lateral flow occurs when water stored in the shallow aquifer exceeds a threshold value.

II. Sediment Component of SWAT

SWAT computes erosion for each HRU caused by rainfall and runoff with the Modified Universal Soil Loss Equation (MUSLE). The modified universal soil loss equation stated by (Williams, JR) is:

$$Sed = 118 * (Q_{Surf} * q_{peak} * A_{hru})^{0.56} * K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * CFRG \dots\dots.. equation\ 3.12$$

Where Sed is the sediment yield on a given day in metric tons, Q_{surf} is the surface runoff from the watershed in mm/ha, q_{peak} is the peak runoff rate in cubic meter per second, A_{hru} is the area of HRU, K_{USLE} is the USLE soil erodability factor, C_{USLE} is the USLE land 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. In SWAT water is routed through the channels network using either the variable storage routing or Muskingum River routing method.

Sediment transport: Sediment transport in the channel network is a function of two processes, deposition and degradation; SWAT compute both of them by using the same channel dimensions for the entire simulation. The amount of sediment degradation in the channel can be calculated by the model by using and:

$$Sed_{deg} = Conc_{sed.ch.i} * V_{ch} * K_{ch} * C_{ch} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. equation\ 3.13$$

The net amount of sediment deposited in the reach segment is calculated by:

$$Sed_{dep} = \left(Conc_{sed,sh,i} - Concmx\right) * V_{ch} \dots\dots\dots\dots\dots\dots\dots equation\ 3.14$$

Where: Sed_{deg} is the amount of sediment re-entrained in the reach segment (metric tons), $Conc_{sed,ch,i}$ is the amount of initial sediment concentration in the reach (kg/l or ton/m3), $Conc_{sed,ch,mx}$ is the maximum concentration of sediment that can be transported by the water (kg/l or ton/m3), K_{ch} is the channel erodbility factor (cm/hr/pa), C_{ch} is the channel cover factor and V_{ch} is the volume of water in the reach segment (m^3), sed_{dep} is the amount of sediment deposited in the reach (metric tons).

Once the amount of degradation and deposition has been calculated, then the final amount of sediment in the reach is as:

$$Sed_{ch} = Sed_{ch,i} - Sed_{dep} + Sed_{deg} \ldots\ldots\ldots\ldots\ldots\ldots\ldots. equation\ 3.15$$

The amount of sediment transported out of the reach is then calculated as:-

$$Sed_{out} = Sed_{ch} * \frac{V_{out}}{V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. equation\ 3.16$$

Where Sed_{ch} is the amount of suspended sediment in the reach (metric tons), $Sed_{ch,i}$ is the amount of suspended sediment in the reach at the beginning of the time period(metric tons), Sed_{deg} is the amount of sediment re-entrained in the reach segment (metric tons), Sed_{out} is the amount of sediment transported out of the reach (metric tons), Sed_{ch} is the amount of suspended sediment in the reach (metric tons), V_{out} is the volume of outflow during the time step (m^3) and V_{ch} is the volume of water in the reach segment (m^3).

Surface Runoff and Sediment lag: In large sub basins with a time of concentration greater than 1 day, only a portion of the surface runoff will reach the main channel on the day it is generated and also Sediment in the surface runoff is lagged as well. SWAT incorporates a surface runoff storage feature to lag part of the surface runoff release to the main channel. Once surface runoff is calculated, the amount of surface runoff released to the main channel is estimated as:

$$Q_{surf} = (Q'_{surf} + Q_{stor,i-1})(1 - \exp\left[\frac{-surlag}{t_{conc}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. equation\ 3.17$$

And after the sediment load in surface runoff is calculated, the amount of sediment released to the main channel is calculated using

$$Sed = (sed' + Sed_{stor,i-1})(1 - \exp[\frac{-surlag}{t_{conc}} \ldots\ldots\ldots\ldots\ldots\ldots equation\ 3.18$$

Where: Q_{surf} is amount of surface runoff discharged to main channel in a day (mm), Q' is amount of surface runoff generated in a sub basin in a day (mm), $Q_{stor,\ i-1}$ is the surface runoff stored or lagged from the previous day (mm), Surlag is the surface runoff lag coefficient, t_{conc} is the time of concentration for the sub basin (hrs.)

and in equation 13 Sed is the amount of sediment discharged to the main channel on a given day (metric tons), Sed’ is the amount of sediment load generated in the HRU on a given day (metric tons), $Sed_{stor,\ i-1}$ is sediment stored or lagged from the previous day (metric tons).

Routing phase of the hydrologic cycle: The second phase of the SWAT hydrologic simulation, the routing phase, consists of the movement of water, sediment and other constituents (e.g. nutrients, pesticides) in the stream network. The change in channel dimensions with time due to down cutting and widening is also included. Similar to the case for the overland flow, the rate and velocity of flow is calculated by using the manning’s equation. The main channels or reaches are assumed to have a trapezoidal shape by the model. Two options are available to route the flow in the channel networks: the variable storage and Muskingum methods. Both are variations of the kinematic wave model. The variable storage method uses a simple continuity equation in routing the storage volume, whereas the Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages. While calculating the water balance in the channel flow, the transmission and evaporation are also well considered by the model. For this study, the variable storage method was adopted. The method was developed by Williams, JR and recommended by Arnold, JG. The Storage routing is based on the continuity equation:

$$\Delta V_{stored} = V_{in} - V_{out} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..equation\ 3.19$$

Where: V_{in} is volume of inflow during the time step (m3), V_{out} is volume of outflow during the time step (m^3), and ΔV_{stored} is change in volume of storage during the time step (m^3).

Limitation of SWAT Model

The model has enormous popularity in multi-disciplinary coverage of processes representing the hydrology but it has also limitation on its low capacity to capture the spatial variability associated with precipitation within a large watershed and it does not simulate detailed event-based flood and sediment routing. Another criticism on SWAT model is that the method of estimating runoff is by means of curve number method that applies universal soil loss equation (infiltration excess method) which considers runoff caused when rain fall intensity rate is higher than infiltration capacity of the soil and the other method is by changing the algorithm of previous SWAT(CN method) to water balance method of estimating runoff(saturated excess) that entails runoff is caused by when infiltration is higher than overland flow.

A systematic assessment of water resources availability with high spatial and temporal resolution is essential in Ethiopia for strategic decision-making on water resource related development projects.

Therefore, a comprehensive understanding of hydrological processes in the watershed is a pre requisite for successful water management and environmental restoration. Due to the spatial and temporal heterogeneity in soil properties, vegetation and land use practices, a hydrologic cycle is a complex system. As a result mathematical model and geospatial analysis tool are required for studying hydrological process and hydrological responses to land use and climatic changes.

3.3 PREVIOUS STUDIES ON BLUE NILE

Various researches were done on the Blue Nile using swat models about runoff and sediment yield modeling.

Research by Fikadu Fetene (M.Sc.) with a title "Development of Rainfall-Runoff-Sediment Discharge Relationship in the Blue Nile Basin". The main objective of this thesis was to determine rainfall, runoff and sediment yield relationship in the Blue Nile basins and also to determine spatiotemporal distribution of sediments in the basin, to evaluate applicability of SWAT model in predicting sediment yield and concentration, To analyze the lag time of Hydrograph, LAG and lag time of sediment graph, LAGs and to Identify sensitive regions for erosion and deposition.

The result has shown that 34% of soil is eroded from three sub basins, Guder, N.Gojam and Jemma (in between 6-9 t/ha per year) that cover an area of 18.6% of total Blue Nile. In similar manner, more than 50% of soil is eroded from an area of around 16% of the whole basin (ranging from 15-30 t/ha of sediment yield). According to the finding of the paper the average annual sediment yield of the whole Blue Nile basin is around 4.26 t/ha/yr and 4.58 t/ha/yr including and excluding Rahad and Dinder sub basins respectively. The total soil eroded from the Blue Nile is 91.24 Million tones and 88.96 Million tones with and without Rahad and Dinder respectively.

As a mitigation measure for prevention of severs erosion and conservation mechanism, he recommended to cover the mountainous and hilly area with plantation and control further degradation by erosion.

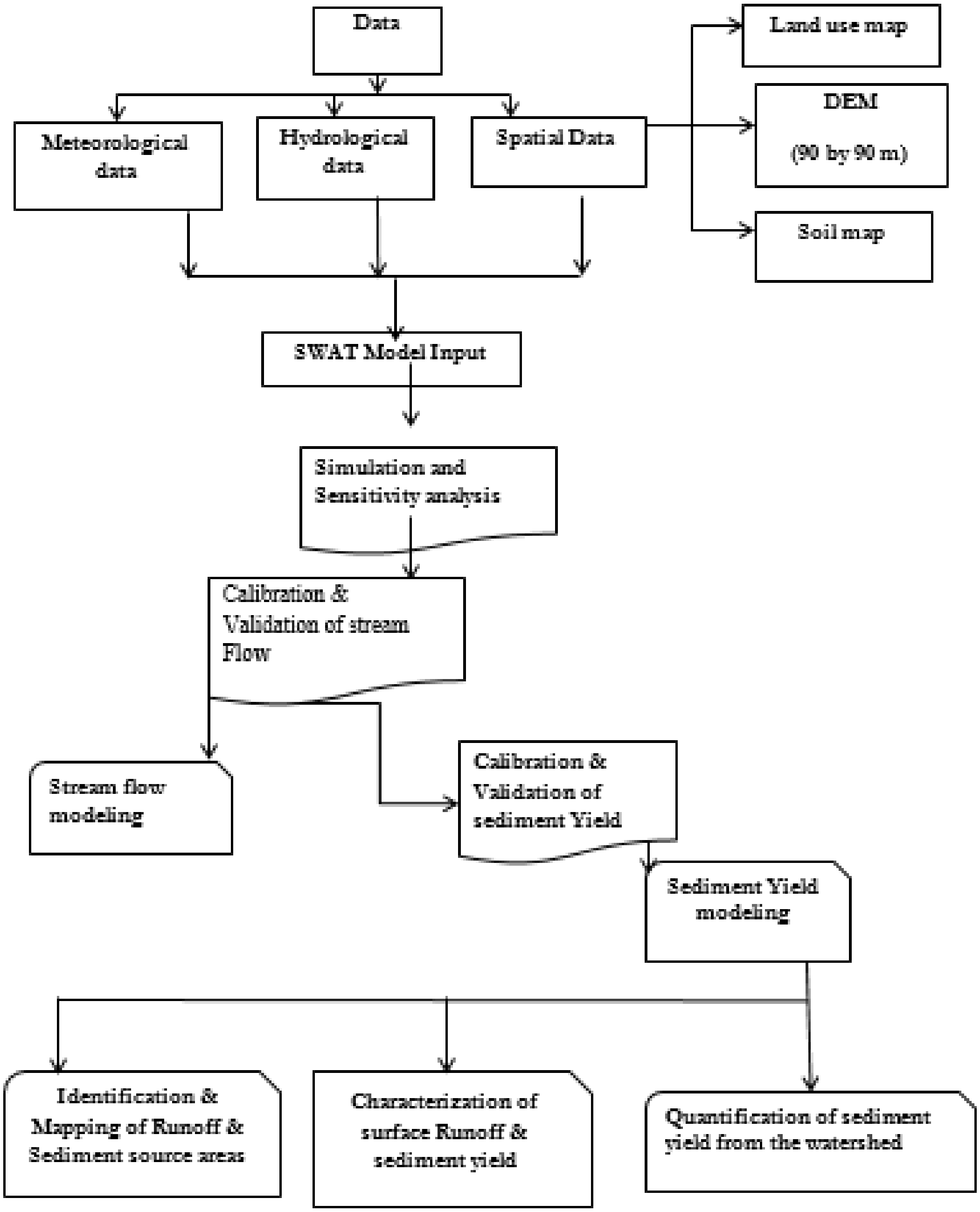
In addition (M.Sc. thesis) executed on the Blue Nile is" impact of land use change on reservoir sedimentation" by Dereje Dergie. The aim of this study was to predict the impact of land use/cover changes on sedimentation in the Blue Nile basin at Karadobi catchment by integrating spatially estimated hydrological parameters, digital elevation model, and land use, with the Soil and Water Assessment Tool (SWAT).

The finding of the paper were; from observed simulation of SWAT annual sediment load at Kessie and Karadobi be 8.98 t/ha and 8.55 t/ha respectively. Scenarios were developed simply to show the potential change of sediment from the corresponding land use change. Based on this the change of agro-pastoral land to agricultural land has great alteration on sediment yield. Change of 10% and 20% agro-pastoral to agriculture land increased sediment by 12% and 60% respectively. But change of 60% of pasture and 90% of forest land to agriculture increased sediment by an amount less than 0.5%. According to Dereja this comes because of small proportion of the two land use uses compared to agriculture and agro-pastoral lands. The other reason for small change of sediment due to change of pasture land is that most of the pasture land is located in sub-basins generating small sediment yield if another sub-basins is considered for percentage of pasture land 22% the monthly sediment per hectare yield becomes 4.54 t/ha.

4. METHODOLOGY

4.1 CONCEPTUAL FRAME WORK OF THE STUDY

For this runoff sediment relationship determination SWAT model is used. The SWAT model is chosen for physically based, uses readily available inputs, is computationally efficient, enable users to study long term impacts, capability for application to large-scale catchments (>100 km2), and capability for interface with a Geographic Information System (GIS).



ArcGIS 10.3 installed having an extension of SWAT 2012, after that DEM 90* 90m, soil and land use data for the basin clipped and layered in the model. The second step will be to add SWAT impute files i.e., daily rain fall, max and min temperature, wind speed, solar radiation and relative humidity in text format after that we run the model. One can edit the input files after model run occurred.

The next step is to check the model output, but the parameters has to calibrate and validate to check the model is acceptable for the intended area. After validation run the model for available year.

Finally result will be printed and based on the printed result, sediment yield for each sub basins will be known and different management intervention scenarios can be made for those hot spot areas.

4.2 HYDRO METEOROLOGICAL DATA ANALYSIS

Hydro meteorological data in Ethiopia is generally limited due to remoteness of many of the catchments and lack of economic resource and infrastructure to build and maintain monitoring sites (Awulachew, et al, 2008). However, what has been considered by Awulachew and his partners as a reason for data scarcity may not be main limiting factor in Ethiopia. Economic and infrastructure constraints can limit number of gauging stations, but can have lesser influence on data generation of established stations.

4.2.1 Meteorological Data Analysis

Meteorological data sets are the key inputs for hydrological modeling purpose, but the selection of representative meteorological gauging station depends on the data availability (including existence of enough length of record and distance from the area of interest).

Gauging stations were selected based on their relevance for the study. Nevertheless, daily metrological data for only seven gauging stations were obtained from the Hydrology Department of the Ministry of Water Resources. Locations of these seven gauging stations are as in the Figure. Even if the Model (SWAT) uses the nearest station from the centroid of each sub basin, the other unused station in the model are used for the purpose of filling in missed data and computation of areal rainfall.

Table 4.1: List of meteorological stations used in the study

Station	XPR	YPR	Elevation
Bahirdar	309,031	1,256,360	1,770
Adet	399,190	1,113,293	2,179
Chagni	204,520	1,169,713	1,620
Motta	291,486	1,244,300	2,417
Debre Markos	324,734	1,1279,59	2,446
Laybirr	306,223	1,149,073	1,707
Sahurah	268,021	1,319,705	2,205

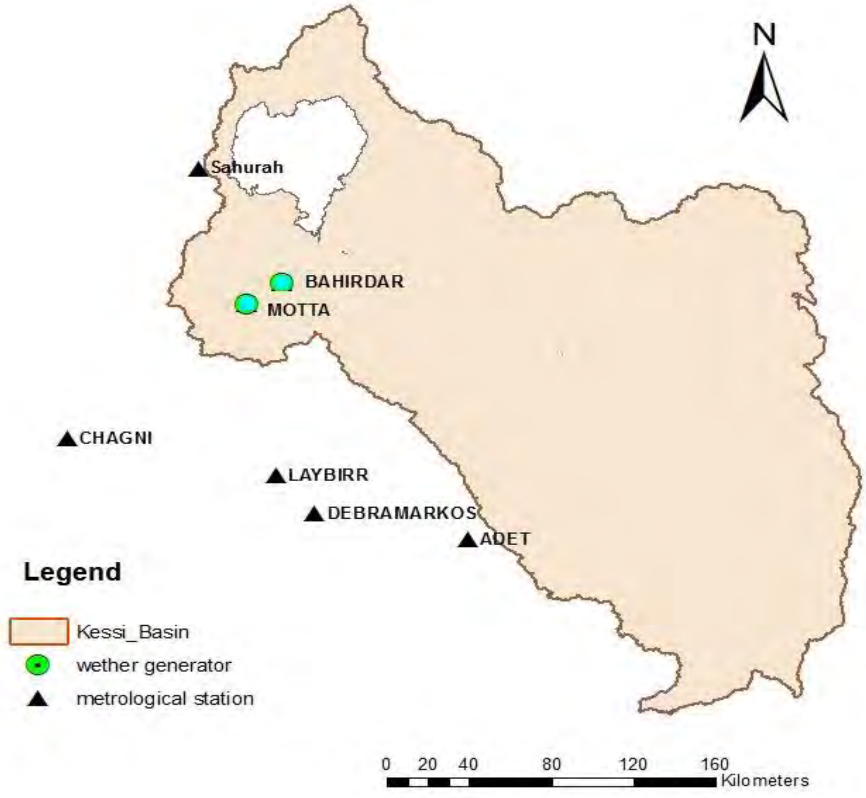


Figure 4.1:. Meterological stations.

