



**Addis Ababa University
Africa Centre of Excellence for
water management**



**Assessment of Land Use/Cover Change Impact on Stream Flow and
Sediment Yield: Case Study on Gilgel Gibe III Reservoir, Omo Gibe Basin**

MSc THESIS

REDIET BERIHUNDEMOZ

November ,2021
Addis Ababa, Ethiopia



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A thesis submitted to School of Graduate Studies, Africa Centre of Excellence for water management and Addis Ababa University in partial fulfilment for the Degree of Masters of Science in Hydrology and water resources

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Addis Ababa, Ethiopia
November, 2021



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WATER MANAGEMENT
ADDIS ABABA UNIVERSITY**

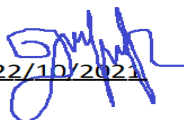


Assessment of Land Use/Cover Change Impact on Stream Flow and Sediment
Yield: case study on Gilgel Gibe III reservoir, Omo Gibe Basin

The thesis entitled “**Assessment of Land Use/Cover Change Impact on Stream Flow and Sediment Yield: case study on Gilgel Gibe III reservoir, Omo Gibe Basin**” by Rediet Berihun is approved for the degree of Master of Science in Hydrology and water resource management.

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Declaration

This thesis entitled “Assessment of Land Use/Cover Change Impact on Stream Flow and Sediment Yield: case study on Gilgel Gibe III reservoir, Omo Gibe Basin” is my original work and has been not presented or published for a degree in other universities and that all sources of materials used in this thesis work are duly acknowledged.

Rediet Berihun Demoz _____

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List of abbreviations

a.m.s.l	above mean sea level
ARC SWAT	SWAT Integrated with Arc GIS
ARSSWAT	Agricultural Research Service Soil and Water Assessment Tool
BMP	Best Management Practice
CN	Curve Number
DEM	Digital Elevation Model
EEPCO	Ethiopian Electric Power Corporation
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GLUE	Generalized Likelihood Uncertainty Estimation
HRU	Hydrological Response Unit
HWSD	Harmonized World Soil Database
ITCZ	Inter-Tropical Convergence Zone
LULC	Land Use-Land Cover
LULCC	Land use and land cover change
MUSLE	Modified Universal Soil Loss Equation
MCMC	Markov Chain Monte Carlo
MoWIE	Ministry of Water, Irrigation and Electricity
MUSLE	Modified Universal Soil Loss Equation
NSE	Nash-Sutcliffe Efficiency
NMSA	National Meteorological Services Agency
NRCS	Natural Resource Conservation Service
R ²	Coefficient of Determination
SCS	Soil Conservation Service
SWAT	Soil and Water Assessment Tool
USDA	United State Department of Agriculture
USLE	Universal Soil Loss Equation
USDA-ARS	United State Department of Agriculture-Agricultural Research Service

Abstract

Land use/land cover (LULC) change is an important landscape process capable of altering the fluxes of water, sediment, contaminants and energy. In this study, Soil and Water Assessment Tool (SWAT) model was used to examine the effects of LULC on the hydrological process of Gibe III Watershed in the Omo-Gibe basin. The performance of the model was evaluated through sensitivity, uncertainty analysis, calibration and validation. The LULC change analyses for two periods (2009 and 2019) were used for estimation of stream flow and sediment yield. The result has shown that during the study period most parts of the forest land were converted into cultivated land with an increase of cultivated land by 6.97%, which resulted in an increase of stream flow and sediment yield by 4.7 m³/s and 0.53 ton/ha/year respectively. The Nash Sutcliffe efficiency (NSE), coefficient of determination (R²) and percent of bias (PBIAS) were used for evaluating the model performance. The model results have shown a good and satisfactory agreement with the observed values with NSE > 0.51, R² > 0.63, and PBIAS < 6.45. values. Based on the validated sediment yield results of 2019 land use, high potential source of spatial variability of sediment yield identified within the watershed. Hence, for the critical sub-watersheds, the design and development of three best management practices (BMPs) were performed. These best management scenarios include: S1 (filter strip), S2 (terrace/ bund) and S3 (reforestation). Based on these scenarios, the findings have shown a sediment yield reduction by 41.56%, 32.49% and 53.77% with the implementation of S1, S2 and S3 respectively. Therefore, based on the findings, implementing S3 is the best management strategy as compared to other options and hence, such intervention should be encouraged at a wider scale for efficient sediment reductions of Gibe III watershed.

Keywords: Arc SWAT, Land use/cover change, Sediment Yield, Omo gibe, Gibe III watershed.

1.INTRODUCTION

1.1. Background

Land use and land cover change (LU/LC) is a global concern because it drives various environmental changes at all spatial and temporal stages. These factors affect the quantity and distribution of both surface and ground water resources, as well as the amount of water available for ecosystem function and human usage, according to Joyce et al., (2017). As the watershed develops, it becomes more hydrologically active, changing flood volume and runoff components, as well as stream flow origin (Andualem & Gebremariam, 2015).

Many research in Ethiopia have indicated that hydrologic models can be used to investigate the effects of land use and land cover change on stream flow (Gashaw et al., 2018; Wakjira et al., 2016; Jemberie et al., 2016; Temesgen et al., 2014; Geremew, 2013). Land use and land cover change in Ethiopia as a whole, and in the study region in particular, is primarily linked to natural and anthropogenic activity such as proximate and underlying causes, as well as the country's fast increasing population, which has nearly doubled in the last 40 years (CSA, 2008). Hence, analyzing the potential impacts of these changes at different scale was found to be fundamental and thereby different thematic maps of land use change were used to assess the impact of these LU/LC change in the watershed.

Dams over rivers are used to create reservoirs for flood protection, hydroelectric generation, irrigation, navigation, water management, fishing, and tourism. Because of these human interventions, environmental changes and long-term morphological impacts on the natural water course are unavoidable. Sedimentation is a major issue that puts reservoir productivity and sustainability at risk. It reduces flood protection reliability, poses navigational risks, changes river and underground water levels, and affects the function of low-level outlet gates and valves, reducing safety, water quality, and recreational benefits (Novak et al., 2001).

Reservoir sedimentation is now a major concern and a major enemy. Dams lose capacity over time, reducing their effectiveness and reducing the benefits of irrigation, hydropower generation, flood control, water supply, navigation, and recreation. Sediment deposition, on the one hand, extends upstream and up tributaries, increases the local groundwater table, reduces channel flood capacity and bridge navigation clearance, and has an impact on water division and withdrawals.

The Omo-Gibe River Basin is almost 79,000km² in area and is situated in the south-west of Ethiopia, between 4°00'N & 9°22'N latitude and between 34°44'E & 38°24'E longitude. It is an enclosed river basin that flows in to the Lake Turkana in Kenya which forms its southern boundary. The western watershed is the range of hills and mountains that separate the Omo-Gibe Basin from the Baro-Akobo Basin. To the north and northwest the basin is bounded by the Blue Nile Basin with small area in the northeast bordering the Awash Basin. The gibe III catchment is also found in the upper part of Omo-gibe basin which covers an area of some 400 km South West of Addis Ababa and 150 km west-South-west of Hawassa. The project is located within the jurisdiction of the Mareka Gana Wereda of the Dawro Zone and Kindo Koyisha Wereda of Sodo zone of the Southern Nations and Nationalities People Regional State (SNNPRS).

Using the SWAT model, this study will investigate the effects of various land use patterns on soil erosion and sediment yield in the basin. The objectives are to parameterize, calibrate, and use the SWAT model to simulate the effects of land use change on soil erosion and sediment yields, compare several options (scenarios), and finally choose the best solution.

1.2 Statement of the problem

As water is such an important aspect of our ecosystem that all must have access to it, predicting its availability for future generations has become a critical task in planning and resource management for a rapidly changing environment. These demands investigating and combining the effects of land-use change on hydrological processes, such as changes in water demand and supply, with the growing interest in land-use science. The impact of land use and land cover change on hydrological processes must be assessed in order to predict reasonably possible land-use changes at the individual cell level, taking into account the dominating land use practices in the area. However, the hydrologic impact of changing land cover at a watershed scale remains unsolved and is now a major concern for most countries, which are seeing changes in land cover patterns as a result of rising population and demand for accommodations (R. Defries and K. N. Eshleman,2004). Despite a high potential for increasing agricultural productivity, resource degradation, soil erosion, and nutrient depletion are significant environmental concerns in south-western Ethiopia. The Gilgel Gibe catchment is one of the land resources affected by land use and land cover dynamics (Amsalu,2010). Land cover changes, which change stream flow regimes in watersheds, are thought to be one kind of resource degradation. The foundation will result in a situation where land with minimal vegetation is subject to high

surface runoff, low infiltration, and reduced groundwater recharge. This eventually, leads to lowering of water tables and intermittence of once-perennial streams (Woldeamlak and Geert ,2005).

Gilgel On the upper reach of the Gibe basin, the Gibe basin contributes flow to the larger Omo Gibe basin, which includes the Cascade Dams on the lower reach. Soil erosion from upstream in the basin, followed by sedimentation in the downstream area, is a major problem that threatens Gibe's present and future water resources development. Alleviating these multifaceted problems of the basin requires proper, coherent and organized land developments for which the land use land cover situation of the area was an input. However, the quantitative data on the land use land cover change and clear insight into the local contributions of the changes in the Gilgel Gibe catchment were absent. Consequently, research on land use land cover change is needed to explore how land use land cover change influences watershed hydrology. Furthermore, detecting and simulating the effects of land use and land cover change on catchment hydrological processes necessitates a new, strategic, and enhanced strategy for preserving the catchment based on hydrological sensitivity as a result of land use change at the sub watershed (Taye, 2009). This allows local governments and policymakers to develop and implement effective and suitable response strategies to reduce the negative consequences of future land use and land cover change (PHE ,2011).

Previously for many years most researches were done through questioners but recently it is also better to make it using well calibrated models. so, it would be better to appreciate models for proper planning and management of the basin. Although a number of researchers have conducted erosion studies in Ethiopia, the lack of compelling tool or method has hindered adoption and implementation of their findings (Ndomba, 2007)

1.3 Research questions

The following questions have been formulated to achieve the core objectives of this MSc research work:

1. What is the effect of the land use land cover change on stream flow and sediment yield?
2. Which sub basin produce high sediment yield?
3. What is the impact of different best management practices on sediment yield?
4. What are the best management practices to reduce sediment yield of the watershed?

1.4. Objective of the study

1.4.1 General objective

The overall goal of this study is to assessment of land use/cover change impact on stream flow and sediment yield in the omo-gibe basin.

1.4.2 Specific objectives

- Determination of spatial variability of sediment yield and identification of high sediment producing sub basins.
- To estimate and compare stream flow and sediment yield of the watershed under different land use land cover change.
- Assess the impact of different best management practice on sediment yield.
- To develop appropriate sediment yield reduction scenario.

1.5. Significance of the study

The study provides information for researcher of omo gibe basin about high sediment yield producing sub basin and amount of sediment inflow to the reservoir to implement effective and appropriate response strategies to minimize the future problem of sedimentation and used as input during selection of type of reservoir. Therefore, the research will address the relevant issues related to land degradation mainly surface runoff and sediment loading and provide or develop management options and recommendations of mitigation measure which may contribute to the sustainable use of land and water resources in the catchment and hence the improvement of the design period of water resource projects.

1.6 Scope of the Study

The scope of this research is to model flow-sediment yield for Gilgel gibe Catchment, to characterizes the flow from catchment and associated sediment yield, to evaluate spatial distribution of sediment source areas and identify hot spot areas, to assess important different Best Management Practice (BMP)scenarios to enable proper soil and water conservation for appropriate use of water for the schemes. Finally, this research shows the methods of preventing watershed from erosion by using different conservation practical measures and management planning.