Adequate number of gauging stations might have been established in the Blue Nile Basin. However, long records are not available at most of the stations and the reliability of available data is also questionable. The number of operational stream flow gauging stations has increased in recent years (MoWE, 2010). This might have been recorded as good change which may only be increase in number rather than quality oriented improvement. The Hydrological Department under the Ministry of Water Resources is responsible for hydrological and sediment data collection, processing and distribution to the data users.

A. Filling Missed Meteorological data's

Complete record of meteorological data is required for hydrological modeling and analysis. There exists small and large duration of missed records in the selected meteorological stations especially on rainfall and temperature. Data for the period of those missing data could be filled using estimation technique. Arithmetic mean, Normal ratio, Regression and distance power method are the most commonly used methods for estimation of missing rainfall & temperature data sets. Depending on the simplicity and length of missing data, regression and distance power method are selected for estimation of missing temperature & rainfall data.

Distance Power Method: The method is easy to use for fill in missing precipitation data (Hubbard, K.G, 1994). It is reliable if only the weather stations are situated inside of 100 Km radius (Tronci N ,Molteni F, Bozzini, M, 1986).

The rainfall at a station is estimated as a weighted average of the observed rainfall at the neighboring stations. The weights are equal to the reciprocal of the distance or some power of the reciprocal of the distance of the estimator stations from the estimated stations. Let Di be the distance of the estimator station from the estimated station. If the weights are an inverse square of distance, the estimated rainfall at point of interest (missed) is:

$$P_A = \frac{\sum_{i=1}^{n} {P_i}/{{D_i}^2}}{\sum_{i=1}^{n} 1/{{D_i}^2}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \mathit{equation}\ 4.1$$

Where P_i and P_A are precipitation at neighboring stations and at the target station respectively

D_i is the distance between the target station and the neighboring stations, estimated as:

$${D_i}^2 = [(X - X_i)^2 + (Y - Y_i)^2] \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \mathit{equation}\ 4.2$$

Where X and Y are the coordinates of the station whose data is estimated and X_i and Y_i are the co-ordinates of stations whose data are used in estimation.

Regression Method: This method of data infilling is applied for gaps having short duration of missing value for temperature and precipitation by considering strong correlation from the existing stations.

4.2.2 Data Quality Assessment

Engineering studies of water resources development and management depends on hydrological and meteorological data. These data should be stationary, consistent, and homogeneous when they are used for frequency analyses or to simulate a hydrological system. To determine whether the data meet these criteria, the engineer needs a simple but efficient screening procedure statistical variability.

Accordingly, in this study, the data quality assessment goes through the following key tests.

A. Rough screening of the data and compute or verify the totals for the hydrological year
B. Test for Absence of trend
C. Test for stationery of time series.
D. Homogeneity Test
E. Consistency test

I. Test for Absence of trend

After plotting a time series, one must be sure that there is no correlation between the order in which the data have been collected and the increase (or decrease) in magnitude of those data. It is common practice to test the whole time series for absence of trend.

Accordingly test for absence trend is checked by applying spearman correlation method in this study as it was simple, distribution free and power full for both linear & nonlinear trend.

$$R_{sp} = 1 - \frac{6 * \sum_{i=1}^{n} D_i^2}{n^2(n-1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. equation\ 4.3$$

Where n is the total number of sample data's, D is the difference and Rsp is spear man correlation coefficient.

$$D = KX_i - DY \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots equation\ 4.4$$

Where Kxi is the rank of the variable and K is chronological transformed series for observation y.

The Null hypothesis is finally checked for the acceptance with t-test statics which is described by:

$$t_t = R_{sp}(\frac{n-2)}{1-R_{sp}})^{0.5} \ldots\ldots\ldots\ldots\ldots\ldots equation\ 4.5$$

With t as student t distribution having degree of freedom (v) as n-2 and bounded at two tailed 5% level of significance in between:

$$\left(-\infty, t(v, 2.5\%)\right) U \left(t(v, 97.5\%)\right), +\infty) \ldots\ldots\ldots\ldots\ldots\ldots\ldots equation\ 4.6$$

With the bounded region of the null hypothesis, the time series has to be said “No Trend” if it satisfies and fall for t_t in between:

$$\left(t(v, 2.5\%)\right) < t_t < \left(t(v, 97.5\%)\right)$$

Stations having Rainfall and stream flow was tested for the absence of trend

II. Test for stationery

A time series of hydrological data is strictly stationary if its statistical properties (e.g. its mean, variance, and higher-order moments) are unaffected by the choice of time origin. (By ‘unaffected’, we mean that estimates of these properties agree within the range of expected.

Stationery of time series was checked based upon split-record tests for stability of the variance (F-test) and stability of mean (t-test). The tests for stability of variance and mean verify not only the stationary of a time series, but also its consistency and homogeneity. In the basic data-screening procedure, these two tests are reinforced by a third one, for absence of trend. Although stability of these two properties indicates only a weak form of stationary, this is enough to identify a non-stationary time series or to select those parts of a time series that are acceptable for use.

A time series is first divided in to subsets and computation of standard deviation for each subset will be attained first, then variance of the two subsets is checked for the acceptable range for stability of variance.

$$F_t = \frac{{\sigma_1}^2}{{\sigma_2}^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots equtaion\ 4.7$$

The t-test for stability of mean involves computing for the two subsets and then comparing the means of two or three non-overlapping sub-sets of the time series (the same subsets from the F-test for stability of variance) A suitable statistic for testing the null hypothesis, Ho: XI = X, against the alternate hypothesis, HI: XI < > X, is:

$$t_t = \frac{\bar{X}_1 - \bar{X}_2}{\left[\frac{n_1 - 1) * {S_1}^2 + n_2 - 1) * {S_2}^2}{n_1 + n_2 - 2} * \left(\frac{1}{n_1} * \frac{1}{n_2}\right)\right]^{0.5}} \ldots\ldots equation\ 4.8$$

Where n is the number of data in the sub-set, X the mean of the sub-set, and s^2 its variance.

III. Test for homogeneity

The data qualities with regard to possible temporal and spatial variations or errors should have to be investigated by checking homogeneity and consistency of selected stations. Non- homogeneity is a change in the statistical properties of the time series. Its causes can either natural or man-made. These include alterations to land use, relocation of the observation station, and implementation of flow diversions. Rainbow and non-dimensional plot are the widely used methods for checking homogeneity of time series data's of rainfall. In this study Absolute homogeneity is checked by rainbow software and relative homogeneity is checked by non-dimensional plot.

In RAINBOW the test for absolute homogeneity is based on the cumulative deviation from the mean and clearly shows the probability of rejecting homogeneity.

There exist two types of homogeneity called absolute homogeneity and relative homogeneity; once the absolute homogeneity of each station alone is checked their relative homogeneity is then checked (by using Non Dimensional Plot) in this study.

IV. Test for Consistency

A time series of hydro meteorological data is relatively consistent if the periodic data are proportional to an appropriate simultaneous time series.

Double mass curve is a simple, visual and practical method, and it is widely used in the study of the consistency hydro-meteorological data and it was a commonly used data analysis approach for investigating the behavior of records made of hydrological or meteorological data at a number of locations. It is used to determine whether there is a need for corrections to the data to account for changes in data collection procedures or other local conditions. Such changes may result from a variety of things including changes in instrumentation, changes in observation procedures, or changes in gauge location or surrounding conditions. Double mass analysis for checking consistency of a hydrological or meteorological record is considered to be an essential tool before taking it for analysis purpose. This method is based on the hypothesis that each item of the recorded data of a population is consistent.

Double mass curve method is adopted for checking consistency of both meteorological and hydrological data.

B. Estimation of Areal Rainfall

For Hydrologic application it is often necessary to compute estimates of areal precipitation of a catchment from rain gauge observations. Although rainfall may vary in space across a river basin, the majority of simpler methods for relating rainfall to stream flow require the average depth over the catchment. Most of the methods that are used for computing areal precipitation are Arithmetic mean, Thessien Polygon, Isoheytal method and Inverse distance Correlation method. But the selection of each method depends on the topography of the catchment (if flat Arithmetic mean is adopted), uniformity of rain gauges and availability of station in the catchment.

2.2.3 Hydrological data analysis

I. Infilling of hydrological data (Stream flow)

Complete river flow time series are vital to the sustainable management of water resources and even very short gaps can severely compromise data utility. There are a number of methods applied for infilling missed flow data, from which the selection of a suitable method depends on the existing gauging stations (existence of neighboring stations and availability data's). Regression method, interpolation method and application of hydrological models are among the most widely, common used methods for infilling purpose of stream flow.

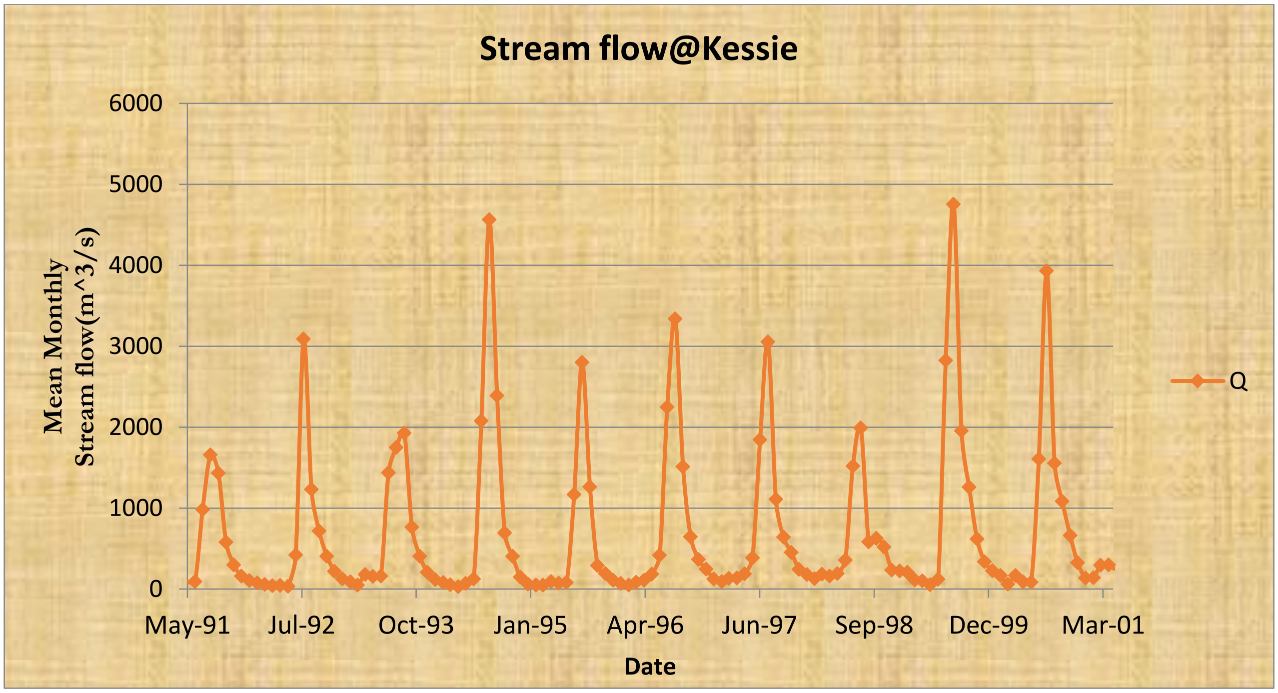


Figure 4.2. Over Year mean Monthly stream flow at Kessie Watershed

In similar way with the meteorological data's the assessment of data quality test for hydrological data (stream flow) of the used gauging stations of Kessie flow data's for absence of trend ,instability (stationery-test), absence of inconsistency and absence of inhomogeneity has been checked.

II. Sediment Data Analysis and preparation of Sediment Rating Curve

Sediment observations are a necessary basis for solving major water management problems which helps to ensure that water resources are used to the best advantage and at the same time protected, as well as protecting the watershed against negative effects. Data acquirement for sediment is widely issued for the purpose of assessing long term sediment yield of the catchment, to know sediment capacity of the river and to identify and undertake management scenario changes in river slope & plan formation.

Lack of available sediment data is experienced in our country as a whole and it was quite difficult to assess the watershed modeling with the scarce data. An option to solve this kind of scarcity is by generation of sediment rating curve.

Table 4.2. Sediment data chronograms for Kessie stations.

		Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Year	1990			2							1		
	1991												
	1992									3			
	1995							3	3	3			
	2003					3							
	2004								9	3	9		

☐ month with no data

n month with "n" number of data

Sediment rating curve describes the average relation between water discharge and suspended sediment concentration. A relationship between discharge and concentration can be developed which, although exhibiting scatter, will allow the mean sediment yield to be determined on the basis of discharge history (Morris and Fan, 1998). Although apparently simple in concept, critical evaluation of the data, careful application of the technique, and appreciation of its limitations are required if the approach is to be used effectively (Walling, 1977). Most river loads estimated by this method have been underestimated and the degree of underestimation increases with the degree of scatter about the rating curve and can reach 50% (Ferguson, 1986; Walling, 1977).

The Rating curve in this study is developed at Kessie Gauging station which have sediment data not more than 15 days in respective with flow. Segments of the sediment rating curve are usually approximated by a power relation of the form:

$$Q_t = m * Q^n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. equation\ 4.10$$

Where Qs is suspended sediment transport (tons/day), Q = water discharge (m3/s), m and n are coefficient and exponent respectively.

For ease of unit conversion sediment concentration of the measured data to sediment load converted as:

$$S = 0.0864 * Q * C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. equation\ 4.11$$

Where: S is sediment load in (ton/day), Q is flow of the stream (m^3/s), C is sediment concentration (mg/l) and 0.0864 is conversion factor.