1.7. Thesis out line

This thesis contains six chapters and organized as follows:

The first chapter gives a brief overview of the problem that inspired this research, as well as the study's objective, significance, and overall scope. The literature review on this topic is presented in Chapter 2. The chapter provides several authors' perspectives on the spatial variability of sediment production within a watershed, as well as the impact of land use/cover change on stream flow and sediment yield. Hydrological models were also discussed as a sub-topic. SWAT model and the reason why it is selected for this study was presented in detail. The chapter came to a close with a detailed description of the SWAT model. The Omo Gibe basin in general and the Gilgel Gibe watershed in particular are discussed in length in Chapter three. The climate of the basin, topography, soil, and land use type of the watershed are all extensively documented in this chapter. This section focuses on the data source, model setup, methodology used, and analysis of the watershed's meteorological and hydrological data. The missing data filling for rainfall and data quality analysis (consistency and homogeneity checking) of the used meteorological stations were discussed. The results and findings of the SWAT model simulation, the regional distribution of sediment yield, and the effect analysis of the different catchment intervention scenarios or best management practices are discussed in Chapter four. The conclusion and recommendations in Chapter five are based on the results of the models and the data utilized in this study. In addition, there are references and appendices at the end of the document.

2. LITERATURE REVIEW

2.1 Runoff - Sediment Yield and Sedimentation

Sediment is interpreted differently by different people and consequently there are a variety of different terms and phrases used to express sediment. Mud and sludge are terms that are often used by the public or non-scientific community when referring to sediment. Mud is also a term used by certain groups of scientists when referring to fine-grained organic and inorganic material (i.e. Clay-and silt-sized material), as opposed to coarse-grained sediment. For many, especially managers and regulators, sediment is synonymous with dredged material. It is perhaps here that some of the problems and issues of sediment management arise, i.e. The lack of appreciation and agreement on what sediment is.

General speaking, sediment yield refers to the amount of sediment exported by a river basin over a period of time, which is also the amount which will enter a reservoir or water conveying structures like irrigation canal, located at the downstream limit of its tributary watershed. It is also the amount of eroded sediment discharged by a stream at any given point. It represents the total amount of fluvial sediment exported by the watershed tributary to a measurement point, and is the parameter of primary concern in reservoir and water conveying structures studies. Because much eroded sediment is re-deposited before it leaves a watershed, the sediment yield is always less than and often much less than, the erosion rate within that same watershed (Morris & Fan, 1998).

Soil erosion by water is one of the most important land degradation problems and a critical environmental hazard in worldwide. Specially, accelerated erosion due to human-induced environmental alterations at global scale is causing extravagant increase of geomorphic process activity and sediment fluxes in many parts of the world. Global estimates of erosion and sediment transport in major rivers of the world vary widely, reflecting the difficulty in obtaining reliable values for sediment concentration and discharge in many countries, the assumptions that are made by different researchers, and the opposing effects of accelerated erosion due to human activities (deforestation, poor agricultural practices, road construction, etc.) relative to sediment storage by dam construction (FAO., 1998).

A high level of sedimentation in rivers leads to physical disruption of the hydraulic characteristics of the channel and/or canal. This can have serious impacts on navigation

through reduction in depth of the channel, and can lead to increased flooding because of reductions in capacity of the river channel to efficiently route water through the drainage basin. The sediment largely originates from rapidly eroding sub-basins due to poor agricultural practices (FAO, 1998).

Traditional approaches to sediment management have not considered the need for sustained use. Large initial storage volumes and erosion control have traditionally been recommended to reduce sediment inflow and delay the eventual "death" of reservoirs, but erosion control alone cannot achieve the sediment balance required to stabilize reservoir storage capacity and achieve sustainable use. Furthermore, many erosion control programs are poorly conceived and implemented, and fail to achieve the desired reductions in sediment yield. As a result, reservoirs worldwide are losing storage capacity rapidly, possibly as fast as 1 percent per year (Mahmoud, 1987). Conversion of sedimenting reservoirs into sustainable resources which generate long term benefits requires fundamental changes in the way they are designed and operated. It requires that the concept of a reservoir life limited by sedimentation be replaced by a concept of managing both water and sediment to sustain reservoir function.

2.2 Soil erosion process

2.2.1 The mechanisms of soil erosion

As shown in Figure 2.1, several erosion processes can be identified. The first one, the splash erosion, starts when raindrop impact on the ground surface detaches particles (Julien 2002). After been detached, particles are transported to the rills by a thin overland flow. Rill erosion is an erosion process that occurs when water from the sheet erosion combines to form small concentrated channels (Fortuin 2006). This is the most common type of surface erosion and is small enough to be removed by normal tillage operation. When water in rills concentrates to form larger channels, it results in gully erosion (Fortuin 2006). Stream channel erosion takes place when concentrated water which forms from rills and gullies, and contains sediment removed from stream bed and stream bank (Fortuin 2006). When the amount of detached soil overcomes the transport capacity, only the sediment corresponding to the transport capacity will be carried downslope and the rest will be deposited in the channel.

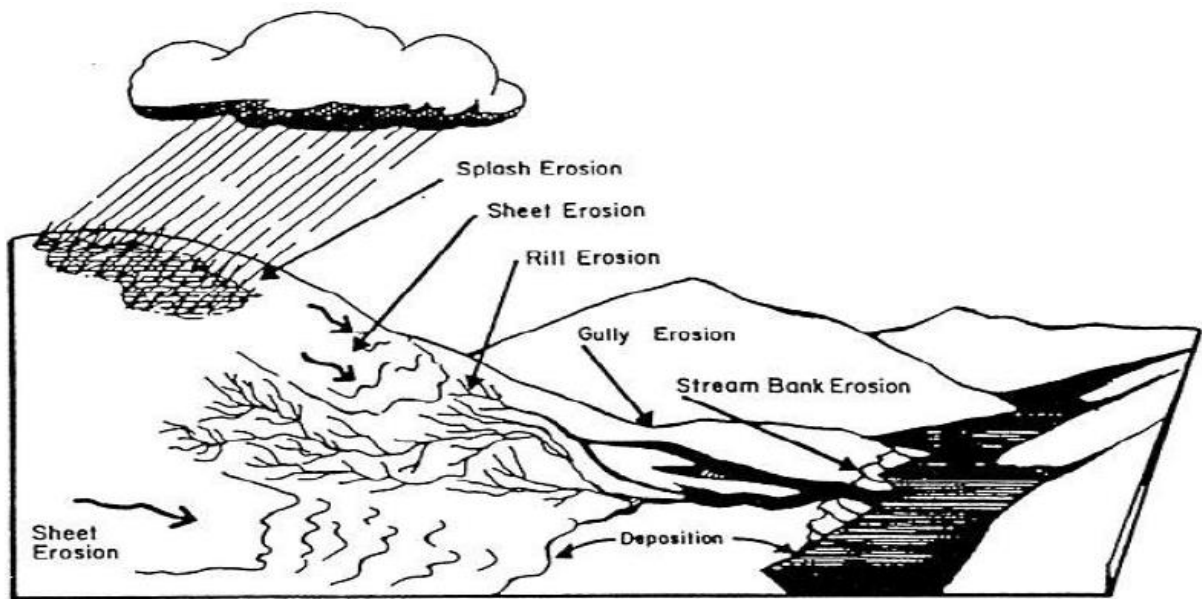


Figure 2-1 The mechanisms of soil erosion (USACE 1985)

2.2.2 Sediment transport

The sediment transport capacity of overland flow is defined as the maximum amount of sediment that can be transported at a particular discharge rate on a certain slope (Merten et al., 2001). Several studies confirmed that the transport capacity of overland flow mainly depends upon slope gradient, unit discharge, and flow velocity (Govers and Rauws, 1986; Govers, 1990; Everaert, 1991; Jayawardena and Bhuiyan, 1999; Prosser and Rustomji, 2000; Zhang et al., 2009). Under field conditions, slope gradient and flow discharge can be measured precisely, while flow velocity is hard to observe, especially in shallow and unconfined flow conditions. The majority of the existing spatially distributed soil erosion models are using empirical stream flow resistance equations (i.e., Manning or Darcy Weisbach) for the estimation of mean flow velocity (KINEROS2, Smith et al., 1995; LISEM, De Roo et al., 1996; WEPP, Flanagan et al., 2001). These equations are not always appropriate to overland flow conditions, because they were not originally derived for shallow water depths, steep slopes and dynamic bed roughness's (Hessel, 2002). Furthermore, stream flow transport capacity functions are being used in most of the existing soil erosion models for the quantification of sediment transport capacity (KINEROS2, Smith et al., 1995; WEPP, Flanagan et al., 2001). But the hydraulic conditions like flow discharge and slope gradient under overland flow, which are the main driving forces, are entirely different from the conditions in stream flow that make their use debatable (Hessel and Jetten, 2007).

During the last three decades, several studies were carried out to understand the hydraulics of overland flow (e.g., Line and Meyer, 1988; Govers, 1992a,b; Nearing et al., 1997, Takken et al., 1998; Nearing et al., 1999; Takken and Govers, 2000), but research is still needed for the precise estimation of major hydraulic variables of overland flow, such as mean flow velocity, discharge, sediment transport capacity, etc. Many efforts have already been made to better understand the processes involved in transport of sediment under overland flow conditions (e.g., Beasley and Huggins, 1982; Govers and Rauws, 1986; Govers, 1990; Guy et al., 1990; Everaert, 1991; Abrahams and Li, 1998; Prosser and Rustomji, 2000; Abrahams et al., 2001; Zhang et al., 2009; Zhang et al., 2010a, b, c). But, there is still a need to improve the mathematical framework for the estimation of sediment transport capacity of overland flow by considering physical parameters. In order to do so, it is imperative to study the impact of hydraulic parameters like unit discharge, slope gradient and mean flow velocity on sediment transport capacity.

2.2.3 Representation of erosion on temporal and spatial scales

Scaling is not exactly the same as scale. Scale refers to a characteristic length or time and can be used either as a qualitative term (e.g., a small-scale process) or as a quantitative measure in space or time dimensions. The spatial dimension represented as coordinates in (x , y , z) directions varies temporally along a time domain t . There are five accepted meanings of scale used in environmental analysis, namely the cartographic, geographical, process, measurement and modelling scales (Beven, 1995).

Models operate at certain scales, but not necessarily those matching the process or observation scales. Scaling is a change in either spatial or temporal scale and has a certain direction and magnitude (Bogena and Diekkrüger, 2002). It focuses on what happens to the characteristics of an object or process when its scale is changed proportionally. Hydrological and erosional processes (including spatial variability and relevant physical, chemical and biological phenomena) occur on a wide range of temporal and spatial scales.

To apply the concept of scaling to the erosion process, it should be analyzed how topographical attributes change if the spatial resolution of a digital elevation model (DEM) is doubled or how the drainage area changes if the length of a stream doubles (Zhang et al., 2002). One of the major challenges in soil erosion modelling, which has become even more important with the

increasing use of models linked to GIS, is the mismatch between the small spatial and temporal scales of data collection and model conceptualization, and the large spatial and temporal scales of most intended model applications (Renschler and Flanagan, 2003).

Mannaerts (1993), Kirkby et al. (1998) and Zhang et al. (2004b) report that soil erosion model predictions are very sensitive to changes at both the spatial and temporal scales. The major errors in erosion modelling come from incompatibilities between model scale, scale of input parameter data, and the intended scale of the model outputs.

It is clear that the variability, nonlinearity and the interacting nature of erosion and deposition processes over various scales significantly influence the mechanics of surface runoff generation and soil erosion. In particular, the important temporal dynamics of precipitation and surface characteristics (*i.e.*, vegetation cover), which also vary spatially, have strong controls on surface runoff generation and the resulting soil erosion, owing in particular to the nonlinear nature of infiltration, soil detachment and transport processes. These controls are instantaneous phenomena and modelling them ideally requires fine time resolution data, but because data availability is often limited to annual time steps it is often done at annual, and only rarely at daily, time steps.

Therefore, a key consideration in choosing an appropriate erosion deposition model is the time scale at which the erosion processes will be predicted (Veldkamp et al., 2001). Soil erosion by overland flow leads to specific forms of landform development over both short and long-time scales (Kandel et al., 2004). In some cases, the landscape can be dramatically modified in a matter of hours as a result of an extreme storm event (Renschler et al., 1999). Thus, rates of soil erosion typically show major variability both within events and between them. This variability is not only a reflection of spatial and temporal variability in the factors that control erosion, such as rainfall intensity and infiltration, but both the process and stochastic elements of the erosion also vary. The temporal variability of weather, especially rainfall, is extremely important in soil erosion assessment (Kinnell, 2003). Soil erosion totals can be dominated by a few extreme events, thus monitoring as well as simulation studies need to be long enough to capture these erosive events. However, low-magnitude, high-frequency events can also be significant for long-term erosion rates.

Alternatively, a larger temporal resolution is used in models that explore general trends over time with respect to changes in rainfall, vegetation or land management (Renschler and Flanagan, 2003). The variation in the contributions of eroded sediment within storm events is not considered. A third approach is to use a continuous time step, usually daily, that is responsive to, for example, the development and recession of saturated zones or other processes that can be captured at this time step, yet does not capture land surface response to high-intensity and short-duration events (Wainwright et al., 2003). As computing power has increased, many of the models originally developed to be applied to a single event (*e.g.*, AGNPS, ANSWERS) have undergone modifications and can now be applied as continuous simulations. Those models that have moved from an event-based to a continuous simulation mode often retain the ability to shift between, for example, a daily model time step to finer temporal resolutions during events.

2.3 Effect of land use/cover change on stream flow and sediment yield

Land use and land cover modifications can be grouped as conversion and alteration into two broad groups. Conversion refers to modifications from one type of cover or use to another while alteration means retaining the broad type of cover or use in the face of changes in its attributes.

Therefore, research into land use and land cover transition (LULCC) needs to discuss the detection, qualitative definition and parameterization of factors influencing changes in land use and land cover, as well as the synthesis of their effects and input. One of the key difficulties in LULCC research, however is to relate people's actions to biophysical knowledge at the necessary spatial and temporal scales. However, it is claimed that changes in land use and land cover transition can be readily accessible and connected to population data whether the research unit is state, provincial, district or municipal.

2.3.1 Land use land cover change

Vegetation provides considerable protection against degradation by absorbing the energy of the falling drops, and usually reducing the drop sizes that reach the ground. In addition, a strong vegetal cover usually improves penetration potential by adding organic matter to the soil. As a consequence, greater penetration potential means less overland flow and less erosion and less sediment yield. Different studies report that the condition and cover of vegetation are the important factors that decide the time of most extreme erosion (Hagos, 2006).

Land use and land cover changes in natural, economic and political settings result from diverse environmental and human factors. Therefore, it is possible to measure local human activities reflecting the drivers by measuring the proportions and forms of changes and analyzing other relevant data sources such as population dynamics, household characteristics and land management policies (Oumer, 2009). Land use/land cover plays a crucial role in water transport in the hydrological cycle and mainly helps in reducing overland flow. LULC is a driving force in the energy balance within the hydrologic cycle because of its effect on evaporation, transpiration, and solar radiation interception (Tadese, 2014).

Due to enormous agricultural and demographic strain, land is becoming a scarce resource, requiring the exploitation of knowledge on land use land cover transition and prospects for their optimum use for the collection, preparation and introduction of land use programs to satisfy the growing demand for basic human needs and welfare (Assefa & Wossenu, 2016).

2.3.2 Effect of Land use land cover change on stream flow

Changes in land cover can have an immediate and long-lasting effect on terrestrial hydrology and change the long-term relationship between rainfall and evapotranspiration and stream flow. In the short term, disruptive changes in land use will influence the hydrological cycle in certain situations, either by raising water yield or decreasing or even removing low flow (Worku, 2009).

The influence of human induced abstractions and its impact on the hydrology of the basin, it is very important for investigation of land use/cover changes within the basin and their impacts on the hydrological regime. Long-term impacts of land use land-cover change on stream flow are important to study different environmental conditions. Analysis of hydrological responses to land use land cover change in a basin can be performed by combining a calibrated basin-scale model with historical data or future scenario (Yure, 2014).

The relationship between land use land cover change and hydrology is complicated, with linkages existing at a wide variety of spatial and temporal scales; but, land use change indisputably has a strong influence on global wateryield. These factors control the water yields of surface streams and groundwater aquifers and thus the amount of water available for both ecosystem function and human use (Orkodjo, 2014).

2.3.3 Sediment yield variation induced by land use land cover change

Vegetation cover is widely accepted as a significant parameter in the erosion and sediment yield of drainage basins. Vegetation and land use are important factors in respect to the hydrology and sediment production of catchments because they are more dynamic than many other factors, with short seasonal changes as well as long- term climatic or land use management changes (Thornes, 1990).

According to the study undertaken in Southwest England by Thornes (1990) the highest rate of suspended sediment delivery in surface runoff was observed from the heavily grazed permanent grassland. For cereal and temporary grass, the rate of suspended sediment delivery was low. The main control of surface runoff production is the amount of surface compaction and the presence or absence of vegetation cover. The runoff volume from heavily grazed permanent grassland is at least double compared to that of lightly grazed areas, and nearly 12 times greater than that of ungrazed (temporary grassland) areas. In this case the suspended sediment varied with season and land use.

Sediment yield are determined by different factors such as soil type, topography, climate, land use and/or cover and catchment size. In areas where soil type and topography are similar, differences in erosion rates are commonly related to land use land cover (Hagos, 2006).

2.3.4 Impact of Land use land cover change on stream flow and sediment yield in Ethiopia

Impact on Soil Erosion.

LULC change exerts negative impacts on ecosystem services, in general, and on biodiversity, climate, soil, water, and air, in particular (Hailemariam et al, 2016). Soil erosion is affected by LULC change despite other factors such as climate, soil characteristics, and topography. Land cover plays a significant role in controlling soil erosion by reducing the direct impacts of raindrops on the soil, enhancing the organic matter content in the soil, increasing the infiltration rate of water, reducing the velocity of runoff, and reducing the transportation of sediments on the surface (Zhang et al.,2020). Hence, a change in land use and land cover due to anthropogenic activities significantly affects the rate of soil erosion.

Different studies undertaken in different parts of Ethiopia indicated the impacts of land use and land cover change on soil erosion. Among these, a recent study made by (Woldemariam and Harka,2020) at Erer Sub basin, Northeast Wabi-Shebelle Basin of Ethiopia, indicated that the

expansion of cropland, bare land, and settlement from 47.92%, 8.03%, and 0.20%, respectively, in 2000 to 64.36%, 9.71%, and 0.61%, respectively, in 2018 and the decline of forestland, scrubland, and water body from 2.99%, 40.67%, and 0.18%, respectively, in 2000 to 1.42%, 23.87%, and 0.03%, respectively, in 2018 increased the mean soil loss rate of the sub basin from 75.85 t·ha⁻¹·year⁻¹ in 2000 to 107.07 t·ha⁻¹·year⁻¹ in 2018. Similarly, (Kidane et al., 2019) revealed that the expansion of cultivated land at the expense of forest and scrubland increased the mean rate of soil erosion from 25.8 t·ha⁻¹·year⁻¹ in 1973 to 28.7 t·ha⁻¹·year⁻¹ in 1995 and 30.3 t·ha⁻¹·year⁻¹ in 2015 and the total soil loss from 198 million t·year⁻¹ in 1973 to 221 million t·year⁻¹ in 1995 and 239 million t·year⁻¹ in 2015 in Guder Sub watershed, Blue Nile basin of Ethiopia. The conversion of forest and scrubland into cultivated land in the watershed has also increased the mean sediment yield from 6.79 t·ha⁻¹·year⁻¹ in 1973 to 8.65 t·ha⁻¹·year⁻¹ and 9.44 t·ha⁻¹·year⁻¹ in 1995 and 2015, respectively. Another recent study by (Aneseyee et al., 2020) in the Winike Watershed, Omo Gibe Basin of Ethiopia, reported that total soil loss and sediment export of the watershed increased by 176.35 and 3.85 thousand tons, respectively, over the periods between 1988 and 2018 due to the change in land use and land cover. The research conducted by (Tadesse et al., 2017) on land use and land cover changes and soil erosion in Yezat Watershed, Northwestern Ethiopia, showed that the expansion of cultivated land and decline of sparsely wooded land, grassland, and scrubland during the period between 2001 and 2010 have increased the estimated average soil loss from 7.2 t·ha⁻¹·year⁻¹ in 2001 to 7.7 t·ha⁻¹·year⁻¹ in 2010 in the watershed. However, the implementation of integrated watershed management development programs in the watershed between 2010 and 2015 increased the extents of woodland, grassland, and homesteads by 101.69 ha (0.67%), 610.69 ha (4%), and 126.6 ha (0.83%), respectively, and consequently, the estimated average soil loss of the watershed decreased from 7.7 t·ha⁻¹·year⁻¹ in 2010 to 4.8 t·ha⁻¹·year⁻¹ in 2015.

Impact on stream flow

Watersheds hydrological processes are affected by a multitude of factors such as land use and land cover, climate, soil properties, geology of the land, and topography. Land use and land cover change mainly caused by anthropogenic interference modifies watershed hydrological processes by altering the balance between rainfall, evaporation, and runoff response of an area (Chimdessa et al., 2018.) The change in LULC alters infiltration, ground water recharge, surface runoff, and river flow within a watershed (Getahun and Haj, 2015). Therefore, a better understanding of LULC change and its effect on hydrological processes in Ethiopia is highly indispensable for the management of water resources in the country.

LULC change contributes to the change in the hydrological system in Ethiopia. Quantifying the effects of LULC change on watershed hydrological processes has recently been given much attention by the researchers, and previous studies in the country have quantified watershed hydrological responses as a result of the change in land use and land cover. A study in Gilgel Tekeze Catchment, Northern Highlands of Ethiopia, by (Haregeweyn et al., 2015) found that the increment of cultivated land by 15.4% and settlements by 9.9% at the expense of scrubland and grazing lands triggered the increment of annual surface runoff by 101 mm, reduction of groundwater recharge by 39 mm, and reduction of annual evapotranspiration by 91 mm over the period between 1976 and 2003. Similarly, (Gashaw et al., 2018) reported the continuous expansion of cultivated land and built-up area and diminishing of forestland, scrubland, and grassland, which have occurred from 1985 to 2015, had increased the annual flow by 2.2%, wet seasonal flow by 4.6%, surface runoff by 9.3%, and water yield by 2.4%. On the other hand, the observed changes had reduced dry season flow by 2.8%, lateral flow by 5.7%, groundwater flow by 7.8%, and evaporation and transpiration (ET) by 0.3% in the Andassa Watershed, Blue Nile Basin of Ethiopia. Another study by (Welde and Gebremariam, 2017) in Tekeze Dam Watershed, Northern Ethiopia, also reported that the increment of cultivated land by 8.51% and bare land by 0.9% and the reduction of scrubland by 5.62% and grassland by 3.33% between 1986 and 2008 caused an increase of the mean annual stream flow from 129.20 m³/s in 1986 to 137.74 m³/s in 2008 and the annual sediment yield from 12.54 t/ha in 1986 to 15.17 t/ha in 2008. A similar study in Gojeb Watershed, Omo-Gibe basin of Ethiopia, by (Choto and Fetene, 2019) found that an increase of cultivated land by 14.97% at the expense of forest land and scrubland between 1985 and 2015 resulted in an increase of stream flow by 8.6 m³/s and sediment yield by 41.07 tons/km².

2.4. Runoff and Sediment Management Practice

Soil and water conservation planning requires knowledge of the relationship between factors that cause loss of soil, water and those that help to reduce such losses. Soil and water conservation is major part of watershed management intervention that involves the development of systems for the management and utilization of land, water and vegetation resources that are economic, productive and sustained in the long run. Agronomic or vegetative measures and Physical (engineering measures) are the two commonly used soil and water conservation practices (Hurni H. E.-S., 1983, 1996). Both conservation practices influence the rate of soil erosion and are useful parameters to be considered in runoff and erosion

modeling. Although the general strategies for reservoir sediment management are the same for large reservoirs and small reservoirs, sediment management practices for those two categories of reservoirs are often as different as their magnitudes.