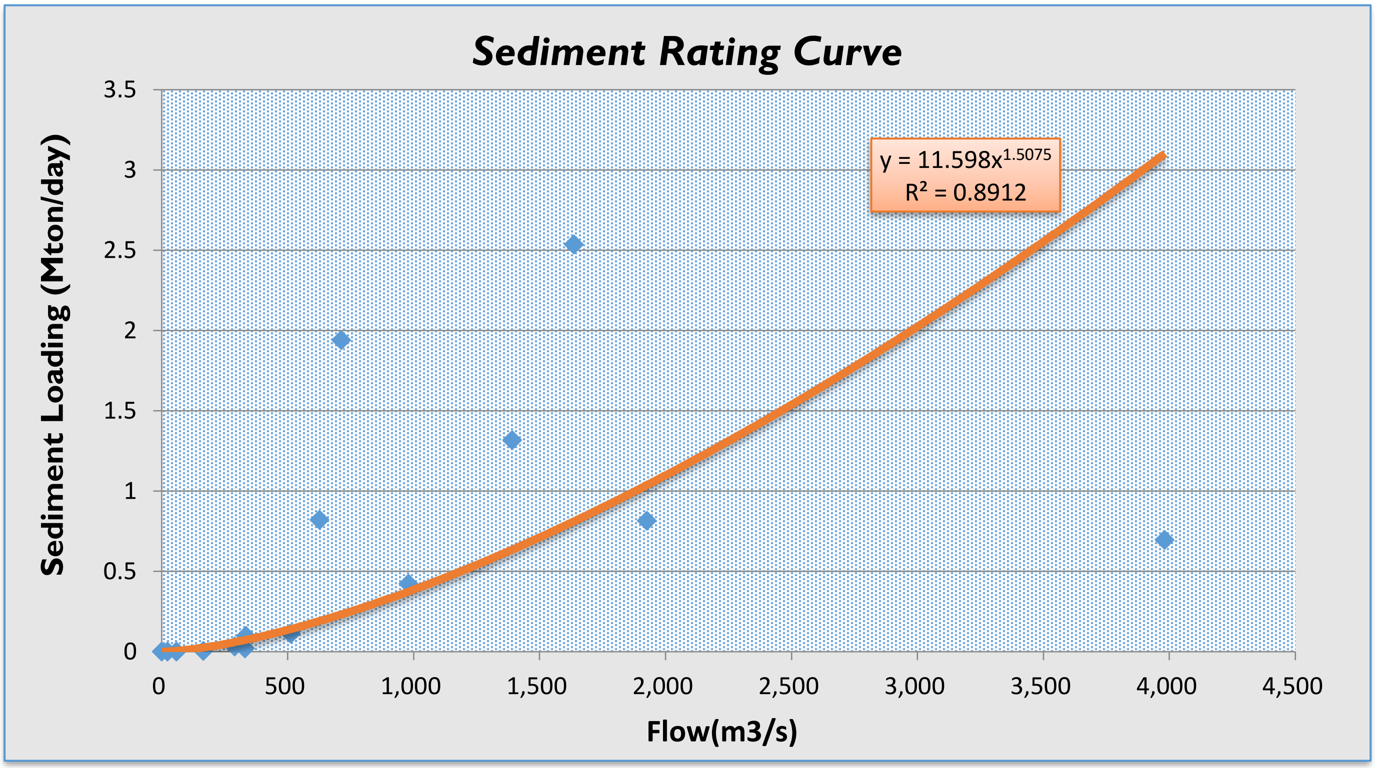


Figure 4.3:. Sediment rating curve at kessie station.

4.3 SWAT MODEL SETUP AND INPUTS

SWAT requires specific statistics about watershed characteristics such as topography, land use/cover, soil types, weather data and management practices. The model uses a two-level taste schemes; first basin and sub-basin delineation is performed based on topographic information, followed by further crumbling into HRUs using land use and soil type consideration in order to represent heterogeneous watershed properties. Climate inputs are required since they control water balance that drives all the processes simulated in the watershed. Management practice of a watershed is needed because it greatly influences the sediment transported from basins.

Before the model is set up and inputs are added, the computation of required water balance components for the simulation on the algorithm embedded in SWAT model should have to be identified.

A catchment might not have infiltration excess or saturation excess exclusively, but these may happen at the same place at different moments in time, or, at the same time, both processes might happen depending on the position of a place within the landscape, but the concern is better estimation and characterization of the spatial dynamics. Infiltration excess method of runoff computation was used.

Channel water routing method in the reaches and Potential evapotranspiration calculation by SWAT model in this study is by using, a default settled variable routing and Hargreaves method respectively. Skewed normal distribution for rainfall distribution during the simulation was selected.

The inputs required to run SWAT were collected and analyzed as described in the data analysis part above, the critical inputs were elevation, land use, climatic data and stream flow information & sediment data's.

4.3.1 Model Parameterization

A. Watershed Delineation

The watershed delineation interface in SWAT is separated in to five sections including DEM setup, Stream definition, outlet and inlet definition, watershed outlet selection and calculation of sub basin parameters. After the initial sub basin definition delineation, the generated stream network can be redefined by inclusion of additional sub basin sub basin inlet and out let. Adding an outlet at the location of established monitoring stations (the location of flow gauging station) is useful for the comparison of flow concentration between the predicted and observed data. Accordingly the sub basin outlet was manually located in to the watershed based on stream gauge location (Kessie) that had sufficient stream flow data available from 1990-2004.

B. HRU analysis

Hydrologic response units (HRUs) are lumped land areas within the sub-basin that comprised of unique land cover, soil and management combinations. HRUs enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils. The runoff is estimated separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy in flow prediction and provides a much better physical description of the water balance. The land use and the soil data in a projected shape file format were loaded into the SWAT interface to determine the area and hydrologic parameters of each land-soil category simulated within each sub-watershed. The land cover classes were defined using the look up table. A look-up table that identifies the 4-letter SWAT code for the different categories of land cover/land use was prepared so as to relate the grid values to SWAT land cover/land use classes.

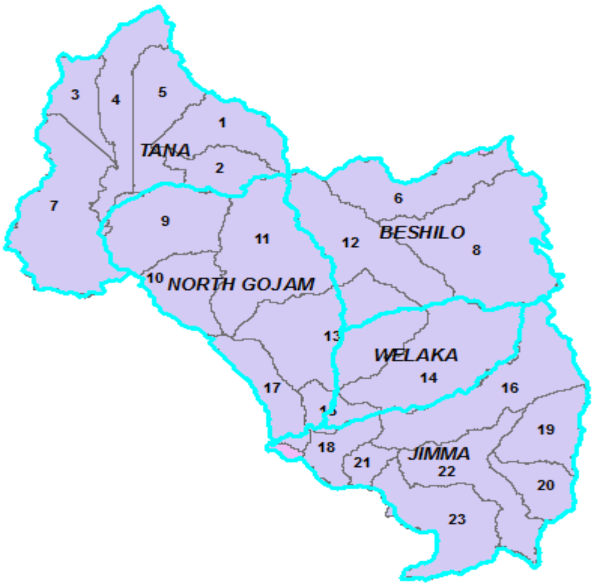


Figure 4.4: SWAT classification Sub basins of Kessie watershed

After the land use SWAT code is assigned to all map categories, calculation of the area covered by each land use and reclassification were done. As for the land use, the soil layer in the map was linked to the user soil database information by loading the soil look-up table and reclassification applied. The DEM data used during the watershed delineation was also used for slope classification. After the reclassification of the land use, soil overlay operation was performed.

The last step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. The land use, soil and slope map of Kessie catchment were overlaid to produce a hydrologic response group by setting a thresh hold value of 5, 20 and 20 % for land use, soil and slope domination to which land use percentage over the sub basin, soil over the land use and slope class percentage over the land use respectively were adopted in these study during HRU definition. Those thresholds were selected by considering the effect of on the formulation of hydrologic response and for making the HRU formulation in a manageable amount.

Accordingly, the study area (Kessie) is divided in 23 sub basin and 178 HRU were generated with the same hydrological response for the final water balance analysis.

4.3.2 Model Inputs

A. Digital Elevation Model (DEM)

Topography is defined by a Digital Elevation Model (DEM), which describes the elevation of any point in a given area at a specific spatial resolution as a digital file. A digital elevation model is needed for raster-based hydrological analysis in a GIS. The DEM used in the study was a 3 arc-second (approximately 90 m) medium resolution elevation data which was taken from Minister of water and agriculture GIS department.

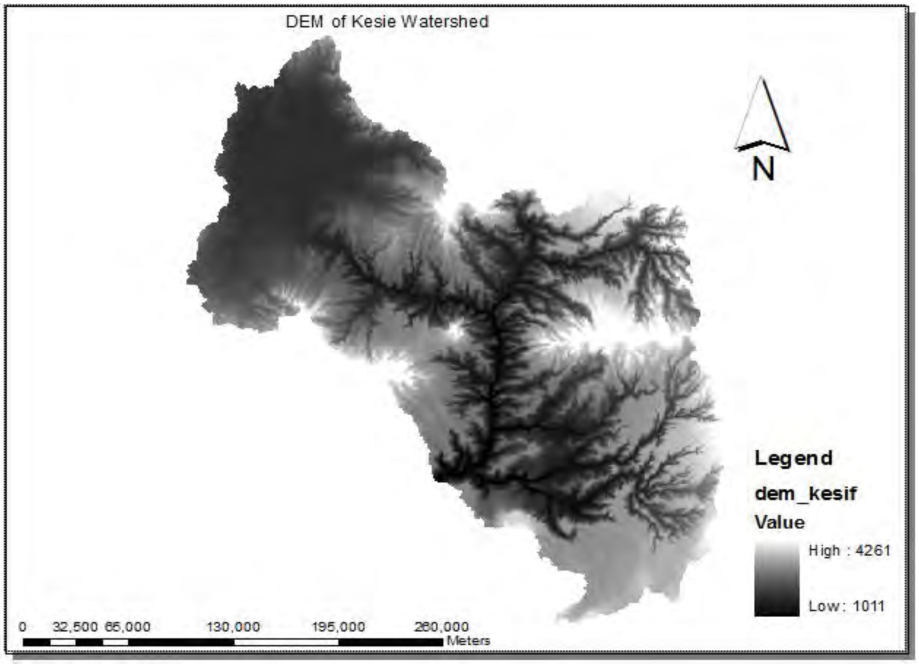


Figure 4.5:. DEM of kessie watershade.

The DEM was used to generate percent slope values, to automatically delineate watershed boundary, define stream networks, and identify gage outlets. Figure shows the boundary of the Kessie basin, the SRTM-DEM and the user-defined DEM mask to limit the processing of the source DEM within the approximated area of the Kessie Basin.

B. Soil Data and Maps

SWAT model requires different soil textural and physic-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. These data were obtained mainly from MOWE (Abbay river basin master plan project- phase 2- reconnaissance soils survey). Major soil types in the watershed are Eutric Leptosols, Heplic Luvisols, Eutric Vertisols and Eutric Cambisols.

Table 4.3: Redefined soil for Kessie Watershed

ITEM	SOILS:	Area [km^2]	% Watershed Area
1	ALISOLS	2,131.1	3.32
2	ARENOSOLS	606.3	0.94
3	CAMBISOLS	3,523.0	5.49
4	FLUVISOLS	2,730.4	4.25
5	LEPTOSOLS	29,508.5	45.94
6	LUVISOLS	7,834.1	12.20
7	NITISOLS	760.5	1.18
8	REGOSOLS	1,134.3	1.77
9	URBAN LAND	23.8	0.04
10	VERTISOLS	12,914.7	20.11
11	WATER	3,062.5	4.77
	SUM	**64,229.2**	**100.00**

SWAT database needs the soil runoff potential. In the min time soil may be place in one of four hydrologic groups, A, B, C, and D, or three dual classes, A/D, B/D, and C/D.

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

B. The soils have a moderate infiltration rate when thought wetted. They chiefly are moderately depth to deep, moderately well-drained to well-drained soils that have moderately fine to moderately coarse textures. They have 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 the 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.

In order to integrate the soil map within the SWAT model, it is necessary to make the User Soil Database, which contains textural properties and physicochemical properties for each soil layers. Then the prepared user soil database which was in excel format has to be inserted into the SWAT database.

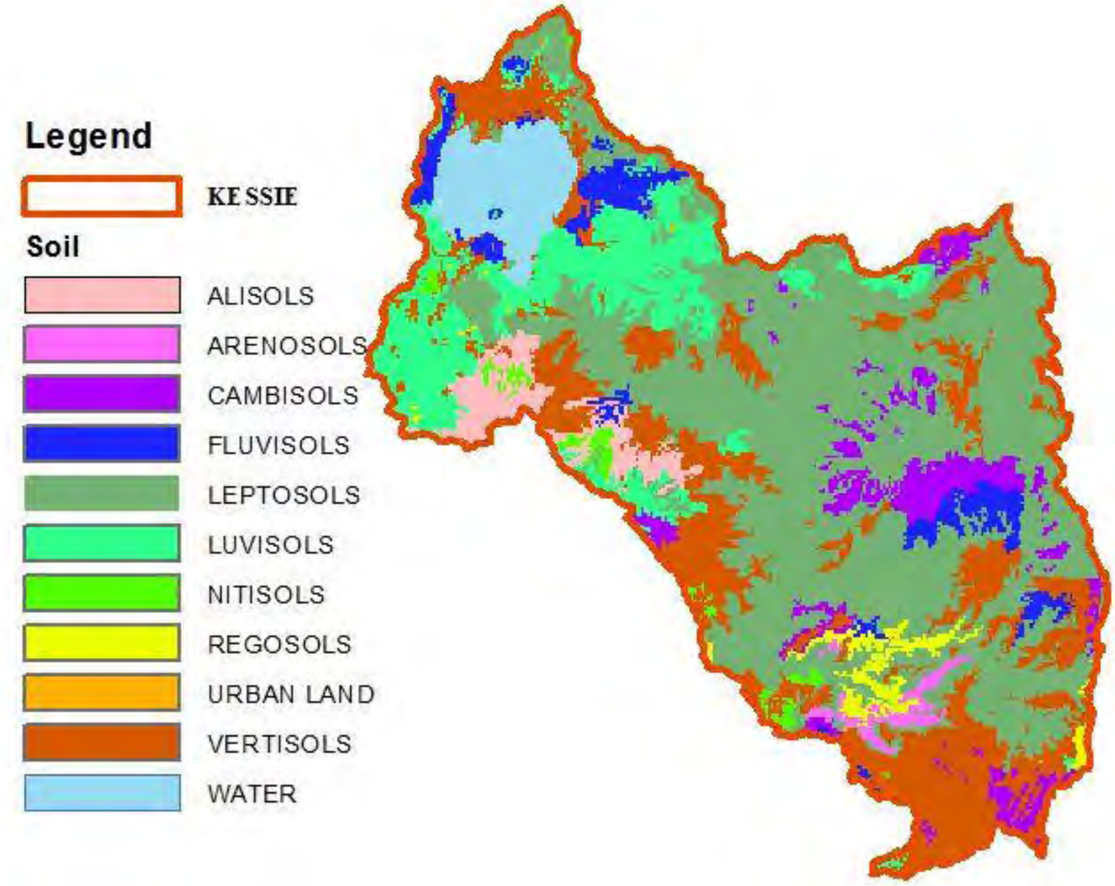


Figure 4.6:. Soil of kessie watershade.

C. Land Use/Land Cover Data

Land cover and soil are factors greatly influencing the hydrological properties of a watershed that are required by SWAT to describe a sub-basin or HRU. Once watershed topographic parameters have been computed for each sub basin, the interface uses land cover and soils data to generate multiple hydrologic response units (HRUs) within each sub basin by GIS overlay process to assign soil parameters and SCS curve numbers. HRUs are lumped land areas within the sub watershed that are comprised of distinctive land cover, soil, and management combinations (Neitsch et al., 2002). Such subdivision of sub-basins in to HRUs enables the SWAT model to reflect the spatial variations of the hydrologic conditions for different land cover and soil distributions within the sub-basins.

The land use map for Kessie watershed is collected from water & land resource center (WLRC) for the year 2011. The data contain the redefined land use of the area. In the land use attribute table integer values interred for the same land covers.

Table 4.4: Redefined and original land covers for Kessie Watershed

Original Land Covers	Redefined land Cover According to SWAT	SWAT Code	Coverage over the watershed (%)
Water	Water	WATR	4.81
Settlement	Residential-Med/Low Density	URML	0.33
Cultivated Land	Agricultural Land-Generic	AGRL	0.41
	Spring Barley	BARL	9.33
	Eragrostis Teff	TEFF	24.45
	Grain Sorghum	GRSG	10.39
	Corn	CORN	0.98
	Rice	RICE	1.55
	Winter Wheat	WWHT	16.69
Grass Land	Pasture	PAST	6.50
Deciduous Forest	Forest-Deciduous	FRSD	3.59
Shrub Bush	Range-Grasses	RNGE	5.80
Bare Land	Barren	BARR	10.29
Wet Land	Wetlands-Mixed	WETL	0.45
Mixed Forest	Forest-Mixed	FRST	4.42

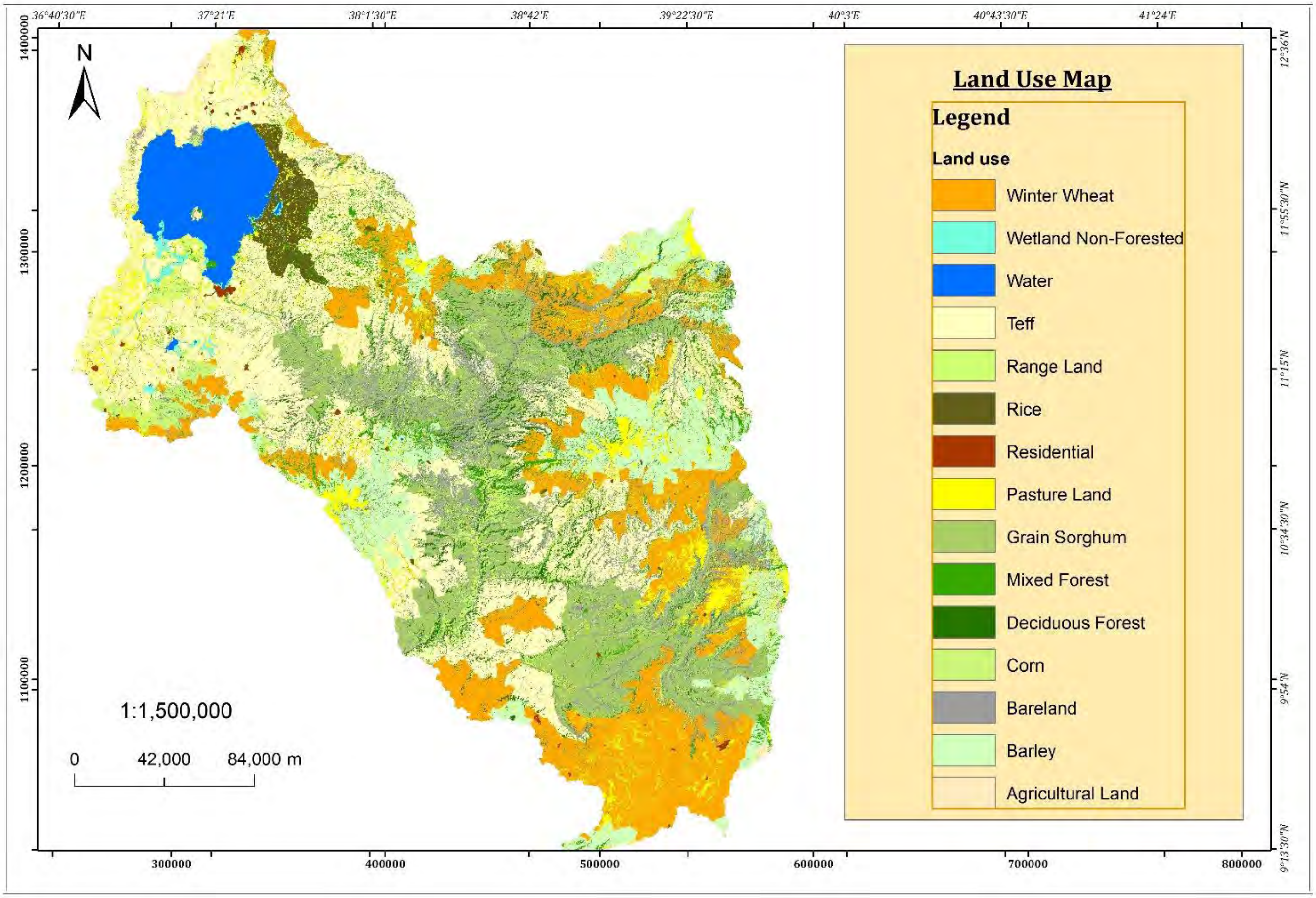


Figure 4.7:. Land use of kessi watershade.

D. Weather Data Definition and Weather generator

For missing data and shortage of daily data, SWAT generates from average monthly values. The model generates a set of weather data for each sub basin. The values for any sub basin will be generated independently and there will be no spatial correlation of generated values between the different sub basins. These are generation of precipitation, temperature, wind speed, solar radiation and relative humidity of a given station in the basin. On top of these data statistical analysis of monthly daily average, standard deviations, and probability of wet and dry days, skew ness coefficients and dew temperature were determined by FORTRAN program known as pcpSTAT (Stliersch, 2003) and program dew02.exe (S. Liersch, 2003) for generating missing data (identified by -99) and predicting unmeasured and missing data in the basins.

SWAT uses a model developed by Nicks (1974) to generate daily precipitation for simulations which are not available in measured data. This precipitation model is also used to fill in missing data in the measured records. The precipitation generator uses a first-order Markov chain model to define a day as wet or dry by comparing a random number (0.0-1.0) generated by the model to monthly wet dry probabilities input by the user. If the day is classified as wet, the amount of precipitation is generated from a skewed distribution or a modified exponential distribution.

The metrological data required were: daily precipitation, daily maximum and daily minimum air temperature, daily solar radiation, daily wind speed, and daily relative humidity. For this daily statistical values are needed from daily data values were needed to be generated from daily ones.

- **Precipitation and temperature**: the daily precipitation and temperature of all gauging stations were prepared in text format.

- **Solar radiation, relative humidity, and wind speed** data were available only for principal stations (Bahirdar and motta). These data’s for the rest of the stations were generated by SWAT. More over these data’s were required when penman Montheith equation is used to evaluate potential evapotranspiration.

- Weather simulation data: these data consists of monthly average values of all the values required by the SWAT model in order to generate daily values.

The metrological data were collected from Ethiopian National metrological agency for the base period from 1990 to 2004 G.C.

4.3.3 Sensitivity Analysis, Calibration & Validation

Sensitivity Analysis:

Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be apportioned to different sources of uncertainty in its inputs. . The analysis evaluates how different parameters influence a predicted output. After undertaking simulation of the model with in the required data period, sensitivity analysis was conducted by setting the simulated scenario as a default simulation and the method of sensitivity analysis which was performed in this study was the built-in

SWAT sensitivity analysis tool that uses the Latin Hypercube One-factor-AT-a-Time (LH-OAT) proposed by (Morris, 1991) , the analysis was performed by using the observed flow and sediment yield data at the Kessie gauging station (considered outlet).

According to (Lenhart, T and Eckhardt, K and Fohrer, N and Frede, H-G, 2002) the sensitivity of a flow to a parameter can be categorized into four classes as describe in the Table 4-2 and the sensitivity class for the governing parameters was taken in consideration by the specified values.

Table 4.5: Sensitivity class assigned in SWAT Model

Class	Mean Index	category of sensitivity
1	$0 \leq I \leq 0.05$	Small to negligible
2	$0.05 \leq I < 0.2$	Medium
3	$0.2 \leq I < 1$	High
4	$I \geq 1$	very High

Model Calibration:

Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters (within their respective un-certainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions. In sediment transporting modelling two-step calibration procedures has been suggested by (Neitsch, S and Arnold, J and Kiniry, J and Williams, J, 2005) the first is to check water balance contribution, then calibrate stream flow and followed by sediment calibration.

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 (Eckhardt & Arnold, 2001). Automatic calibration involves the use of a search algorithm to determine best-fit parameters. It is desirable as it is less subjective and due to extensive search of parameter possibilities can give results better than if done manually. SWAT has two built-in calibration tools. 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 is used to obtain an optimal fit of process parameters which is based on a multi-objective calibration and incorporates the Shuffled Complex Evolution Method algorithms (Green and van Griensven, 2005).

The calibration period for both flow and sediment was from 01/01/1990 to 30/12/2000 including the warm-up period. In this process, model parameters varied until recorded flow patterns are accurately simulated. For this study, the manual calibration was applied due to its simplicity. Where a trial-and-error process of parameter adjustment; after each parameter adjustment is made, the simulated and observed hydrographs are visually compared to see if the match is improved.

Model Validation:

Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, although "sufficiently accurate" can vary based on project goals (Refsgaard, Jens Christian, 1997). Validation involves running a model using parameters that were determined during the calibration process, and comparing the predictions to observed data not used in the calibration. In general, a good model calibration and validation should involve:-

- ✓ Observed data that include wet, average, and dry years.
- ✓ Multiple evaluation techniques.
- ✓ Calibrating all constituents to be evaluated and Verification that other important model outputs are reasonable.

Accordingly the model validation period adopted in this study is from 01/01/2001 to 30/12/2004.

5. RESULT AND DISCUSSION

SWAT model was calibrated and validated on a monthly basis to check its capability to model stream flow and sediment yield of Kessie watershed using a time series dataset of 15 years from 1990 to 2004. The first year of the modeling period were used for 'model warm up. Data for the period 1991 to 2000 were used for calibration and the remaining part of the dataset was reserved for validation. The watershed was subdivided into 23 sub basins based on a default threshold area. The simulated stream flow and sediment yield was calibrated and validated at Kessie Gauging station which was taken as an outlet of the watershed and compared with the observed flow and sediment yields.

Table 5.1: SWAT model warm-up, calibration and validation time period description.

Description	Time Frame		Number of year
	From	To	
Model Warm-up	1/1/1990	12/31/1990	1
Calibration	1/1/1991	12/31/2000	10
Validation	1/1/2001	12/31/2004	4
SWAT simulation	**1/1/1990**	**12/31/2004**	**15**

5.1 STREAM FLOW MODELING

5.1.1 Sensitivity Analysis

Sensitivity analysis was carried out to identify which model parameter is most important or sensitive. Flow sensitivity analysis was carried out for a period of 11 years, which includes both the calibration period (from January 1, 1990 to December 31, 2000) and one year of warm-up period (from January 1, 1990 to December 31, 1990). About 270 iterations have been done by the model at the point where Kessie gauging station was found. Table 5.2 shows the most sensitive parameters for stream flow drawn by SWAT model.

From the sensitivity result about eight Parameters were taken as governing parameters which were believed to have effect on the simulated values are considered for calibration. The result denotes that, hydraulic response unit parameters such as the SCS_CN for moisture condition II (Cn2), maximum potential index

(Canmx) , soil evaporation compensation factor (Esco) had influence was found sensitive which indicates that the parameters had a governing effect on simulated surface flow in respective with the observed flow.

Furthermore, ground water parameters like base flow alpha factor (Alpha_Bf), thresh fold depth of water in the shallow aquifer required for return flow to occur (Gwqmn), and thresh hold depth of water in the shallow aquifer required for evaporation to occur (Revapmn) are found the influencing flow parameters (having relative mean sensitivity from medium to high degree of sensitivity). Finally, the soil parameters inclusive of soil depth (Sol_Z) and soil available water capacity (Sol_Awc) had also contributing effect on stream flow and were taken as a guideline for the calibration. The sensitivity analysis result that the model with drawn is as shown in the table below.

Table 5.2: Result of sensitive analysis of flow parameters in Kessie watershed

Parameters	Rank	Mean Sensitivity	Category of Sensitivity
Alpha_Bf	2	0.4	High
Canmx	9	0.0639	High
Sol_Awc	8	0.0738	High
Cn2	1	0.768	High
Revapmn	7	0.0837	Medium
Gwqmn	3	0.151	High
Esco	5	0.102	High
Epco	6	0.082	High
Sol_Z	10	0.0553	High
Blai	4	0.105	High

5.1.2 Stream Flow Calibration & Validation

Even if there exists numerous flows gauging station in Kessie watershed that are found in Lake Tana, Beshilo, North Gojjam, Jimma and Welaka sub basins, considering the availability of reliable data, spatial consideration of outlet point (areal extent to cover all the drainage area according to the outlined objectives) and drainage areal coverage the gauging station at Abbay near Kessie having the all stream discharge of the five sub basins was selected and used as calibration point.

The calibration of stream flow was conducted depending on the sensitive parameters which were demonstrated as influential variables on the simulated water balance by the model. The parameters which were believed to have influence on the simulated flow were taken in to consideration from sensitivity analysis result.

Due to its realistic representation in the users knowhow based for the watershed and its simplicity, manual calibration was used in this study. Before calibration proceeds, the performance of the model was evaluated from the initial simulation run with model default parameter values resulting Nash Sutcliffe model efficiency (ENS) of _0.67, correlation coefficient (R^2) of 0.64 and mean deviation of _106.2% were obtained from the initial model run. The default simulation has shown poor result which insights that the model needs strong calibration.

The SWAT default parameters values were adjusted as follows. First, the surface flow component of average annual water balance was adjusted by fine-tuning the CN. An effort was also made to keep the curve numbers close to standard table values. Next, Gwqmn, Esco, SOL_AWC, Sol_Z, GW_REVAP & REVAPMN were adjusted till the deviation between simulated and observed values get minimized and the performance indicators lie in the acceptable range. Accordingly the final calibrated parameters were presented as shown Table 5.3 for flow in Kessie watershed.

Table 5.3: Result of final calibrated flow parameters for Kessie Watershed

Parameter	Range	Initial Default Values	Calibrated Value
Alpha_Bf	0 – 1	0.048	0.09
Cn2	_+25%	Default*	_21%(Reduced)
Esco	0 _ 1	0.95	1
Gwqmn	0 – 5000	0	4150
Revapmn	0 – 500	1	150
Sol_Awc	_+25%	***	_20% (Reduced)
Canmx	0 _ 1	0	0.4
Sol_Z	_+25%	***	+20% (Added)

The model goodness-of-fit was evaluated and the model performance after adjusting all the above parameters. Calibration resulted in Nash–Sutcliffe simulation efficiency (ENS) of 0.76 & 0.83, correlation coefficient (R^2) of 0.77 and 0.86, and mean deviation of _5.16% and +22.1% in the calibration and validation period respectively. The values of the above statistical indicators fall in the acceptable range. This shows a good agreement was observed between measured and simulated mean monthly flows.

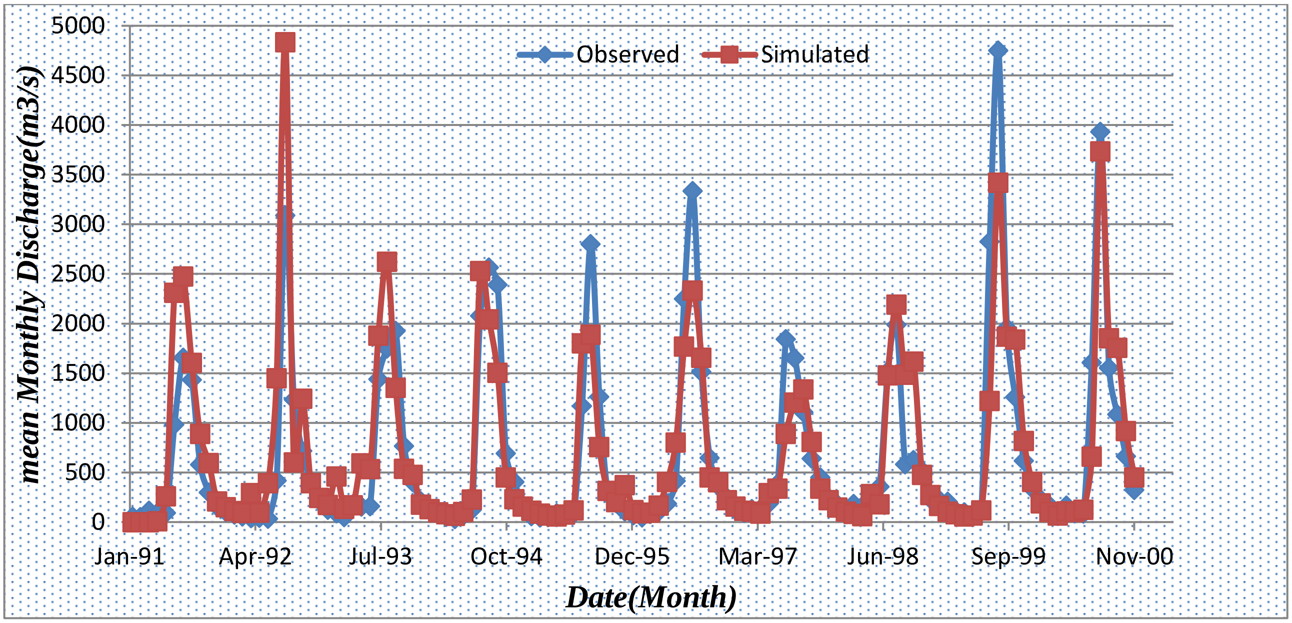


Figure 5.1. Calibration results of average monthly Observed and simulated flow hydrograph (1991-2000)