In the upstream watershed, three basic patterns of soil conservation measures are commonly taken to reduce sediment load entering the reservoir: structural measures, vegetative measures, and tillage practice. Structural measures include terraced farmlands, flood interception and diversion work, gully head protection works, bank protection works, check dams, and silt trapping dams. Vegetative measures include growing soil and water conservation forests, Filter striping, closing off hillsides, and reforestation. Tillage practices includes contour farming, ridge and furrow farming, pit planting, rotation cropping of grain and grass, deep ploughing, intercropping and inter planting, and no tillage farming.

The effectiveness of soil conservation measures in reducing sediment inflow to a reservoir is different for different watershed sizes. For a large watershed with poor natural conditions, soil conservation can hardly be effective in the short term.

2.5 Selection of Hydrological models

Each type of model uses certain applications, and the choice of an acceptable model structure depends heavily on the purpose that the model has to serve. Although each project has its own unique specifications and requirements, most of the parameters depend primarily on the project (Juraj, 2003). There are different parameters that can be used for a particular problem to select the right hydrological model. As each project has its own unique specifications and needs, these standards are often project based. In addition, certain parameters are user-dependent (and thus subjective) as well. There are four common, essential criteria among the different project-dependent selection criteria that must always be answered: -

- Does the model predict the variables required by the project? (Required model outputs important to the project and therefore to be estimated by the model.
- Is the model capable of simulating single-event or continuous processes? (Hydrological processes that need to be modeled to estimate the desired outputs adequately.
- Can all the inputs required by the model be provided within the time and cost constraints of the project? (Availability of input data).
- Does the investment appear to be worthwhile for the objectives of the project? (Price)

The selection of the model was based on the aforementioned parameters, including the availability of the Info, application stage, purpose, accuracy needed, space and time scale, area of catchment, simplicity, past patterns (studies) in the surrounding area and Ethiopia as a whole. For the following reasons, I have selected the SWAT model for this analysis, considering all the parameters set above:

- ✓ It is physically based, spatially distributed and belongs to the public domain. Rather than incorporating regression equations to describe the relationship between inputs and output variables, SWAT requires specific information about weather, soil properties, and topography, vegetation, and land management practices occurring in the watershed.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The Omo-Gibe River Basin covers around 79,000km² and is located in Ethiopia's south-west, between 4°00'N and 9°22'N latitude and 34°44'E and 38°24'E longitude. The lowlands cover about 51% of the basin's total area. The Omo River and its tributaries, the gibe and the Gojeb, drain the north and west of the basin, respectively, and flow into Lake Turkana.

It is a river basin that flows into Lake Turkana in Kenya, which serves as its southern border. The Omo-Gibe Basin is separated from the Baro-Akobo Basin by a range of hills and mountains known as the western watershed. The BlueNile Basin borders the basin to the north and northwest, with a small area in the northeast bordering the Awash Basin.

The gibe III catchment is also found in the upper part of Omo-gibe basin which covers an area of some 400 km South West of Addis Ababa and 150 km west-South-west of Hawassa. The project is located within the jurisdiction of the Mareka Gana Wereda of the Dawro Zone and Kindo Koyisha Wereda of Sodo zone of the Southern Nations and Nationalities People Regional State (SNNPRS).

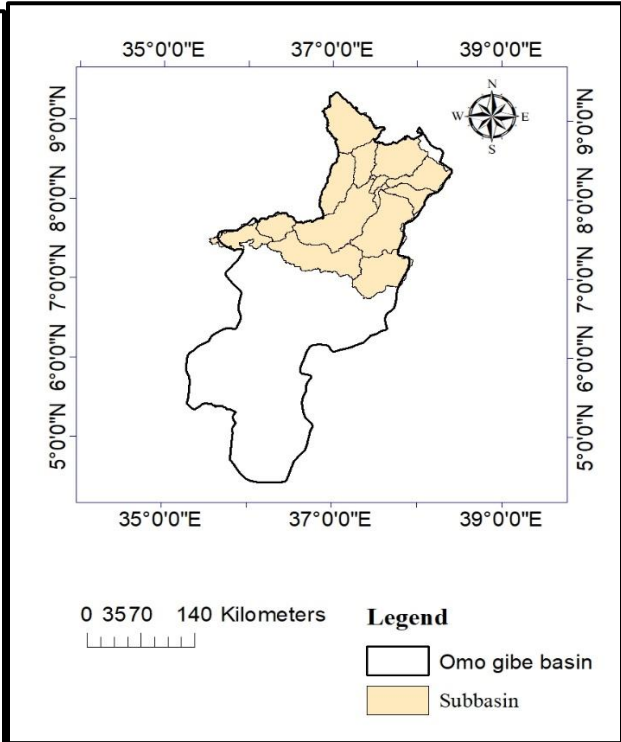
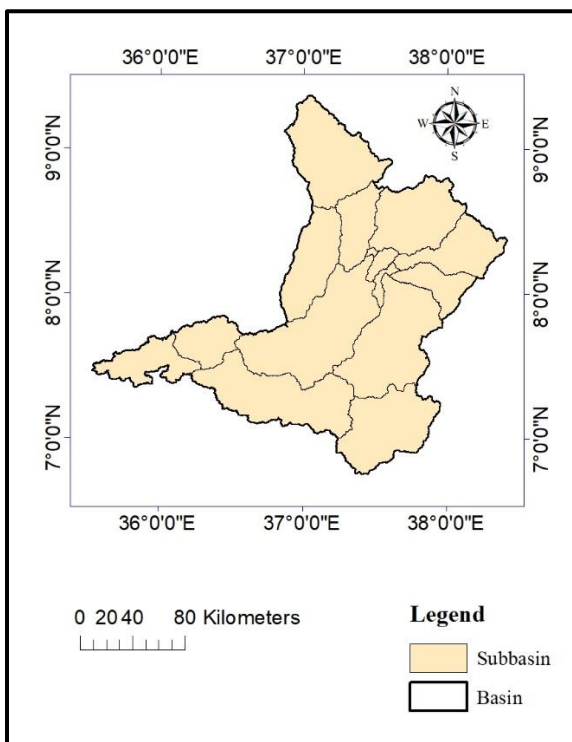
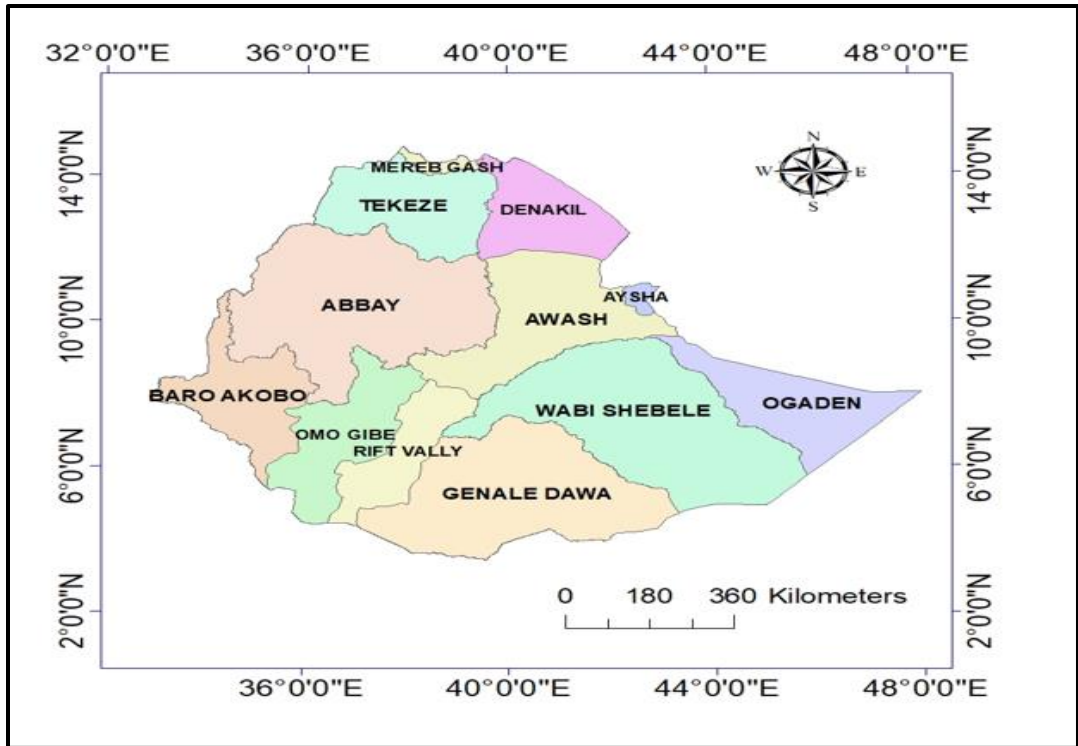


Figure 3-1 Location map of Gibe III Watershed

3.1.2 Topography

Physical variation characterizes the topography of the Omo-Gibe basin as a whole. The Omo, Gojeb, and Gilgel-Gibe Rivers gorges pass across mountainous to hilly terrain in the northern two-thirds of the basin, while the southern one-third is a flat alluvial plain punctuated by steep areas. The northern and central halves together basin is above 1500 m a.s.l., with a maximum elevation of 3360 m a.s.l. (between the Gilgel-Gibe and Gojeb tributaries), and the lower Omo plains are between 400 and 500 m a.s.l.

The Great-Gibe River's headwaters are around 2200 meters above sea level. The Gibe River flows southwards, towards the Omo River and then to Lake Turkana, a fault feature filled with alluvial and lacustrine sediments of recent origin associated with the Great Rift Valley, despite the presence of some significant tributaries from various directions. In its lower sections, southwest of the confluence with the Gojeb River, the Gibe River is known as the Omo River. This is how the Omo-Gibe River Basin got its name (Richard Woodroof and Associates, 1996).

3.1.3 Gibe- III Hydropower Project Characteristics

Gibe-III hydroelectric power is located in the Gibe-Omo River Basin, in the middle reach of the Omo River, approximately 450 kilometres south of Addis Ababa by road (EEPCO, 2007). The Gibe-III reservoir is about 155 kilometres long (from Gilgel Gibe-powerhouse II's to Gibe-dam). III's The dam axis is located between 312,044 E, 757,343 N, 312,542 E, and 757,107 N, according to UTM geographic coordinates.

The Gilgel Gibe III Dam is a roller-compacted concrete dam with a length of 610 meters and a height of 243 meters. It holds a reservoir with a capacity of 14.7 km³ and a surface area of 210 km², and a 34,150 km² catchment area. The reservoir has 11.75 km³ of live (active or "useful") storage and 2.95 km³ of dead storage. The reservoir's typical operating level is 892 meters above sea level, with a maximum of 893 meters and a minimum of 800 meters. The spillway of the dam is 108 meters long and floodgate-controlled, having a discharge capacity of 18,000 m³/s. Its gates may discharge water up to 873 meters above sea level. Two penstocks feed the dam's powerhouse, with each branched into five separate tunnels for each turbine. The power plant has ten 187 MW generators that are supplemented by Francis turbines, totaling 1,870 MW of installed capacity.

3.1.3 Soil

The soils of the basin's upper and middle reach are largely permeable and well drained, while the valley bottoms have less permeable drainage-impeded soils. Humic Nitisol (32.4 percent) and Humic Alisol (20.48 percent) were the dominant soil forms in the sample. The FAO-UNESCO soil classification map, obtained from the Ethiopian Ministry of Water and Resources, was used to analyze more detailed soil details for the study area.