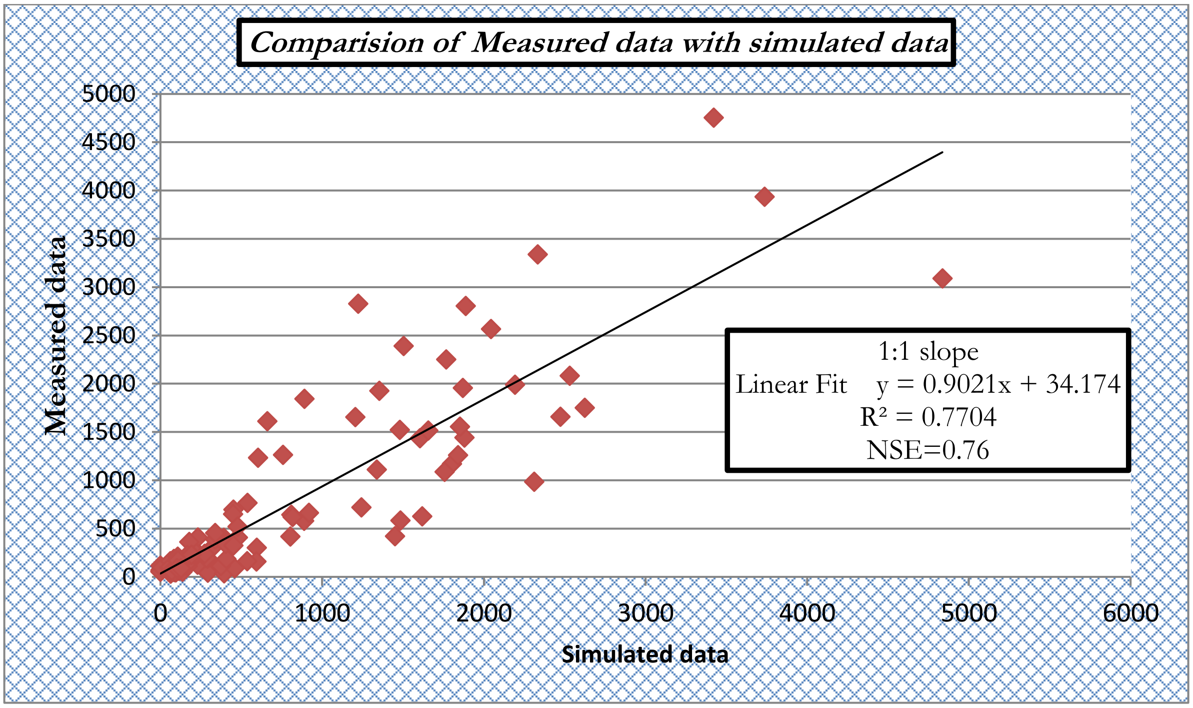


Figure 5.2. Simulated versus observed monthly flow during calibration period (1991–2000).

The hydrograph for the calibration period of the observed and simulated flow is in a mean monthly base estimation. It is observed that the model over estimates the peak flows of the months July 01, Aug 01, Aug 02, Aug 93 & Aug 98 which may be resulted from the quality of weather or flow data used as an input to the model . The models low capability to capture peak flows may be another reason for the slight variation between measured and simulated flows at low and minimal discharges.

Table 5.4: Calibration result statistic for monthly measured and simulated Stream flow @Kessie

Monthly time step simulation	**Over Year Mean Monthly Stream flow(m^3/s)**		**Model Performance**		
	Observed	**Simulated**	**R^2**	**NSE**	**PBIAS**
Calibration period (1991-2000)	665.12	699.425	0.77	0.76	_5.16%

Flow validation was carried out from January 1, 2001 to December 31, 2004 without further adjustment of the parameters of flows. The hydrograph for the validation period of the observed and simulated flow is in a monthly base estimation. The hydrograph of validation period were as presented below in figure 5.3.

Table 5.5: Validation result statistic for monthly measured and simulated Stream flow.

Monthly time step simulation	**Mean Monthly Stream flow(m^3/s)**		**Model Performance**		
	Observed	**Simulated**	**R^2**	**NSE**	**PBIAS**
Validation period (2001-2004)	741.89	580.17	0.86	0.83	22.1%

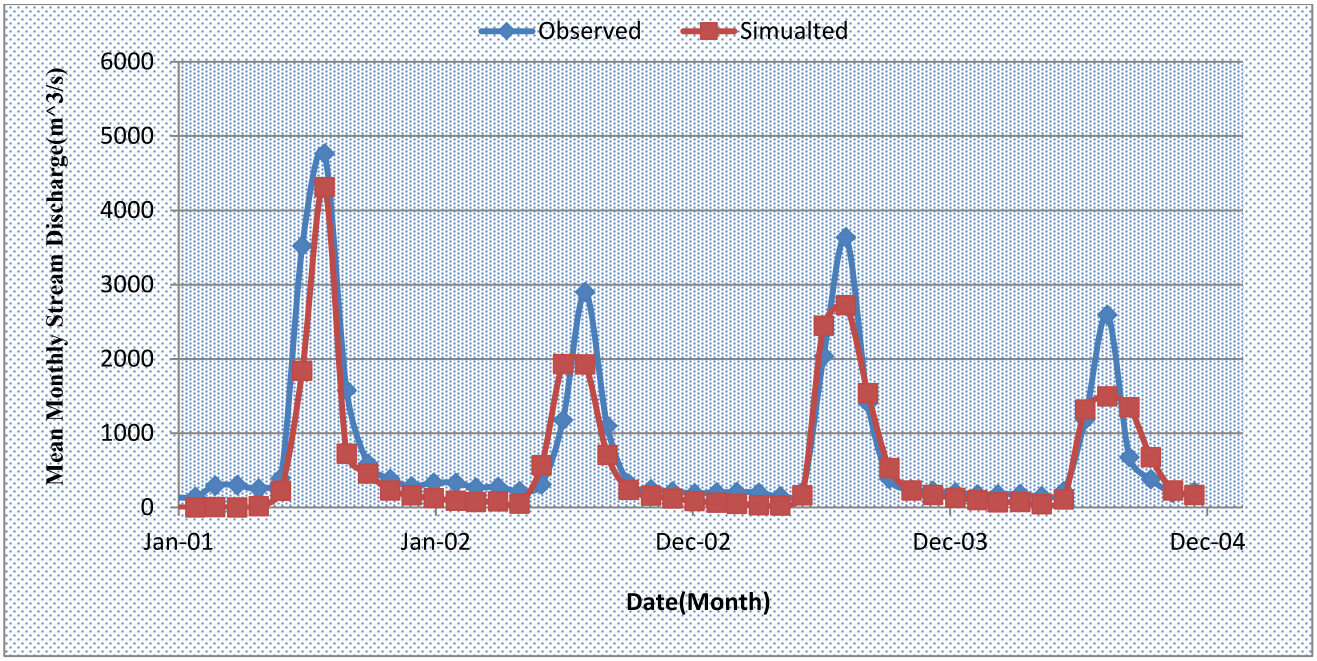


Figure 5.3: Validation results of average monthly Observed and simulated flow hydrograph (2001-2004).

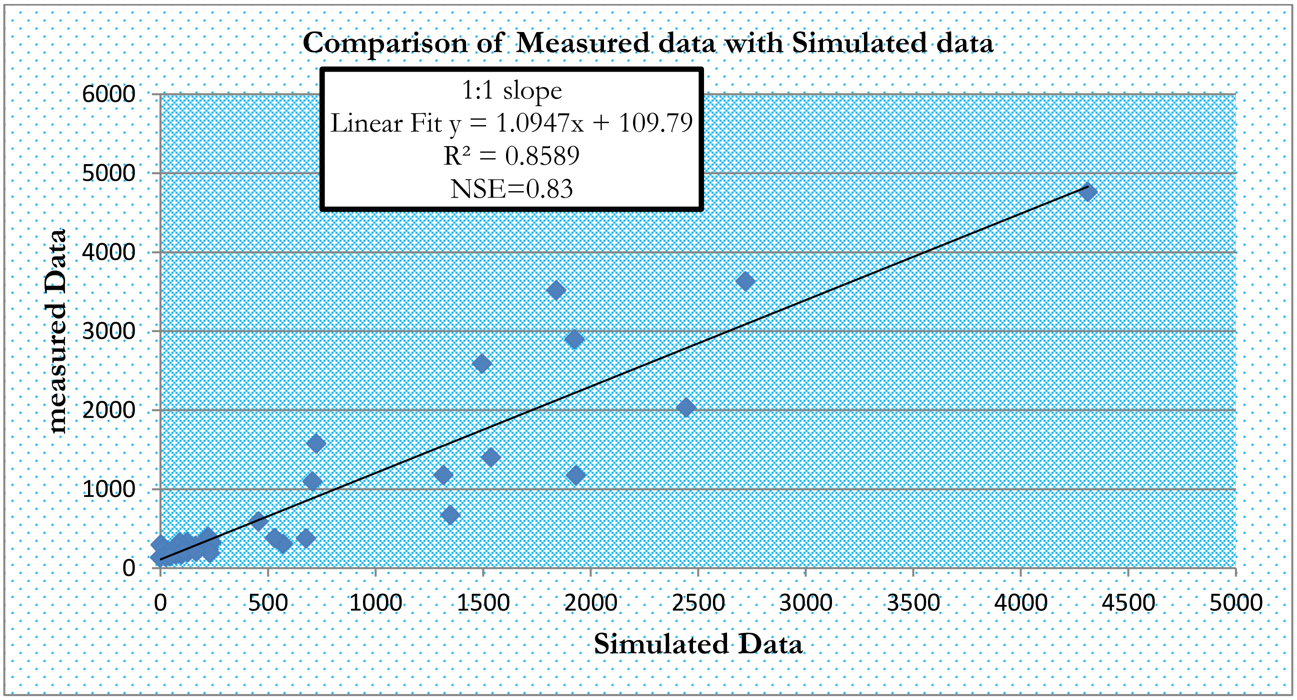


Figure 5.4. Simulated versus observed monthly Flow during validation period (2004–2003).

The performance of the model for validation period is better than that of calibration period. This is due to better quality of recent hydro-meteorological data.

5.2 SEDIMENT YIELD MODELING

Sediment yield is the amount of sediment transported out of a watershed or sub watershed. This value is used for model calibration and validation because it can be compared against available data sets.

5.2.1 Sensitivity Analysis

Once it is shown that the flow was accurately represented by the model the focus is shifted to the calibration of the model for sediments. Sensitivity analysis was carried out for sediment to identify parameters that affect sediment yield. Sensitive parameters for sediment flow in the watershed includes USLE support practice factor (USLE_ P), linear factor for channel sediment routing (SPCON), USLE cover or management factor (USLE_C) and exponential factor for channel sediment routing (SPEXP) were found very high to high sensitive to sediment flow. From those sensitive parameters USLE support practice factor (USLE_P) was the most sensitive of all as shown in Table 5.6.

Table 5.6: Result of sensitive analysis of Sediment parameters in Kessie watershed

Rank	Parameters	Mean sensitivity index	Category of sensitivity
1	**USLE_P**	2.91	very high
2	**USLE_C**	0.618	High
3	**Spcon**	0.23	Small
4	**Spexp**	0.00912	Small

5.2.2 Sediment yield Calibration & Validation

After calibration and validation of flow, the next was calibrating sediment yield of the watershed. Like Flow, sediment calibration for the Kessie watershed by comparing monthly model simulated sediment load against monthly measured sediment from Kessie gauging station for the period January 1, 1991 to December 31, 2000. Also one year (January 1, 1990 to December 31, 1991) was skipped for model initialization (warm-up period). The calibration of sediment yield of the watershed was done based on sediment sensitivity analysis that have identified sensitive parameters for sediment yield of the watershed (Table 5.6) and by varying iteratively within the allowable ranges of the parameters.

USLE support practice factor (USLE_P) that which is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope culture adjusted to 0.116 and the USLE cover and management factor (USLE_C) that indicates the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow was adjusted for each land use types in the watershed, by taking the initial values from Hurni (1985) study was calibrated. From the channel properties, the linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing (SPCON) adjusted to 0.008 and the exponent parameter for calculating sediment re-entrained in channel sediment routing (SPEXP) adjusted to 1.7 (Table 5.7).

Table 5.7: Final Calibrated Sediment Yield Parameters for Kessie Watershed

Parameters	**Default Values**	**Allowable Range To change**	**Adjusted Parameters value**
Spcon	0.0001	0.0001-0.01	0.008
USLE_C	0.03-0.2	0.001-0.5	0.04-0.25
Spexp	1	1 to 2	1.7
USLE_P	1	0 - 1	0.116

As observed in the graphical relationship (Figure 5.5) the model under estimate and overestimate sediment yield during periods of peak sediment values. Such kind of error and discrepancy occur by errors occurs during flow measurement, uncertainty in sediment rating curve (due to lack representative sediment data which is not inclusive of sediment concentration that exists in all the seasons of the year), and the model by itself has limitation to capture the high flows.

Table 5.8: Calibration statistics of observed and simulated Sediment load

Monthly Time step	**Over Year Sediment Loading (ton/ha/yr.)**		**R^2**	**NSE**	**PBIAS**
	Observed	**Simulated**			
Calibration (1991- 2000)	15.06	16.72	0.773	0.71	-2.72%

The model shows good correlation with the generated sediment (observed) in both calibration & validation periods to which the coeffiecnt of determination is 0.77 & 0.82 and Nash Sutcliffe efficiency of 0.71 & 0.72 in the calibration & validation period respectively.

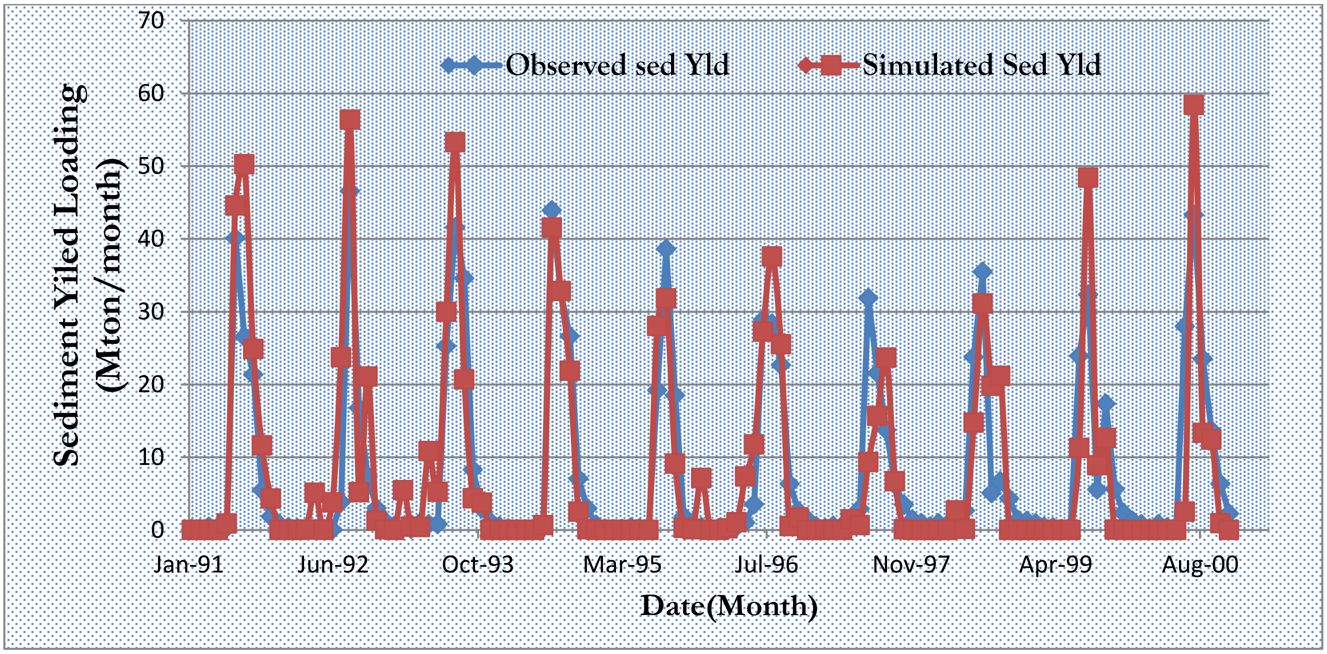


Figure 5.5 Calibration results of monthly Observed and simulated sediment yield hydrograph

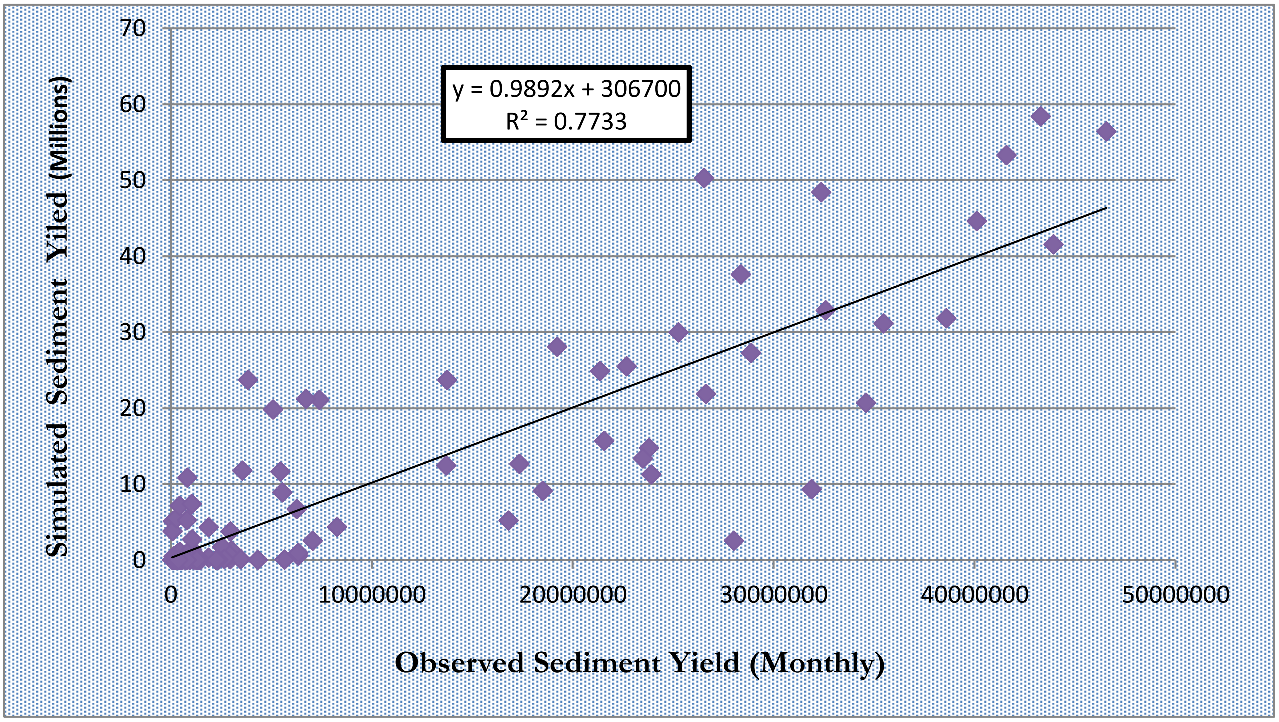


Figure 5.6. Simulated versus observed monthly flow during Calibration period (2001–2004).

Like flow validation, validation of sediment yield of the watershed was carried out four the years January 1, 2001 to December 31, 2004, which includes one year, 2003, for model initialization (warm up). Therefore, for the model performance in validation was considered from 2001 to 2004 without further adjustment of the parameters. The statistical values in the monthly basis of sediment yield estimation in the validation period results the R^2, NSE and PBIAS were 0.82, 0.72 and _2.72 % respectively.

Table 5.9: Validation statistics of observed and simulated Sediment load

Monthly Time step	**Annual Average Sediment Loading (ton/ha/yr.)**		**R^2**	**NSE**	**PBIAS**
	Observed	**Simulated**			
Validation (2001-2004)	15.65	15.37	0.81	0.72	3.89%

The observed and simulated sediment yield in monthly time step of the validation period shows the model overestimate the sediment yields of highly flow time periods (August 01, August 03, July 02) as well as in low and medium flow periods. .

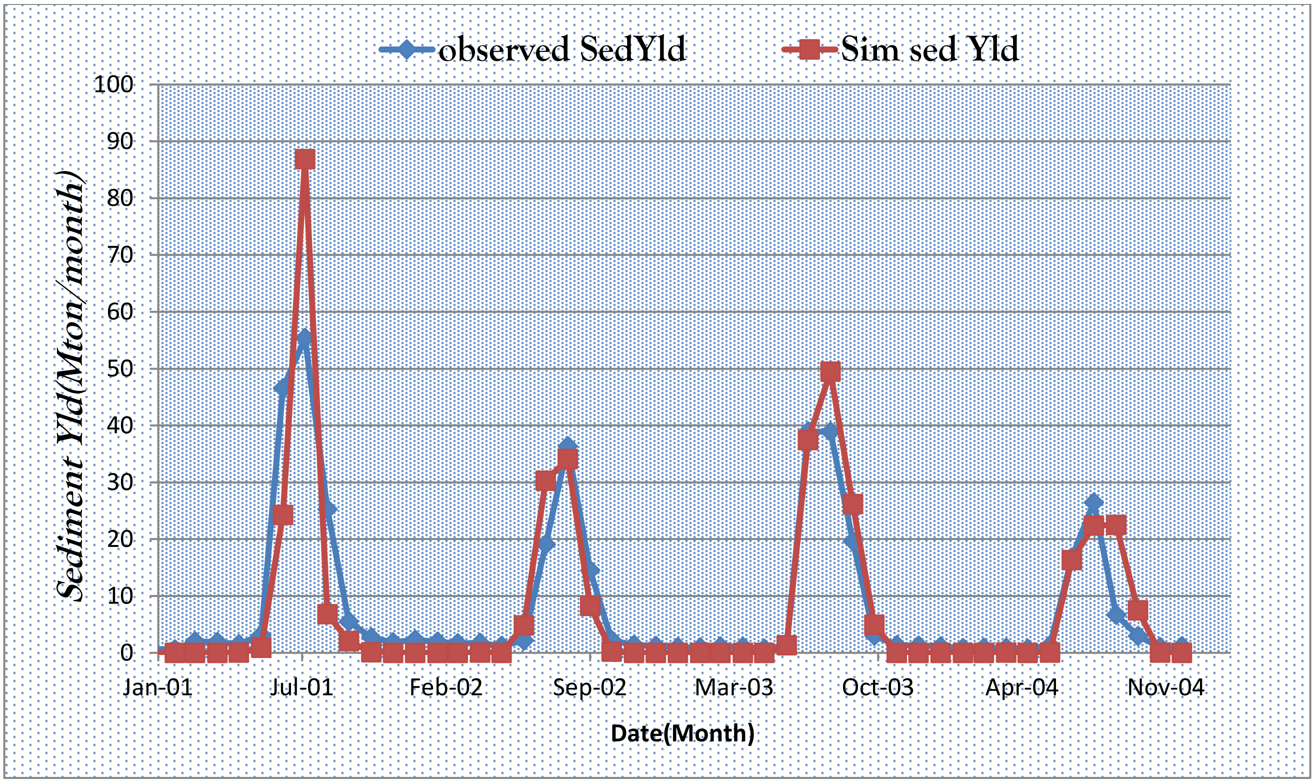


Figure 5.7 Validation results of monthly Observed and simulated sediment yield hydrograph

Generally there was underestimation and Overestimation of simulated sediment yield by the model. Such kind of error and discrepancy occur by errors occurs during flow measurement, uncertainty in sediment rating curve (due to lack representative sediment data which is not inclusive of sediment concentration that exists in all the seasons of the year), and the model by itself has limitation to capture the high flow values. Although there was such gaps, the model shows good correlation with the generated sediment (observed) in bothcalibration&validation and can be applicable for Kessie watershed in characterization of the hydrological balance(stream flow & sediment yield).

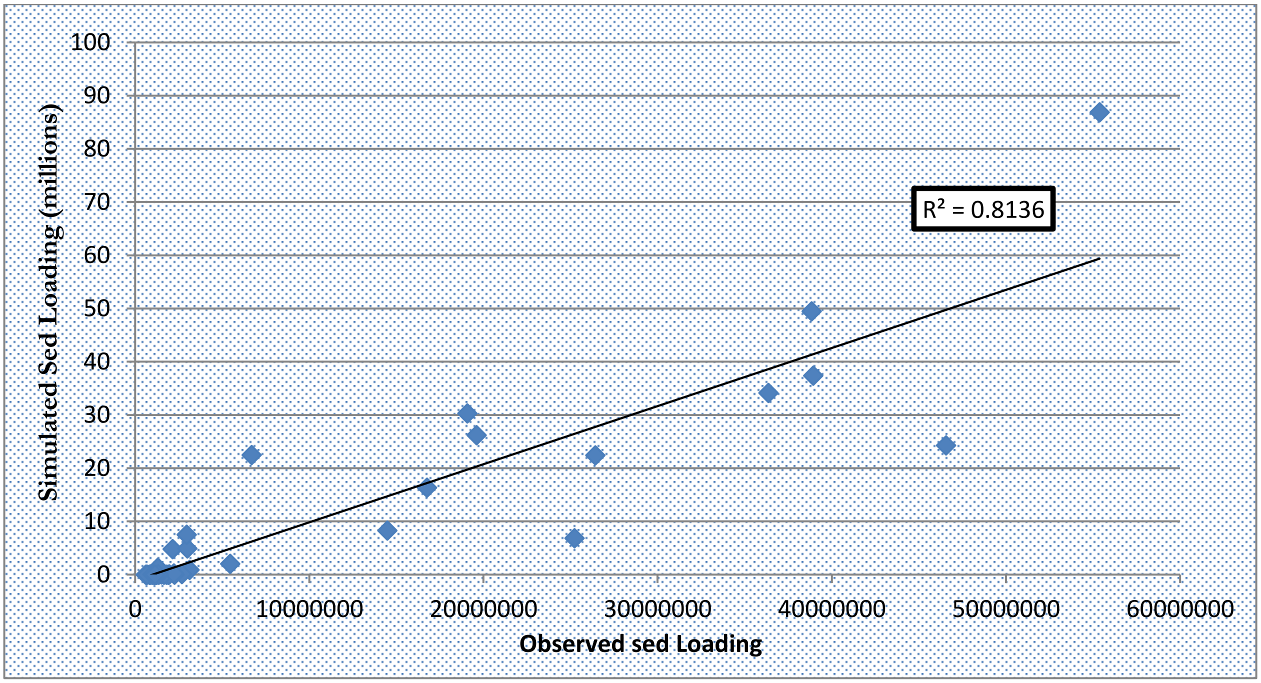


Figure 5.8. Simulated versus observed monthly sediment load during Validation period (2001–2004).

5.3 IDENTIFICATION AND MAPPING OF RUNOFF & SEDIMENT SOURCE AREAS.

Once the model (SWAT) was calibrated and validated, it was run for a period 15 years (1990 to 2004), then the overall simulated output can be used for further application (the catchment can be represented for any hydrologic response) and sediment source areas were identified Watershed.

23 sub basins are classified as per the model (Figure 5.9). The default threshold cell area was taken when streams are defined, these might be the reason for which some of the sub basins have a very small areal

coverage and areal coverage of the sub basins vary from 0.93% to 8.4 %. The largest coverage was occupied by sub basins 7, 8,11,13,14 & 16 having above 6 % coverage.

SWAT calculates the soil erosion and sediment yield in terms of hydrological response units (HRU's) within each sub basins. The GIS tool combines the slope, Land cover, soil and river layers as a major factor which contributes to soil erosion. Sub basins having sediment yield above 12 ton/ha/year were selected as high to medium range sediment source areas of the watershed as shown in Figure 5.10 highlighted in yellow and red colors and their dominant HRU distribution (slope, soil and land use). The identification of dominant HRU distribution of high sediment source areas of the watershed is important for simplifying work in undertaking management options.

The spatial variability of runoff and sedimentation rate were identified and based on which the potential area of intervention can be identified. The total surface runoff and average annual yield of sedimentation for each sub-basin was used to generate runoff and sediment source map. From the model simulation output, runoff and sediment source areas were identified in the Kessie Watershed.

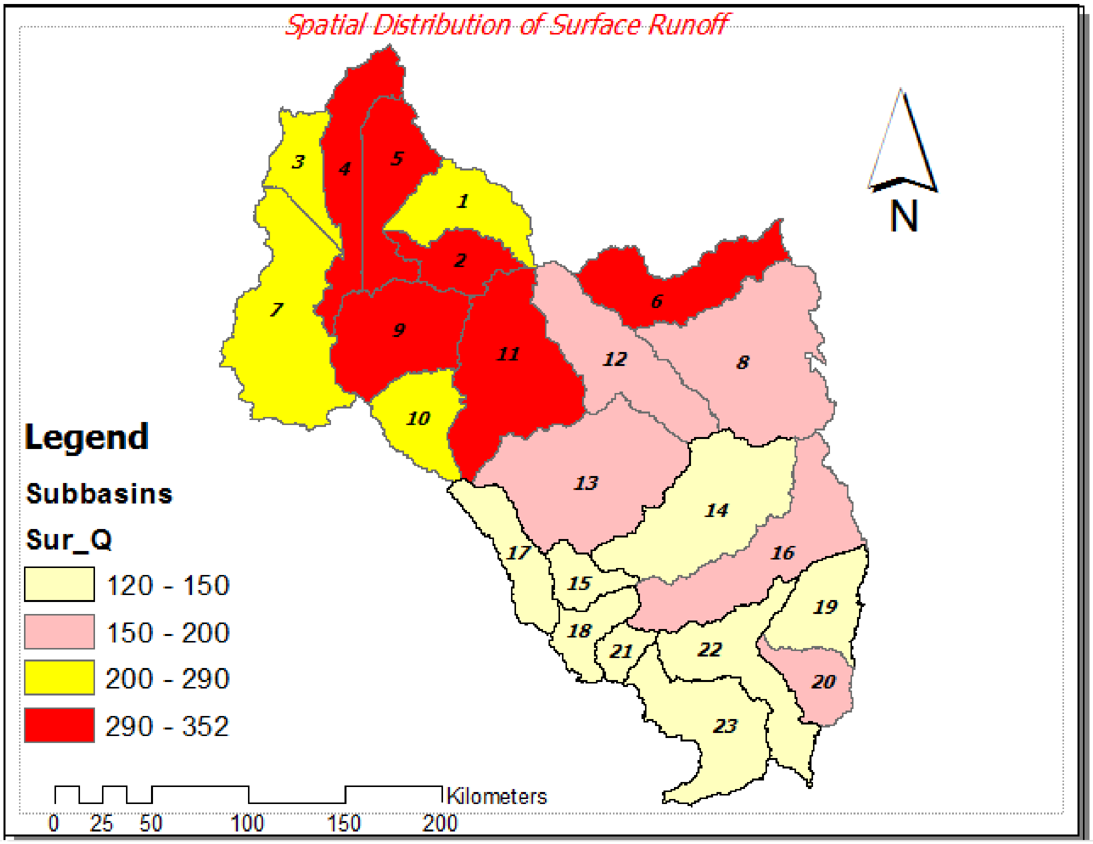


Figure 5.9: Spatial Distribution SWAT simulated annual surface runoff in Kessie watershed.

Assessment of the spatial variability of Surface runoff is useful for catchment management planning and identifying the most erodible catchment. The erosion /runoff prone areas in Kessie Catchment are shown in Fig. 5.10. Most of the extreme erosion was observed in the cultivated land (Agriculture) and low erosion was observed in the pastoral covers. Severe erosion was dominant in sub basins 1, 2, 4, 5, 9, 11 and 6, High erosion in sub basins 1, 3, 7 & 10. Moderate erosion in sub basins 8, 12, 13, 16 & 20; and low erosion was dominant in sub basins 14, 15, 16,17,18,19, 21, 22 & 23. The highest erodible Sub basins having annual surface runoff above 150 mm were found in North Gojjam, Lake Tana and Beshilo sub basins.

Soil formation rates are vital for evaluation of soil loss rate (the extent to which soil loss can be tolerated) and the potential of soil regeneration once soil erosion can be stopped completely. A study of soil formation rates in different agro ecological zone of Ethiopia indicates that the range of the tolerable soil loss level for the various agro-ecological zones of Ethiopia were 2 to 18 t/ha/yr. (Hurni H., 1985). Based on these, classes were assigned depending on their annual average sediment yield loading per coverage; the map was reclassified into four major categories of soil erosion hazards region i.e. low, moderate, high and severe erosion conditions (Figure 5.10 and Table 5.10).