Table 3-1. Distribution and Area Coverage of soils in gibe III watershed (based on FAO-UNESCO soil classification)

Soil Classification	Area(ha)	Area Coverage (%)
Chromic Luvisols	311,737.18	9.17
Dystric Vertisols	262,417.82	7.72
Eutric Vertisols	500,227.41	14.71
Humic Alisol	696,343.17	20.48
Humic Nitisol	1,101,917.69	32.4
Lithic Leptosol	524,509.42	15.43
Rendzic Leptosol	2,302.72	0.07
Water	684.45	0.02
Total	3,400,139.85	100

3.1.4 Climate

The Omo river-gibe basin's climate varies from a hot, arid climate in the flood plain's south to a tropical, humid climate in the highlands, which include the basin's far north and west. For the most part, the basin has a tropical sub-humid climate. Annual rainfall in the Omo-Gibe Basin varies between over 1900 mm in the north central regions to less than 300 mm in the south. Furthermore, the rainfall regime in the northern and central regions of the basin is unimodal, whereas in the south it is bimodal. The average annual temperature in the Omo-Gibe Basin ranges from 16°C in the northern highlands to over 36.4°C in the southern lowlands (Richard Woodroof and Associates, 1996).

3.1.5 Hydrology

The Omo-Gibe Basin is one of Ethiopia's major river basins, originating in the northwestern upper escarpments and bordering the Abbay Basin in the country's south. The Gibe River flows in a north - south direction towards Lake Turkana, with several significant tributaries coming from various directions. The Walga and Wabe rivers, which arise in the north-east, are the main tributaries in the northern part of the catchment. Both the Tunjo and Gilgel Gibe rivers are tributaries that drain primarily agricultural fields with less permeable soils in the south-west. The Gojeb River is an important right bank tributary of the Omo River, draining uplands that have been cultivated less intensely than the rest of the basin. The Sherma, Guma, and Denchak rivers have catchments to the south of the Gojeb River, which is a tapering stream that joins the Omo at the flood plain's northern end. Even in the driest years, these rivers often maintain some flow throughout the year. The Sana, Soke, Dame, and Zage rivers drain the uplands on the eastern side of the middle and lower Omo Gibe catchment, where runoff is comparatively high, and are recognized as seasonal rivers. The Meki River, a tapering stream with perennial tributaries that floods the highlands along the Omo Gibe Basin's southern border, keeps some flow into the Omo River except in the driest years. (According to the WWDSE hydrology sectoral study report from October 2011). Seasonal flow variation at Gilgel Gibe-I and Gibe-III is represented in Figure 3.2. As can be seen in the following graph (Figure 3.2), the months of July and October have the highest average monthly rainfall. However, between November and June, the average monthly rainfall is low.

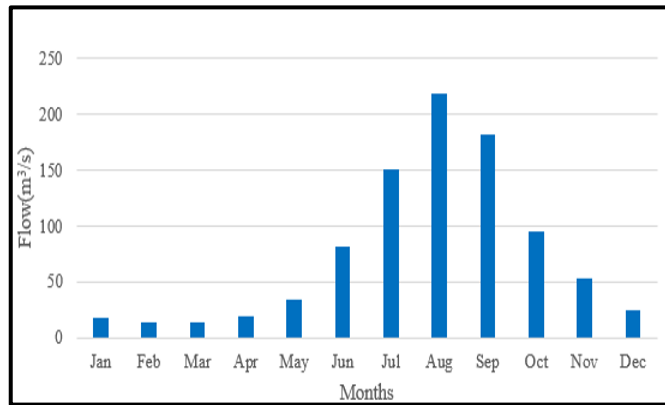
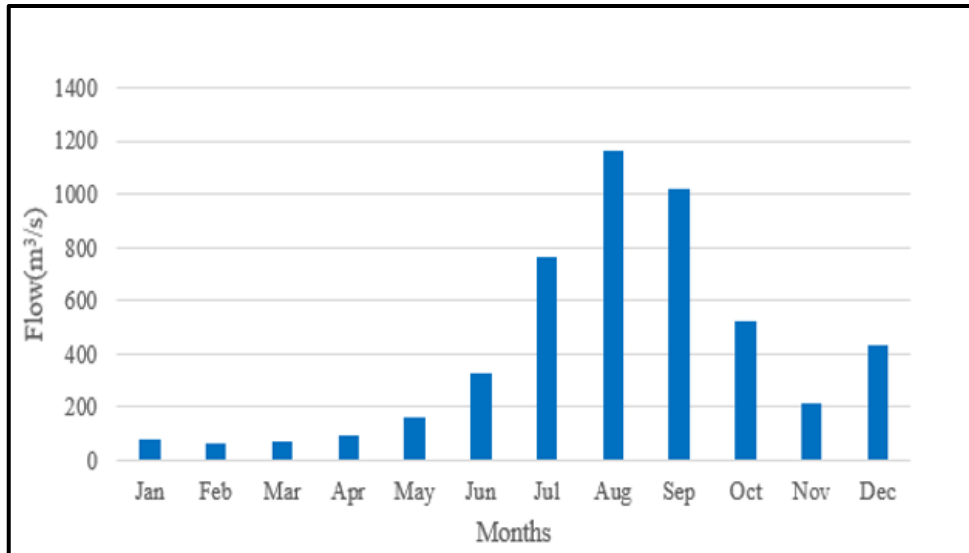


Figure 3-2 Seasonal variation of flow at Gilgel Gibe-I and Gibe-III and Omo (EEPCO, 2009).

3.1.6 Land Use/Land Cover

The northern catchments of the Omo-Gibe Basin are under extensive cultivation with increased land pressure (Figure 3.4 and Table 3.2). Deforested areas are now confined to areas too steep and inaccessible to farm. The main gorges of the basin are relatively unpopulated and support a cover of open wood-land and bush-land with grasses, the eastern part of the basin has some of the most densely populated and intensively farmed areas in the country.

Table 3-2: Distribution and Area Coverage of Land use in Gibe III watershed

Landuse	SWAT-code	Area(ha)	Area Coverage (%)
Plantation and farrow	AGRC	12,118.09	0.36
Residential	URML	49,634.33	1.46
Grassland	RNGE	156,245.58	4.6
Forest	FRSE	347,423.01	10.2
Water body	WATR	13,380.87	0.39
Bare land	BARR	2,654.46	0.08
Wetland	WETF	6,655.95	0.2
Cultivation	AGRL	2,168,598.63	63.78
Shurbland	RNGB	118,170.49	3.48
Woodland	FRSD	525,258.45	15.45
Total		3,400,139.85	100

3.2 Data Collection

The quality and the quantity of data applied for SWAT model determine the performance of the model to account for the physical characteristics of that particular river basin or catchments. Hence, the model required spatial data (the digital elevation model (DEM), land use/ land cover, soil layers), Metrological data (daily measured precipitation, maximum and minimum air temperature, solar radiation, relative humidity, and wind speed) and Hydrological data (daily measured stream flow and sediment concentration) for the simulation of stream flow and sediment.

3.2.1 Digital Elevation Model (DEM) Data

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 30 by 30m Digital Elevation Model (DEM) was collected from Ethiopian Ministry of Water, Irrigation and Electricity GIS department. A Digital Elevation Model (DEM) was used to model the geography of the study area. A DEM is a grid of square cells where each cell represents the elevation value at that location. The size of each cell determines the resolution of the DEM. The larger the cell, the coarser the resolution. For large areas coarser resolutions are preferred

over finer resolutions due to lower computational times and availability issues. In the SWAT model, DEM is used along with data on soil and land use/land cover to delineate the watershed and further divide the watershed into sub-watersheds and units of hydrological response (HRUs). Figure 3.3 Shows delineated DEM of Gibe watershed.

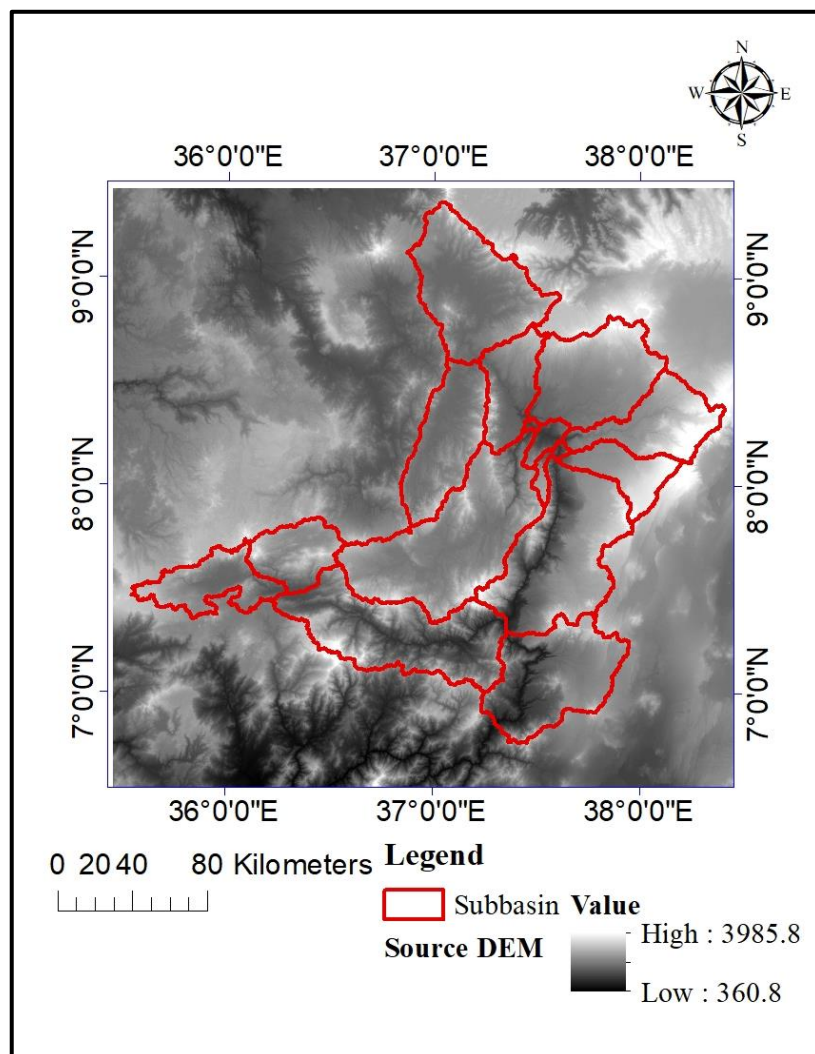


Figure 3-3 Delineated DEM OF Gibe III Watershed

3.2.2 Soil Map

In order to measure the daily rainfall, the soil properties provide information on the physical characteristics of the ground surface in a watershed that is important for determining the amount of water storage for each layer of soil profile. The soil data was derived from the Omo Gibe River Basin master plan project report prepared by EMWIE. The classification was conducted according to the FAO-UNESCO Soil Classification System. The soil data that is needed by the SWAT model has been collected from this database. A database comprising

physical and chemical properties for each soil layer was prepared with an attribute table for the assimilation of the soil digital map to the SWAT model. Figure 3.4 shows the study area's soil map.

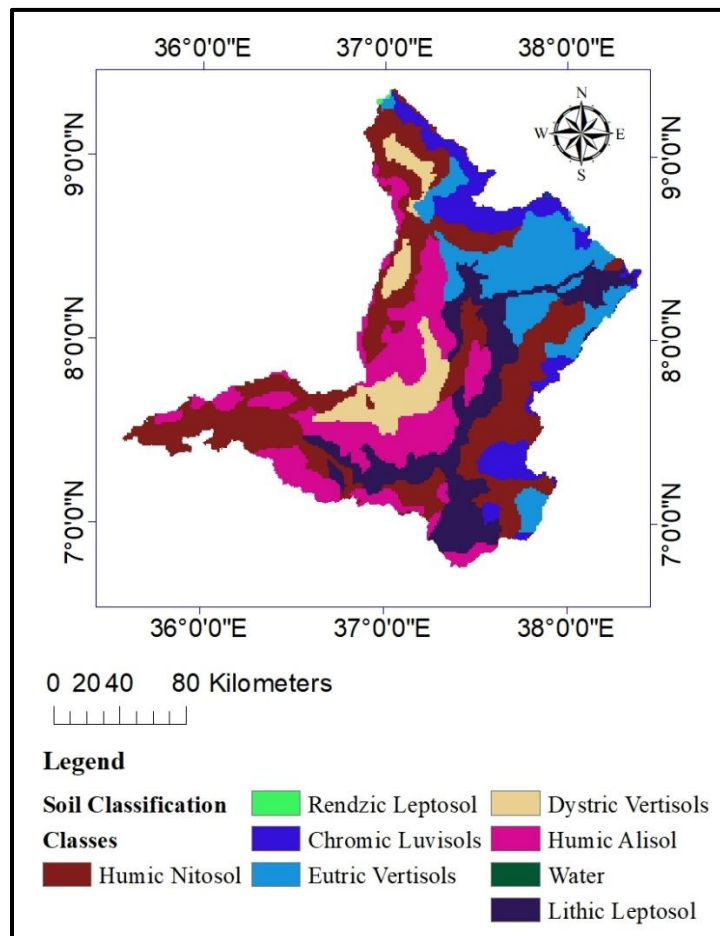


Figure 3-4 Soil map for Gibe III watershed

3.2.3 Land Cover/Use

For proper hydrological modelling, a comprehensive study and mapping of the land use/land cover is important. Surface water runoff, groundwater flow and evapotranspiration in a watershed are influenced by land use and/or land cover. Once topographic watershed parameters have been computed for each sub-basin, the interface uses land cover and soil data to produce several hydrological response units (HRUs) by GIS overlay processes for each sub-basin (Neitsch, 2011). The available land use cover map of the study area was collected from GIS and remote sensing department of EMWIE. Figure 3.5 shows the study area's land use/cover classification of 2019.

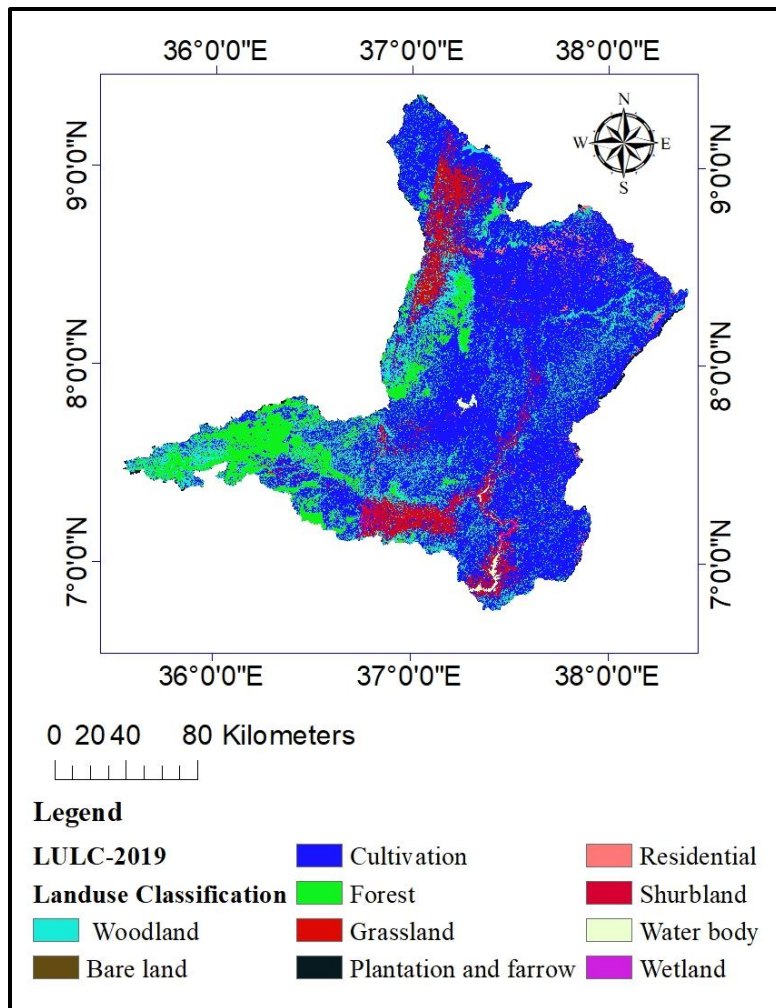


Figure 3-5 Land use/Cover (2019) of Gibe III watershed

3.2.4 Hydrological Data

Stream flow

Stream flows of gauging stations in the omo gibe river basin are mainly maintained by the hydrology department of the Ethiopian Ministry of Water, Irrigation and Energy (EMWIE). But many of these gauges are situated in the upper part of the basin. For this study, 27 years (1992-2019) hydrological flow data of Gibe III station which was located at the outlet of Gibe III watershed were selected for use.

Sediment data

There are few sites which has measured suspended sediment data on omo river basin with a very short period data. However, the sediment data was taken for the basin from Ministry of

Water, Irrigation and Energy Hydrology Directorate are situated in the upper part of the basin. For this study, 27 years (1992-2019) sediment data of Gibe III station was selected for use.

3.2.5 Meteorological Data

Lack of full and realistic long period climatic data is the problem of developing countries. Weather generators solve this problem by generating data having the same statistical properties as the observed ones. The measured daily meteorological data (precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed data) were obtained from Ethiopian Meteorological Services Agency. Welayita Sodo, Abelti, Chida, Gessuba, Hosanna, Asendabo, Jimma, Bonga, Sekoru and Welkite stations were selected for use.

Rainfall data

The rainfall data is one of the most important parameter of SWAT model. This data was collected from Ethiopian National Meteorological Agency. The SWAT model requires daily rainfall data arranged vertically parallel to time series. Eleven stations (1992-2019) which have a continuous rainfall records have been selected for analysis.

Temperature data

For generation of evaporation and evapotranspiration, temperature data is required for SWAT model simulation. Like other climate data even more than precipitation data it is difficult to get continuously record. For this research work eleven stations of (1992-2019) years recorded temperature data were collected and analyzed.

Wind speed, relative humidity and sunshine hours

These are also the vital parameters for SWAT model to generate weather. Since, very few stations have daily data of wind speed, relative humidity and solar radiation; Hossana, welkite and welita sodo station are selected for analysis.

3.3 Filling of missing data

Many hydrological analysis and design problems require measured precipitation data. However, data could be lost if the observer is unable to make the needed visit to the gauge, if recording gauges are damaged, or if the instrument fails (by mechanical or electrical malfunctioning). These missing values can be estimated using various ways. For this analysis, missing values from other stations around the lost record station were computed by taking into consideration the expectations of at least three stations as close to and evenly spaced around

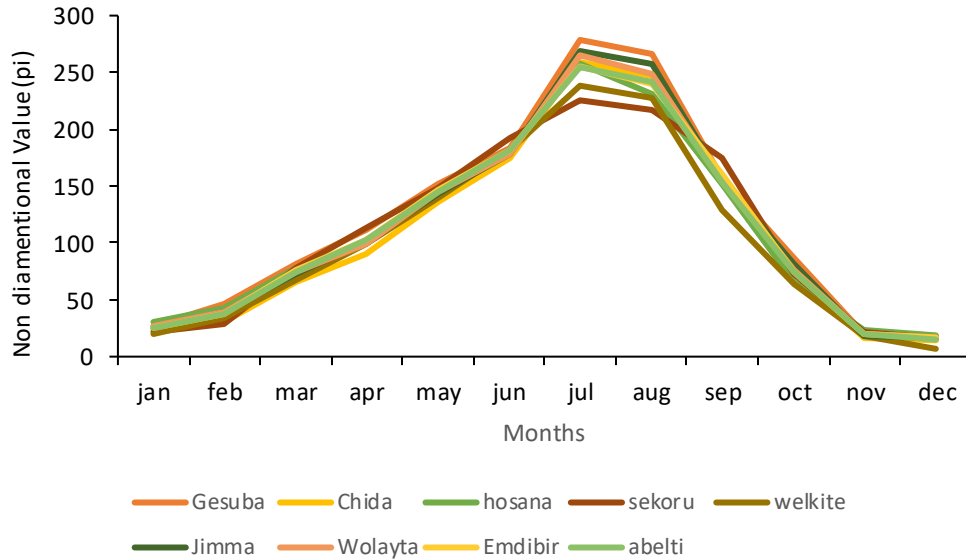


Figure 3-6 non-dimensional plots of selected stations in Gibe III watershed

Sometimes a significant change may occur in and around a particular rain gauge station. Such a change occurring in a particular year will start affecting the rain gauge data, being reported from that particular station. After a number of years, it may be felt that the data of that station is not giving consistent rainfall value. In order to detect any such inconsistency, and to correct and adjust the reported rainfall values, a technique, called double mass curve method generally adopted (Garg, 1976). This inconsistency of records caused by many reasons such as:

- A. Shifting of a rain gauge station to a new location,
- B. If the neighbourhood of the station undergoes a marked change,
- C. Change in the ecosystem due to calamities such as forest fires, landslides
- D. Due to observational error during data reading

$$P'_x = P_x \times \frac{M_c}{M_o} \dots \dots \dots \text{Equation 3.4}$$

Where: P'_x is corrected precipitation at station x, P_x is original recorded precipitation at station x, M_c is original slope of the double mass curve and M_o is corrected slope of the double mass curve. The stations used in this study have not undergone a significant change during the study period (1992–2018). Check the consistency of data of station and found inconsistent, then correct the inconsistent data. But the difference in slope is less 10% no correction needs to be applied.

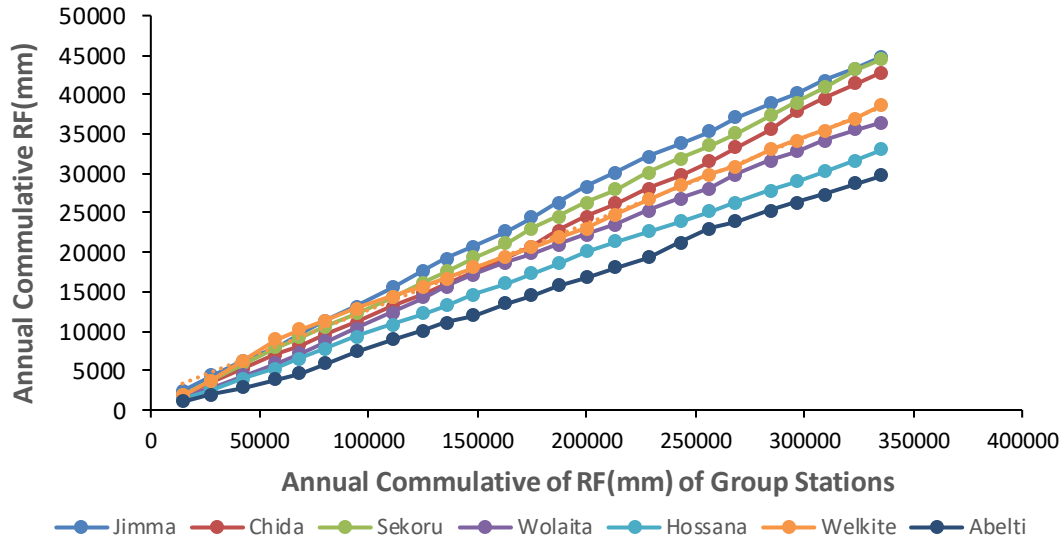


Figure 3-7 Double mass curve of selected stations of Gibe III watershed

3.4.2 Hydrological data analysis

Stream flow data

The annual and monthly characteristics of stream flows of Gibe III gauging stations analyzed for the period 1992-2019. The analysis involved description of the watershed characteristics, data quality assessment, and temporal and spatial characterization of the runoff. The stream flow data quality was first checked for unrealistic records such as no flows and constant observations for successive days following notable rain events. This check was followed to detect outliers in the daily runoff records. The stream flow data was found to be log- normally distributed. The first check enabled to identify few unrealistically constant records for successive days in the stream flow series of Gibe III Watershed. Figure 3.8 shows Homogeneity test graph of Gibe III Stream Flow.