Table 5.10.Class Assigned for Degree of Severity according to Hurni H

Class	Sediment Yld (ton/ha/yr.)	Remarks
1	0 – 6	low
2	6_12	moderate
3	12_18	High
4	Above 18	Severe

The annual average measured suspended sediment generated from the sediment rating curve was 14.71 ton/ha/ yr. and the simulated annual average sediment yield by SWAT model was 16.69 t/ha/yr.

The highest sediment yield sub basin areas are those which are covered with cultivated land (Agriculture) and Vertisols. The yellow and red highlighted areas of the watershed are potential areas which are sucepible for erosion and sediment yield. The HRU distribution for the selected sub basins clearly indicates the land cover Cultivated land is the major controlling factor for sedimnet potential areas.

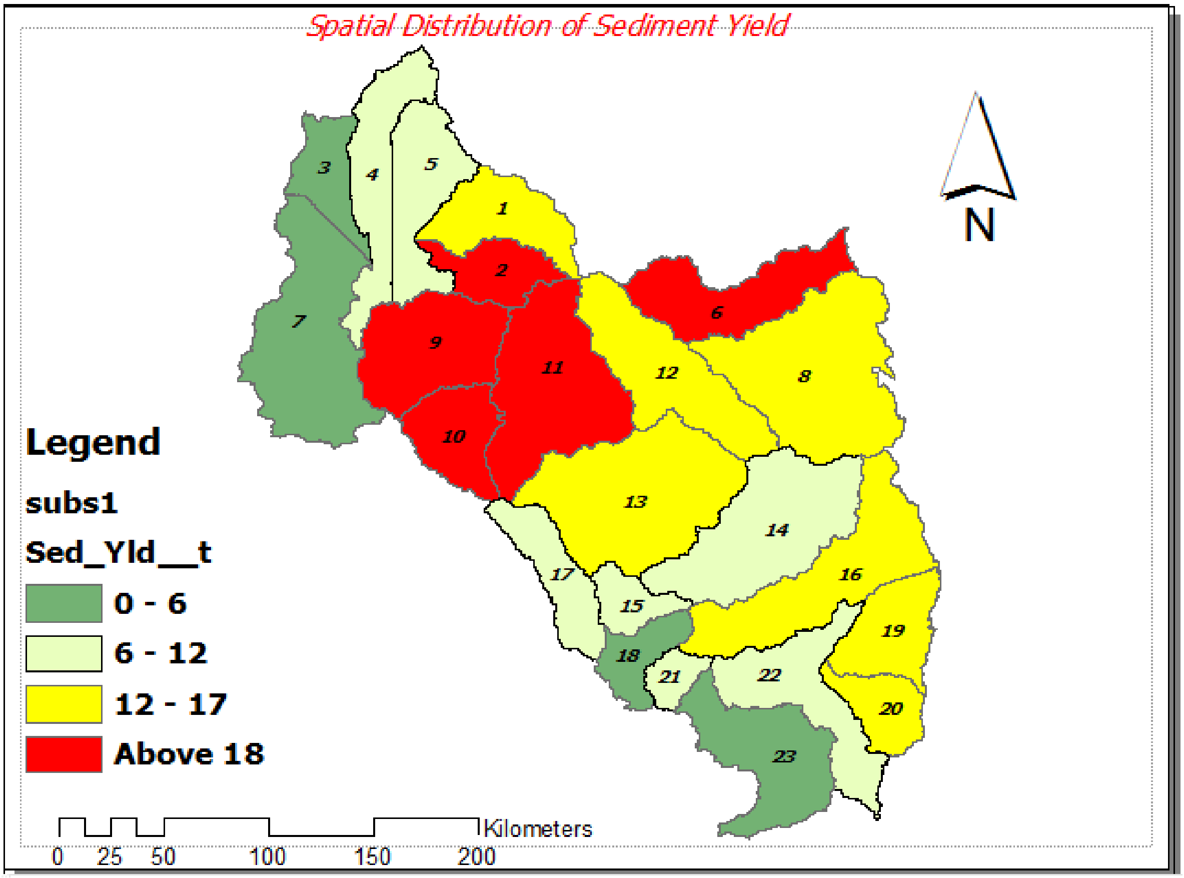


Figure 5.10: Spatial Distribution SWAT simulated annual sediment yield classes

Based on the model's prediction, sediment yield in the watershed varies from HRU to HRU depending on the type of soil and land use in each HRU. The spatial distribution of sediment indicated that, out of the total 23 sub basin 12 sub-basins produce average annual sediment yields above 12 ton/ha/yr and the highest loading found in North Gojjam and Beshilo Sub basins. The spatial map shown in figure 5.11 allows us to identify sub catchments which are producing high sediment yield loading.

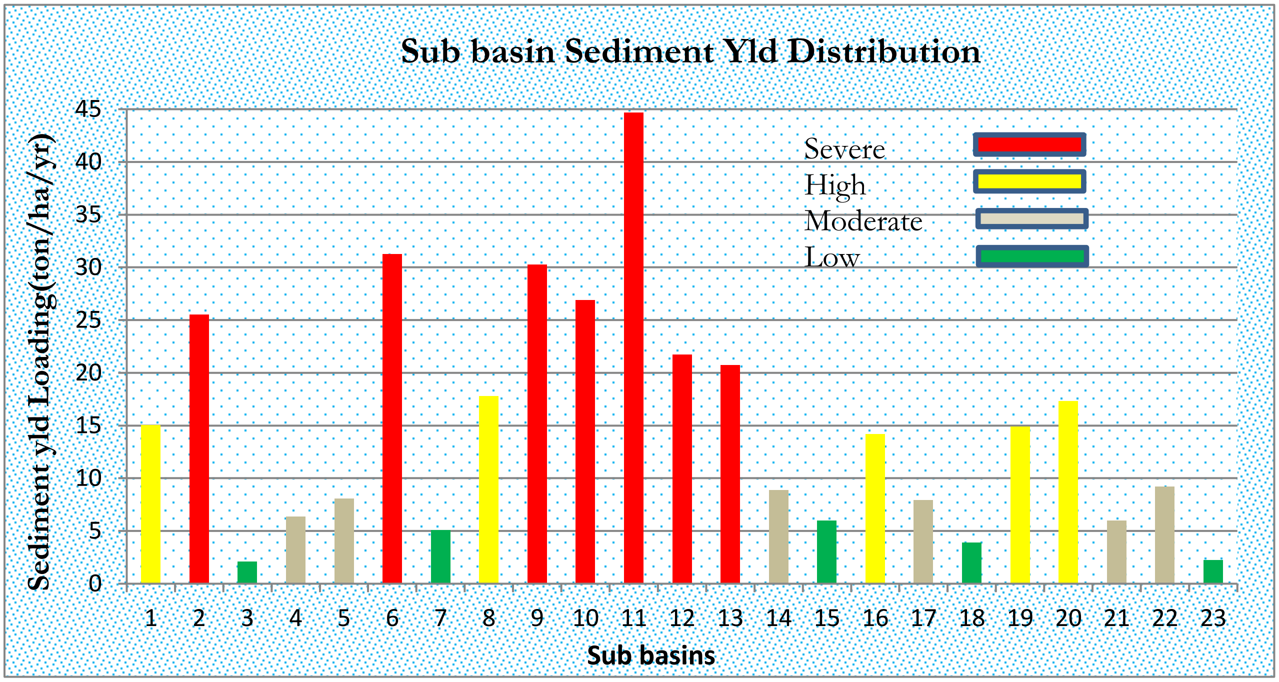


Figure 5.11: Distribution of SWAT simulated annual sediment yield in Kessie watershed sub basins

Sedimnet yield of awatershed is the summation of suspended and bed load. The analysis described above is suspended sedimnet load. Suspended load is the portion of the sediment that is carried by a fluid flow which settle slowly enough such that it almost never touches the bed. Whereas Bed load consists of sediments that are moving along in a river bottom, or just above the bottom, essentially by either rolling or "saltation," where particles bounce along the bottom. These heavier particles are usually sands and gravels. From the total sediment contribution bed load contibutes 10 to 15% of suspended load.

Taking 12.5 % contribution of bed load, the total mean annual measured and simulated sediment loading from the Kessie Watershed is 16.55 and 18.78 ton/ha/yr respectively.

From (Fikadu Fetene, 2008), from the 16 sub basins of Abbay Basin the highest sediment yield is from Guder, North Gojjam, Jemma, South Gojjam, Welaka and Finchaa sub basins respectively. The result obtained from this research has made reasonable agreement (as shown in Table 5.12) with this study to which North Gojjam, Jemma and Welaka Sub basins contributing the higher sediment yield from the available Kessie sub basins. Land use /land cover was found the influential parameters for sediment yield rather than the existing surface runoff and precipitation.

Table 5.11 Average Annual Sediment loading from known Sub basins of Kessie Watershed

	Contributing Sub basin (from SWAT classification)	Avg Sed Yld (t/ha/yr.)	Rank
Lake Tana	1, 2, 3, 4, 5, 7	10.37	3
Beshilo	6 , 8 , 12	23.61	2
North Gojjam	9, 10, 11, 13, 17	25.38	1
Jemma	16, 18, 19, 20, 21, 22, 23	9.68	4
Welaka	14, 15	4.96	5

Finally according to the classs assigned (Table 5.10), efforts were made to know the potential sever and high sediment source areal coverage of kessie watershed and the result has shown that 35.49 % of the watershed has excceded the tolearbe range (more contribution form North Gojjam and Beshilo sub baisns), 23.54 % of the wastershed was exposed in high erosion and sediment yield and about 40 % of the watershed was in moderate and low level.

From this result it is concluded that mitigation measure for prevention of severe erosion and conservation by develop appropriate management option for those selected critical sub watersheds (sub basins) should have to take.

Table 5.12: Percentage of Severity to Sediment for Kessie Sub basins

Range of Severity to Sediment	sub basins #	Areal coverage (km^2)	% of Coverage
Low	3, 7, 15, 18 & 23	11,449.46	17%
Moderate	4, 5, 14, 17, 21 & 22	14,866.61	23.14%
High	1, 8, 16, 19, & 20	15,119	23.54%
Severe	2, 6, 9, 10, 11, 12 & 13	22,794.7	35.49%

It is important to deal with relationship between Surface runoff and sediment yield in any modeling approach to identify the cause & effect and relationship with the model results. Even if the sediment rating curve was generated from observed flow the calibration process changes the simulated flow & sediment yield. As shown in the figure 5.12 high surface runoff values are directly related to high values of sediment yield in the sub basins, accordingly the catchment surface run off has an influence or direct effect for high sediment loading in addition to the effect of land use / cover.

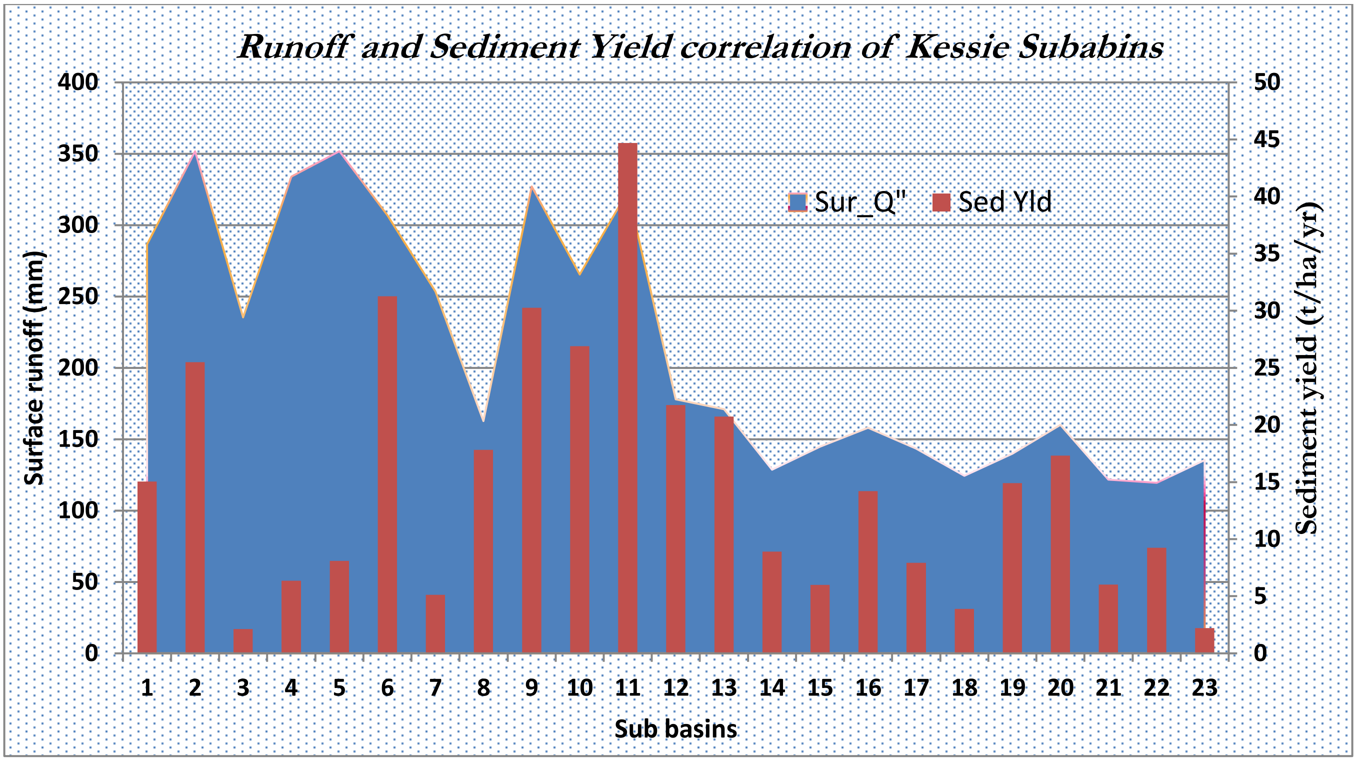


Figure 5.12: Surface Runoff and sediment Yield relationship of Sub basins of Kessie Watershed

6. CONCLUSION AND RECOMMENDATION

6.1 CONCLUSIONS

As the goal of this study was to model sediment yield by using SWAT model, the model was evaluated by using available data from the catchment to attain the required objectives with the following conclusive reports. The physical based model (SWAT) has started the simulation setup by dividing the Kessie catchment in to 23 sub basins having 178 hydrologic response units of unique response to hydrologic outputs, weather data's of in & around stations of the study area were loaded and the model finds the nearest station precipitation values for each of the sub basin for computing the water balance in combination with spatial catchment properties. In this study, attempts were made to characterize Kessie watershed (North Gojjam, Welaka, Beshilo, Lake Tana and Welaka) in terms of sediment yield, surface runoff, to evaluate spatial distribution of sediment source areas, and identify hot spot areas by using SWAT model.

After all, sensitivity analysis shows ground water parameters like Base Flow alpha factor (Alpha_Bf), thresh fold depth of water in the shallow aquifer required for return flow to occur (Gwqmn), soil evaporation compensation factor (Esco), SCS_CN for moisture condition II (Cn2), the soil parameters inclusive of soil depth (Sol_Z) and soil available water capacity (Sol_Awc) are the top most sensitive parameters that govern the simulated stream flow. Channel sediment routing, Sediment retrained in channel routing, USLE-Cover and management factor and USLE-Support practice factor are also governing sensitive parameters for sediment yield.

Before carrying out the simulation of stream flow and sediment yield, the suitability and performance of the SWAT model was evaluated using Standard calibration and validation statistics. A good agreement between measured and simulated monthly stream flow at Kessie gauging station was demonstrated by correlation coefficient (R^2= 0.77) Nash-Sutcliffe model efficiency (NSE = 0.76) and percent bias (PBIAS = _5.16%) for calibration period and R^2= 0.86, NSE = 0.83 and percent bias (PBIAS = 22.1 %) for validation periods. In both calibration and validation periods, simulated Stream flow were overestimated in the calibration period and underestimated in the validation period. The result indicates a good match between measured and simulated stream flow, by considering the acceptable limits of statistical model evaluation criteria. After stream flow is calibrated and validated, sediment yield was calibrated and validated with correlation coefficient (R^2=0.77), Nash-Sutcliffe model efficiency (ENS= 0.71) and percent bias (PBIAS = -2.72 %) in the calibration period and R^2=0.81, NSE=0.71 and PBIAS=3.89% in the validation period. The result indicates a good match between measured and simulated sediment yield, by considering the acceptable limits of statistical model evaluation criteria for calibration (1991 - 2000) and validation periods (2001-2004) respectively.