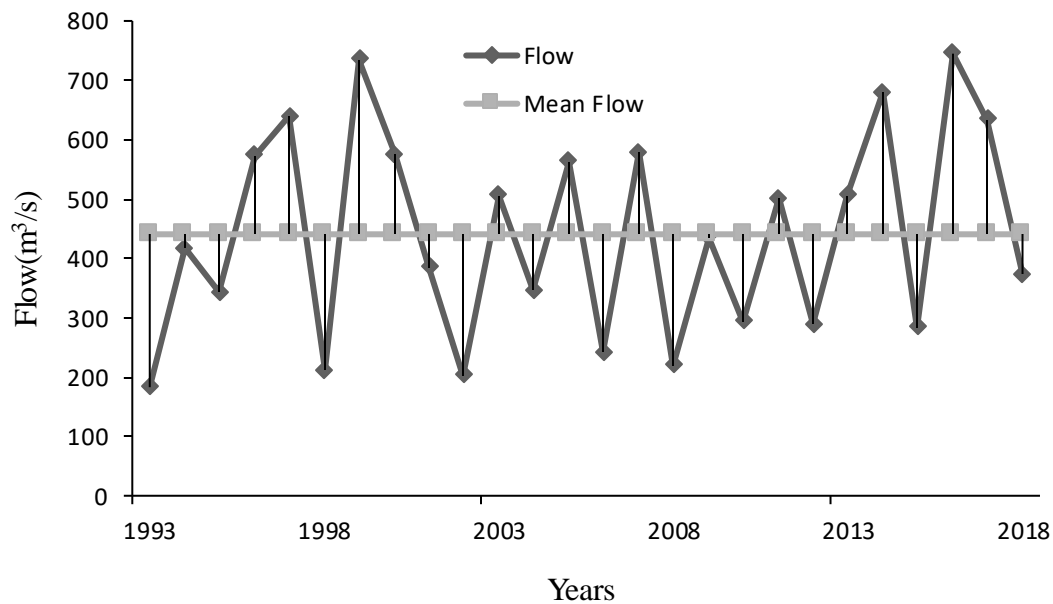


Figure 3-8 Homogeneity test graph of Gibe III Stream Flow

Sediment Rating Curve Preparation

Data requirement for sediment is widely issued for the purpose of assessing long term sediment yield of the catchment, to know sediment capacity of the basin and to identify and undertake management scenario changes to minimize further reservoir sedimentation. 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 (developing exponential relationship between river discharge and sediment concentration for the existing data) but it might increase uncertainty which is not as equal as the real observed values.

A supplementary analysis is carried out in this paragraph aimed to define the suspended sediment rating curve at the Gibe III dam section, that is the relationship $Q_s = aQ_w^n$, where Q_s is the suspended sediment transport in tons/day, Q_w is the discharge in m^3/s , a and n are the coefficients of the correlation. This law will permit the calculation of the sediment load at a given flow rate and therefore it may represent a powerful tool to predict the suspended sediment transport in the Omo River especially if combined with the hydrometrical campaign currently in progress. Since no direct measurement exists at the dam site, a classical statistical procedure has been applied to the sediment data of the upstream gauged stations in order to assess the proper correspondence between liquid and solid flow.

Data of the five main monitored catchments (i.e. Abelti, Wabe, Walga, Asendabo and Shebe) within the Gibe III Catchment have been considered and specifically only official gauges of the 94 OGMP sampling programme have been adopted. Suspended load and discharge have been both normalized by the median of the record and consequently all data have been homogenized and joined in a larger sample. Then, a regional correlation has been found and attributed to the entire Gibe III catchment closing at the dam section. With the intention of making the relationship more consistent, data have been progressively discarded until a maximum of 20% of all the observations laid outside of the 95% confidence interval.

The non-dimensional parameters are related by means of the expression $Q_s = 79.45Q_w^{1.0052}$ (practically the bisector line) with a R^2 coefficient of 0.771, having discarded 57 observations out of 280. The graph of Figure 3.9 shows the regional non-dimensional correlation assumed valid throughout the Gibe III catchment.

In order to scale the rating curve at the section of interest, the evaluation of the two scaling factors for both suspended load and discharge at the dam site is required. Medians at Gibe III are assessed by means of the estimate of two variability factors derived from the June–August 1994 records of data.

A factor for both parameters at each of the 5 stations is determined as ratio between the median of the sample and the mean annual value. For the suspended sediment load the specific yields of the '94 OGMP survey have been translated in tons per day while the mean annual discharges have been extracted from the 40 years (1962-2001) record of monthly flows. The transposition of these factors at Gibe III has been performed through a weighted mean according to the drainage area of each basin. Then the simulated medians at the dam section are obtained multiplying the mean suspended inflow and the mean monthly flows by the respective variability factor.

Table 3-3 Calculations are summarized in the table.

Gauging station			Great Gibe nr	Wabe nr	Walga nr	Gojeb nr	Gilgel Gibe nr	Gibe III dam site***
			Abelti	wolkite	Wolkite	Shebe	Asendabo	
Area	Km ²		15804	1788	1779	3356	2938	34159
Median of the sample*	T _{median}		48300	5032	21698	1706	1598	181173
	Q _{median}	m ³ /s	1269	23	112	103	106	2202
Specific sediment yield***	SSY	Ton/km ² /yr	221	1330	999	126	89	4944
Mean annual Sed.load	T _{mean}	Tons/day	9569	6515	4869	1159	716	46232
From 40 yrs record	Q _{mean}	m ³ /s	191	30	25	60	35	438
Variability factor	VF _r	-	5.048	0.772	4.456	1.473	2.231	3.919
	VF _Q	-	6.644	0.767	4.480	1.717	3.029	5.026

(Source: Gibe III Hydroelectric Project Sedimentation Study Report)

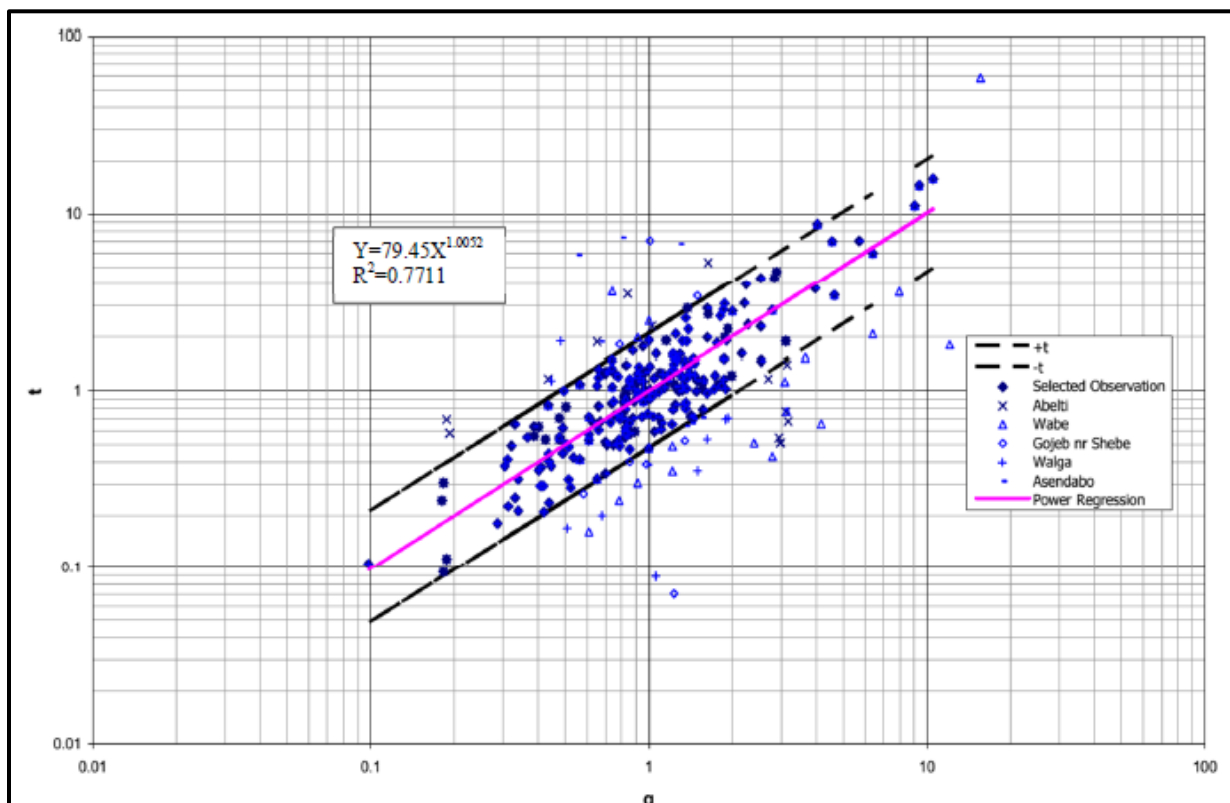
Notes:

- 1) Referred to OGMP sampling programme June – August 1994
- 2) Referred to OGMP sampling programme of the 1994 and updated where possible with the 1964-2001 monthly flows from the Gibe III Basic Design
- 3) Results of calculations are bolded
- 4) Estimated with the revised map method.

As a result the suspended sediment rating curve is written as follows:

$$Q_s = 79.45Q_w^{1.0052} \dots\dots\dots 3.5$$

For Q_w equal to the mean annual flow of 438 m³/s the equation above provides a suspended sediment load of 35,920 tons/day that is 13.11 Mtons/yr which is approximately 20% lower than the annual load estimated 16.31 Mtons/yr. This is consistent with the accuracy range adopted in the revised map method.



(Source: Gibe III Hydroelectric Project Sedimentation Study Report)

Figure 3-9: Non-dimensional suspended sediment rating curve for the Gibe III Basin

3.5.1 Hydrological Component of SWAT

Two different divisions are used to model the hydrology of a watershed. One is the hydrological cycle land process that regulates the volume of water, sediment, nutrient and pesticide loadings in each sub-basin to the main channel. The second division is the hydrologic cycle routing process, which can be defined as the flow of water, sediments, nutrients and organic chemicals through the watershed channel network to the outlet. SWAT simulates the hydrological cycle based on the water balance equation in the soil phase of the hydrological cycle.

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{Sweep} - Q_{gw}) \dots \dots \dots \text{Equation 3.7}$$

Where SW_t is the final soil water content (mm), SW₀ is the initial soil water content on day I (mm), t is the time (days), R_{day} is the amount of precipitation on day I (mm), Q_{surf} is the amount of surface runoff on day I (mm), E_a is the amount of evapotranspiration on day i (mm), W_{Sweep} is the amount of water from the soil profile on day i entering the vadose region (mm), and Q_{gw} is the amount of return flow on day i (mm). Surface runoff happens if the precipitation rate exceeds the penetration rate. SWAT provides two methods for calculating surface runoff: the technique for the SCS curve number (USDA-SCS 1972) and the process of infiltration by Green & Ampt (Lin, 2007). SWAT simulates surface runoff volumes and peak runoff rates for each HRU, using daily or sub daily rainfall.

Surface runoff

Surface runoff occurs at a time whenever the rate of water application to the ground surface exceeds the rate of infiltration of the soil. This is a major component of the water cycle or the hydrological cycle. The SCS curve number method was used to estimate surface runoff because of the unavailability of sub daily data for Green & Ampt method. The SCS curve number equation is:

$$Q_{surf} = \frac{[(R_{day} - 0.2s)]^2}{(R_{day} + 0.8s)} \dots \dots \dots \text{Equation 3.8}$$

Where, Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), S is the retention parameter (mm). The retention parameter is defined by the equation:

$$S = 25.4 \times \left(\frac{100}{CN}\right) - 10 \dots \dots \dots \text{Equation 3.9}$$

Two methods for measuring the retention parameter are used in the SWAT model; the first is that the retention parameter varies with the water content of the soil profile, and the second method is that the retention parameter varies with cumulative evapotranspiration of plants. In shallow soils, the soil moisture system predicts runoff. However, by measuring daily CN as a function of plant evapotranspiration, the value is less soil storage dependent and more temperature dependent.

$$S = S_{\max} \left(1 - \frac{SW}{SW + \exp(w_1 + w_2 SW)}\right) \dots \dots \dots \text{Equation 3.10}$$

In which, S is the retention parameter for a given day (mm),
 S_{\max} is the maximum value that the retention parameter can have on any given day (mm),
 SW is the soil water content of the entire profile excluding the amount of in the profile at wilting point (mm), and
 W_1 and W_2 are shape coefficients.