The 15 years simulation result indicates that the simulated annual average suspended sediment yield by SWAT model was 107,199,551 ton/yr., which is 16.69 t/ha/yr. and the annual average measured suspended sediment was 94,482,049 ton/yr., which is 14.71 ton/ha/yr. The sub watersheds that produce the highest sediment are 11, 6, 9, 10, 2, 12 & 13 their order of importance contributing sediment yield exceeding the soil loss tolerable rates which were found in North Gojjam, Beshilo and Lake Tana.

The result shows annual soil loss rate in the study area exceeds the maximum tolerable soil loss rate 18 t/ha/yr at some sub basins. But the average annual sediment yield of the whole Kessie watershed is around 16.69 t/ha/yr. The model prediction verified that about 35.49 % of the watershed is erosion potential area contributing high sediment yield exceeding the tolerance limit (soil formation rate) in the study area and about 37 % of the watershed area has high potential for soil erosion which produces above an average annual sediment yield of the watershed.

Generally, the SWAT model performed well in predicting both the flow and sediment yields from the study watershed and the results were acceptable. It is a capable for further analysis of the hydrological responses in Kessie watershed. The study can be further extended to similar watersheds in the country, particularly in the Blue Nile Basin of Ethiopia, where quantifying the total volume of runoff and sediment yields is urgently required for better land and water resources planning and management purposes.

6.2 Recommendation

Modeling a watershed in developing countries is a serious challenge due to absence of relevant information and data. Likewise, Understanding the biophysical, hydrological and hydraulic problems and proposing pertinent intervention measures to control degradation, improving land and water productivity, enhancing ecological and environmental functions in developing countries are serious challenges due to absence of relevant information and data.

- The result of this study could help different stakeholders to plan and implement appropriate soil and water conservation strategies in the watershed. The model developed could be used in modeling the watershed to take appropriate measures in advance. As a mitigation measure for prevention of severe erosion and conservation mechanism, it is recommended to do further research on management intervention scenario analysis and develop appropriate management option for those selected critical sub watersheds.

- It is recommended that the calibrated model can also be used for further analysis of the effect of climate and land use changes.
- It is recommended to install more hydro-meteorological gauging stations in the catchment in respective with accurate measurement, so responsible bodies should have expose their contribution in additional installation and measurement accuracy.
- Measurement on sediment concentration is limited in the study area (not more than 15 to 20 days sediment data which are not inclusive of all months of the year); better result will be obtained if reliable long term measurement exists.

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APPENDICES

Appendix 1: Annual Sediment and Stream discharge entered and leave amount at the outlet of Kessie

SUB	YEAR	AREA (km2)	FLOW_INcms	FLOW_OUTcms	EVAPcms	SED_INtons	SEB_OUTtons
17	1990	64230	410.3	409.6	0.6617	67280000	67280000
17	1991	64230	878.7	877.6	1.093	171100000	171100000
17	1992	64230	919.2	918.3	0.9594	193200000	193200000
17	1993	64230	785.4	784.4	1.05	139400000	139400000
17	1994	64230	664.3	663.3	1.064	105700000	105700000
17	1995	64230	518.9	517.9	1.037	78230000	78230000
17	1996	64230	752.1	751.1	1.033	117800000	117800000
17	1997	64230	564.5	563.4	1.029	59060000	59060000
17	1998	64230	884.2	883.1	1.077	87020000	87020000
17	1999	64230	907.2	906.2	1.022	84320000	84320000
17	2000	64230	841.7	840.6	1.03	83660000	83660000
17	2001	64230	1181	1180	1.028	124600000	124600000
17	2002	64230	852.1	851	1.092	77000000	77000000
17	2003	64230	1213	1212	1.103	124600000	124600000
17	2004	64230	968.9	967.8	1.074	67780000	67780000

Where:

FLOW_IN	Average daily stream flow into reach during time step (m3/s).
FLOW_OUT	Average daily stream flow out of reach during time step (m3/s).
EVAP	Average daily rate of water loss from reach by evaporation during time step (m3/s).
SED_IN	Sediment transported with water into reach during time step (metric tons).
SED_OUT	Sediment transported with water out of reach during time step (metric tons).
SEDCONC	Concentration of sediment in reach during time step (mg/L).

Appendix 2: Definition of weather generator parameters

parameter	***Definition***
TMPMX	Average or Mean maximum air temperature for month(^{0}C
TMPMN	Average or Mean minimum air temperature for month(^{0}C
TMPSTMX	Standard deviation for daily maximum temperature for month(^{0}C
TMPSTDMN	Standard deviation for daily maximum temperature for month(^{0}C
PCPMM	Average or Mean total monthly precipitation(mm H_2o)
PCPSTD	Standard Deviation for daily precipitation in month (mm H_2o)
PCPSKW	Skew Coeffiecnt For daily Precipitation in month
PR_W(1)	PR_W1 Probability of a wet following a dry day in the month
PR_W(2)	PR_W2 Probability of a wet following a wet day in the month
PCPD	Average number of days of precipitation in month
SOLARAV	Average daily solar radiation for month (MJ/m^2/day)
RAINHHMX	Average maximum half hour rainfall(mm)
DEWPT	Average daily dew point temperature in month(^{0}c)
WINDAV	Average daily Wind Speed in month(m/s)

Appendix 3: Definition of soil parameters

Code	Description
SNAM	Soil Name
NLAYERS	No of layers
HYDGRP	Soil Hydrologic Group(A,B,C,D)
SOL_ZMX	Maximum Rooting Depth of the soil profile
TEXTURE	Soil texture
SOL_Z	Depth from soil surface to bottom layer
SOL_BD	Moist bulk density for soil
SOL_AWC	Available Water Capacity Of soil Layer
SOL_K	saturated Hydraulic conductivity
SOL_CBN	Organic Carbon Content
CLAY	Clay Content
SILT	Silt Content
SAND	Sand Content
ROCK	Rock Fragment Content
SOL_ALB	Moist Soil Albedo
USLE_K	Soil Erodiblity(K factor)

Appendix 4: Weather generator Statistics for Bahirdar Station

Parameters	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TMPMX	28.42	29.98	31.69	32.3	30.48	28.35	23.93	24.26	25.82	26.94	27.6	27.16
TMPMN	8.95	10.57	12.65	13.95	14.31	13.31	13.56	13.13	12.82	11.34	10.75	8.88
TMPSTMX	1.59	1.49	1.83	1.78	2.04	2.45	2.14	1.59	1.22	0.82	1.08	1.02
TMPSTDMN	2.54	2.57	2.72	2.77	1.84	2.88	1.44	1.74	1.14	2.03	2	2.59
PCPMM	2.39	1.67	10.44	25.27	78.66	199.21	421.88	392.75	197.11	92.06	14.32	3.1
PCPSTD	0.62	0.91	2.68	3.71	6.73	10.38	15.19	15.28	9.77	7.02	2.32	0.75
PCPSKW	10.49	19.31	16.85	6.32	4.39	2.87	2.1	2.67	2.59	3.03	6.9	9.6
PR_W(1)	0.03	0.02	0.06	0.1	0.25	0.6	0.88	0.87	0.57	0.22	0.05	0.03
PR_W(2)	0.24	0.27	0.42	0.43	0.58	0.78	0.95	0.93	0.8	0.59	0.38	0.39
PCPD	1.05	0.55	2.85	4.15	11.2	21.6	29.35	29.05	22.25	11.35	2.8	1.15
SOLARAV	21.088	22.577	23.104	23.49	22.011	19.59	16.384	16.433	19.015	21.37	21.087	20.5
DEWPT	10.42	10.4	10.92	12.04	13.55	15.13	14.69	15.09	14.8	13.24	11.89	10.3
WINDAV	0.6258	0.7129	0.8772	0.986	0.9186	0.932	0.7567	0.6924	0.6855	0.742	0.6644	0.6

Appendix 5: Measured Mean Monthly stream flow (m^3/s) at Kessie Gauging station

M/Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	96.2	78.5	52.3	50.2	30.1	25.2	527.9	1567.3	944.4	393.3	194.7	109.8
1991	68.9	56.0	51.4	115.1	93.7	93.7	983.7	1658.0	1435.4	579.7	300.2	159.1
1992	107.0	78.2	58.2	41.4	44.9	35.0	420.4	3089.7	1233.5	718.1	403.9	219.4
1993	125.8	88.8	50.5	180.0	157.3	162.2	1439.4	1748.8	1926.5	766.0	405.8	208.5
1994	118.8	80.0	53.2	31.3	68.5	125.9	2079.3	2565.9	2390.2	693.9	405.4	148.6
1995	61.5	49.7	50.8	91.6	73.8	83.0	1169.1	2802.1	1262.1	290.6	191.7	110.5
1996	71.1	48.9	84.1	110.5	185.8	415.8	2248.9	3337.8	1513.4	647.1	365.5	247.3
1997	125.2	92.6	133.0	135.7	189.2	387.1	1843.7	1653.2	1109.7	641.6	452.4	243.5
1998	179.3	129.7	184.6	162.2	191.8	358.8	1520.7	1989.5	583.0	626.5	519.8	236.2
1999	224.0	207.4	114.4	100.4	53.4	122.0	2826.5	4752.7	1956.4	1258.6	620.2	340.1
2000	227.6	166.9	63.2	167.6	89.2	86.9	1608.9	3933.2	1554.1	1086.2	663.0	324.8
2001	135.7	140.8	293.4	300.6	253.4	397.8	3520.7	4763.7	1577.7	591.4	383.0	285.5
2002	331.5	329.8	268.4	277.4	219.0	310.1	1175.5	2897.9	1098.1	324.4	243.9	215.9
2003	190.5	201.0	206.3	200.0	148.5	212.9	2037.1	3634.7	1403.5	382.4	241.0	223.1
2004	202.4	176.7	174.3	180.4	150.5	218.3	1182.4	2592.5	675.3	377.3	197.0	211.4

Appendix 6: Redefined and original land covers for Kessie watershed

Original Land Covers	**Redefined land Cover According to SWAT**	**SWAT Code**	**Percentage of coverage over the watershed (%)**
Water	Water	WATR	4.81
Settlement	Residential-Med/Low Density	URML	0.33
Cultivated Land	Agricultural Land-Generic	AGRL	0.41
Cultivated Land	Spring Barley	BARL	9.33
Cultivated Land	Eragrostis Teff	TEFF	24.45
Cultivated Land	Grain Sorghum	GRSG	10.39
Cultivated Land	Corn	CORN	0.98
Cultivated Land	Rice	RICE	1.55
Cultivated Land	Winter Wheat	WWHT	16.69
Grass Land	Pasture	PAST	6.50
Deciduous Forest	Forest-Deciduous	FRSD	3.59
Shrub Bush	Range-Grasses	RNGE	5.80
Bare Land	Barren	BARR	10.29
Wet Land	Wetlands-Mixed	WETL	0.45
Mixed Forest	Forest-Mixed	FRST	4.42

Appendix: 7. Soil parameters of the study area used in the SWAT model

Soil Name	` No of Layers	Soil hydro. Grp.	SOL_ZMX(mm)	Texture	SOL_Z(mm)	SOL_BD(g/cm3)	SOL_AWC(mm/mm)	SOL_K(mm/hr)	SOL_CBN (%)	CLAY (%)	SILT (%)	SAND (%)	SOL_ALB	USLE_K
Cambisols	1													
	2													
	3									`				

Appendix 8: Available Sediment Data at Kessie

Date	**Flow(m3/s)**	**Sed Conce (mg/l)**	**Sed Conc (kg/m^3)**	**Sed load(ton/day)**
3-Mar-90	58.96	301.6	0.3016	1536.13
8-May-90	22.96	724.1	0.7241	1436.35
20-Oct-90	330.73	728.0	0.7280	20803.59
26-Sep-92	290.00	1286.9	1.2869	32244.23
18-Jul-95	712.74	31528.6	31.5286	1941565.29
25-Aug-95	1926.44	4899.4	4.8994	815484.04
21-Sep-95	627.32	15166.2	15.1662	822018.27
24-May-03	0.81	251.1	0.2511	17.57
1-Aug-04	1392.17	10953.7	10.9537	1317549.24
13-Aug-04	1637.00	17929.7	17.9297	2535912.79
28-Aug-04	980.22	4995.6	4.9956	423084.09
18-Sep-04	3982.00	2022.5	2.0225	695822.58
1-Oct-04	512.90	2516.1	2.5161	111499.52
7-Oct-04	335.00	3391.3	3.3913	98157.11
22-Oct-04	165.49	372.2	0.3722	5321.11

Appendix 9: Average Monthly Hydrological response of Kessie watershed values of SWAT Output

	RF (mm)	**SUR_Q (mm)**	**LAT_Q(mm)**	**Water Yield(mmm)**	**Sed Yld (ton/ha)**	**ET (mm)**	**PET (mm)**
Jan	3.1	0	5.53	6.79	0	19.19	96.4
Feb	7	0.71	4.12	5.05	0.07	16.96	101.51
Mar	18.26	0.18	3.6	3.82	0.01	54.81	121.19
Apr	41.93	1.11	3.22	4.36	0.08	83.99	121.76
May	95.81	3.45	3.85	7.51	0.27	93.46	119.6
Jun	181.52	8.24	5.79	14.63	0.54	86.11	96.92
Jul	350.78	57.82	11.4	74.04	4.28	78.47	83.72
Aug	318.07	84.24	15.31	116.9	7.27	69.04	84.44
Sep	180.42	29.86	14.27	66.48	2.65	66.21	92.52
Oct	105.71	15.8	13.09	49.12	1.23	55.55	104.53
Nov	30.67	3.38	9.84	25.82	0.23	36.12	96.61
Dec	8.7	0.67	7.73	13.48	0.07	24.75	96.55
Annul	***1341.97***	***205.46***	***97.75***	***388***	***16.7***	***684.66***	***1215.75***

Appendix 10: Sub basins Surface Runoff and Sediment Yield distribution

Sub basin	Area (Km^2)	Sur_Q(mm)	Sed Yld (t/ha/yr)
1	2123.6	286.53	15.03
2	1407	351.65	25.51
3	1374.2	235.27	2.12
4	2617.2	333.92	6.37
5	2501.4	351.77	8.09
6	2860.7	306.9	31.28
7	4905.2	253.49	5.11
8	5617.6	162.81	17.81
9	3193.7	327.12	30.25
10	1808.7	265.34	26.9
11	4567.5	323.61	44.69
12	3541.9	177.92	21.75
13	5415.2	171.05	20.74
14	4456	128.56	8.9
15	904.26	144.89	5.99
16	4165.5	158.04	14.21
17	1729	143.5	7.93
18	1135.7	124.32	3.88
19	1923.2	139.8	14.91
20	1289.1	160.04	17.32
21	599.31	121.68	6.01
22	2963.7	119.48	9.23
23	3130.1	135.39	2.22

Appendix 11: flow sensitivity parameters and there mean sensitivity

Parameters Description	Parameter Code	Rank	Mean Sensitivity	Category of sensitivity
Base Flow alpha factor	Alpha_Bf	2	0.399	High
Maximum canopy Index(mm)	Canmx	9	0.0633	High
Available Water capacity pf the soil layer(mm)	Sol_Awc	8	0.0681	High
SCS_CN for moisture condition II9unitless)	Cn2	1	0.756	High

Thresh hold depth of water in the shallow aquifer required for evaporation to occur	Revapmn	7	0.0827	Medium
Thresh fold depth of water in the shallow aquifer required for return flow to occur(mm)	Gwqmn	3	0.154	High
Effective Channel Hydraulic conductivity(mm/h)	Ch_K2	11	0.0323	Medium
Soil evaporation compensation factor	Esco	5	0.102	High
Plant evaporation compensation factor(unit less)	Epco	6	0.0832	High
Average slope steepness(m/m)	slope	13	0.00531	Small
Soil depth	Sol_Z	10	0.0564	High
Ground water evaporation coefficient	GW_Revap	12	0.0244	Medium
maximum potential leaf area index	Blai	4	0.108	High