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

$$S = S_{\text{prev}} + E_o \times \exp\left(\frac{-\text{cncoef} - S_{\text{prev}}}{S_{\max}}\right) - R_{\text{day}} - Q_{\text{surf}} \dots \dots \dots \text{Equation 3.11}$$

In which, S_{prev} is the retention parameter for the previous day(mm), E_o is the potential evapotranspiration for the day (mm/day), cncoef is the weighting coefficient used to calculate the retention coefficient for daily curve number calculations dependent on plant evapotranspiration, S_{\max} is the maximum value the retention parameter can achieve on any given day(mm), R_{day} is the rainfall depth for the day (mm), and Q_{surf} is the surface runoff (mm).

Peak runoff rate

The peak runoff is a pointer of the erosive power of a storm and is used to estimate sediment loss. Maximum runoff flow rate that occurs with a specified rainfall event is the peak runoff rate. Modified rational method is used in SWAT for peak runoff rate calculation. The rational method mainly assumes that if a rainfall of intensity I begins at time t=0 and continues indefinitely, the rate of runoff will increase until the time of concentration.

$$Q_{peak} = \frac{\alpha_{tc} \times Q_{surf} \times A}{3.6 \times t_{conc}} \dots \dots \dots \text{Equation 3.12}$$

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

Evapotranspiration

Evapotranspiration is a collective term that includes evaporation from the land surface and evaporation from vegetation cover. Generally, it does mean that water removed from the watershed. A relatively accurate estimation of evapotranspiration is an essential element in the assessment of water resources and the study of impact of climate change. Normally, SWAT includes three options to estimate evapotranspiration. These are the Penman-Monteith method (Monteith,1965), the Priestley-Taylor method (Priestley and Taylor,1972) and the Hargreaves method (Hargreaves et al., 1985). One of the three methods is selected to calculate the potential evapotranspiration from the watershed depending up on the data available. The model will also read if a separate daily PET values are applied for potential evapotranspiration method.

The data requirements for the application of these three PET methods are very different. The Penman Monteith method requires solar radiation, air temperature, relative humidity and wind speed. The Priestley-Taylor method requires solar radiation, air temperature and relative humidity. The Hargreaves method requires air temperature only. SWAT estimates the components of evapotranspiration step by step. The details steps are presented in the user’s manual (Neitsch et al., 2005).

Percolation and Lateral Flows

Percolation is the vertical movement of water into the soil. In SWAT, percolation is computed for each soil layer in the profile. Storage routing technique of SWAT was utilized to estimate the percolation of flow through each soil layer in the root zone. Hence, the formula applied to estimate the volume of water available for percolation in the soil layer and the lateral flows are collected from the User’s manual and they are given chronologically by equations 3.13-3.14:

$$SW_{ly,excess} = SW_{ly} - FC_{ly} \text{ if } SW_{ly} > FC_{ly} \dots \dots \dots \text{Equation 3.13}$$

$$SW_{ly,excess} = 0 \text{ if } SW_{ly} \leq FC_{ly} \dots\dots\dots \text{Equation 3.14}$$

Where $SW_{ly,excess}$ is the drainable volume of water in the soil layer on a given day (mm of water), SW_{ly} is the water content of the soil layer on a given day (mm of water) FC_{ly} is the water content of the soil layer at field capacity (mm of water).

Storage routing method is applied to calculate the amount of water that moves from one layer to the underlying layer. The equation utilized to calculate the amount of water that percolates to the next layer is:

$$w_{perc,ly} = SW_{ly,excess} \times \left[1 - \exp \left[\frac{-\Delta t}{TT_{perc}} \right] \right] \dots\dots\dots \text{Equation 3.15}$$

Where:

$w_{perc,ly}$ is the amount of water percolating to the underlying soil is layer on a given day (mm of water), $SW_{ly,excess}$ is the drainable volume of water in the soil layer on a given day (mm of water), and $-\Delta t$ is the length of the time step (hr), and TT_{perc} is the travel time for percolation (hr).

The travel time for percolation TT_{perc} is distinct for each layer and it is calculated using the following equation

$$TT_{perc} = \frac{SAT_{ly} - FC_{ly}}{K_{sat}} \dots\dots\dots \text{Equation 3.16}$$

Where TT_{perc} is the travel time for percolation (hr), SAT_{ly} is the amount of water in the soil layer when completely saturated (mm), FC_{ly} is the water content of the soil layer at field capacity (mm), K_{sat} is the saturated hydraulic conductivity for the layer (mm· h-1).

Lateral flow is water that moves through soil pores laterally in subsurface. In areas with soils having high hydraulic conductivities in surface layers and an impermeable or semi-permeable layer at a shallow depth, rainfall will percolate vertically until it encounters the impermeable layer then the water ponds above the impermeable layer forming a saturated zone of water, i.e., a perched water table (Neitsch et al., 2005). This saturated zone is the source of water for lateral subsurface flow.

A kinematic storage routing technique is utilized to calculate lateral subsurface flow as a function of soil slope, hill slope length, drainable porosity, and excess soil water as given in the following equation (4.20).

$$q_{lat} = 0.024 \left[\frac{2 * SW * k_{sat} * \sin \alpha}{\phi_d * L_{hill}} \right] \dots \dots \dots \text{Equation 3.17}$$

q_{lat} is lateral flow (mm/d), ϕ_d is drainable porosity (mm/mm), L_{hill} is flow length (m), k_{sat} SW is drainable volume of soil water (mm) α is slope (m/m),

Groundwater and Base flow

Groundwater flow system can be classified into three based on depth and proximity to surface drainage features: shallow, intermediate, and regional flow systems (Arnold et al., 1995). However, SWAT partitions groundwater into two aquifer systems: a shallow, unconfined aquifer which contribute return flow to streams within the watershed and a deep, confined aquifer which contributes no return flow to streams inside the watershed (Neitsch et al., 2004). Base flow is permitted to enter the stream only if the amount of water stored in the shallow aquifer exceeds a threshold value specified by the user. The steady state response of groundwater flow to recharge is estimated utilizing Hooghoudt 1940. Properties governing water movement into and out of the aquifers are initialized in the groundwater input file of SWAT.

Base flow isolation uses the stream flow time-series record to obtain the signature of the base flow. Methods of graphical differentiation aim to focus on distinguishing the points where the rising and dropping limbs of the short flow reaction are intersected by base flow. To derive a base flow hydrograph, filtering methods process the whole stream hydrograph. In order to derive a low-frequency base flow signal, recursive digital filters, which are routine methods in signal processing, are widely used to eliminate the high-frequency rapid flow signal. These filters are simple and stable, but the effects are very sensitive to the filter parameter, which needs to be tuned before numerically accurate results can be considered.

The most frequently used method for stream flow separation is the filtering separation method that separates the base flow by processing or filtering technique from the stream flow time series results. Although these strategies have no physical or hydrological basis, they seek to

produce an objective, repeatable and easily automated index that can be connected to the catchment's base flow response (Tesfa, 2015).

The Base Flow Index (BFI) is used as a measure of the base flow characteristics of catchments. It provides a systematic way of assessing the proportion of base flow in the total runoff of a catchment. It indicates the influence of soil and geology on river flows, and is important for low flow studies (Eckhardt, 2005) proposed the general form of a digital filter considering a digital filter parameter and BFI_{max} (maximum value of long-term ratio of base flow to total stream flow).

$$b_t = \frac{(1 - BFI_{max}) \times \alpha + b_{t-1} + (1 - \alpha) \times BFI_{max} \times Q_t}{1 - \alpha \times BFI_{max}} \dots\dots\dots \text{Equation 3.18}$$

Where b_t is the filtered base flow at the t time step; b_{t-1} is the filtered base flow at the t-1 time step; BFI_{max} is the maximum value of long-term ratio of base flow to total stream flow; α is the filter parameter; and Q_t is the total stream flow at the t time step. BFI_{max} is a new variable introduced in the digital filter method by Eckhardt (2005). To reduce the subjective influence of using BFI_{max} on base flow separation, representative BFI_{max} values were estimated for different hydrological and hydrogeological situations by comparing the base flow from conventional separation methods with those of the Eckhardt digital filter method.

3.5.2 Soil erosion and sediment component of SWAT

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

$$\text{Sed} = 11.8 \times (Q_{surf} \times q_{peak} \times \text{area}_{hru})^{0.56} \times K_{usle} \times C_{usle} \times P_{usle} \times LS_{usle} \times \text{CFRG} \dots \text{E.q 3.19}$$

In which, Sed is the sediment yield on a given day (metric tons),

- Q_{surf} is the surface runoff volume(mm/ha),
- q_{peak} is the peak runoff rate(m^3/s),
- area_{hru} is the area of the HRU (ha),
- K_{usle} is the soil erodibility factor,

- C_{usle} is the cover and management factor,
- P_{usle} is the support practice factor,
- LS_{usle} is the topographic factor and CFRG is the coarse fragment factor.

MUSLE improves the sediment yield prediction, eliminates the need for delivery ratios, and allows the equation to be applied to individual storm events since rainfall energy factor is replaced with a runoff factor in MUSLE. Sediment yield estimation becomes better because runoff is a function of antecedent moisture condition as well as rainfall energy (Kidane, 2015).

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: -

$$Sed_{deg} = (Conc_{sed,ch,mx} - Conc_{sed,ch,i}) * V_{ch} * K_{ch} * C_{ch} \dots \dots \dots \text{Equation 3.20}$$

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

$$Sed_{dep} = (Conc_{sed,ch,i} - Conc_{sed,ch,mx}) * V_{ch} \dots \dots \dots \text{Equation 3.21}$$

Sed_{deg} is the amount of sediment re-entrained in the reach segment (metric tons),

$Conc_{sed,ch,mx}$ is the amount of initial sediment concentration in the reach (kg/l or ton/m³),

$Conc_{sed,ch,i}$ is the maximum concentration of sediment that can be transported by the water (kg/l or ton/m³).

V_{ch} is the channel erodibility factor (cm/hr./pa),

K_{ch} is the channel cover factor and

C_{ch} is the volume of water in the reach segment (m³),

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:

$$Sed_{ch} = Sed_{ch,i} - Sed_{dep} + Sed_{deg} \dots \dots \dots \text{Equation 3.22}$$

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

$$Sed_{out} = Sed_{ch} * \frac{V_{out}}{V_{ch}} \dots\dots\dots \text{Equation 3.23}$$

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_{dep} is the amount of sediment re-entrained in the reach segment (metric tons), Sed_{deg} is the amount of sediment deposited in the reach (metric tons). Sed_{out} is the amount of sediment transported out of the reach (metric tons), V_{out} is the volume of outflow during the time step (m³) and V_{ch} is the volume of water in the reach segment (m³).

3.5.3 Watershed and Channel Delineation

The Arc Map interface of ArcGIS 10.1 was used in a project for the managing and processing of spatial data used as SWAT input data. Using 30 by 30 resolution DEM data using the Arc SWAT model watershed delineation function, the watershed and sub watershed delineation was conducted. Next the project set up by SWAT was established. The method of watershed delineation consists of five main steps: setup of DEM, stream definition, definition of outlet and inlet, selection of watershed outlets, and definition and calculation of sub-basin parameters. Once the DEM configuration has been completed and the outlet position has been specified at **6 17 '03' N and 36 2 '35' E** on the dam cross-section DEM, the model calculates the flow path and flow accumulation automatically. Subsequently, using the respective methods, stream networks, sub watersheds and topographic parameters were determined. Figure 3.10 shows delineated watershed and sub basins Gibe III

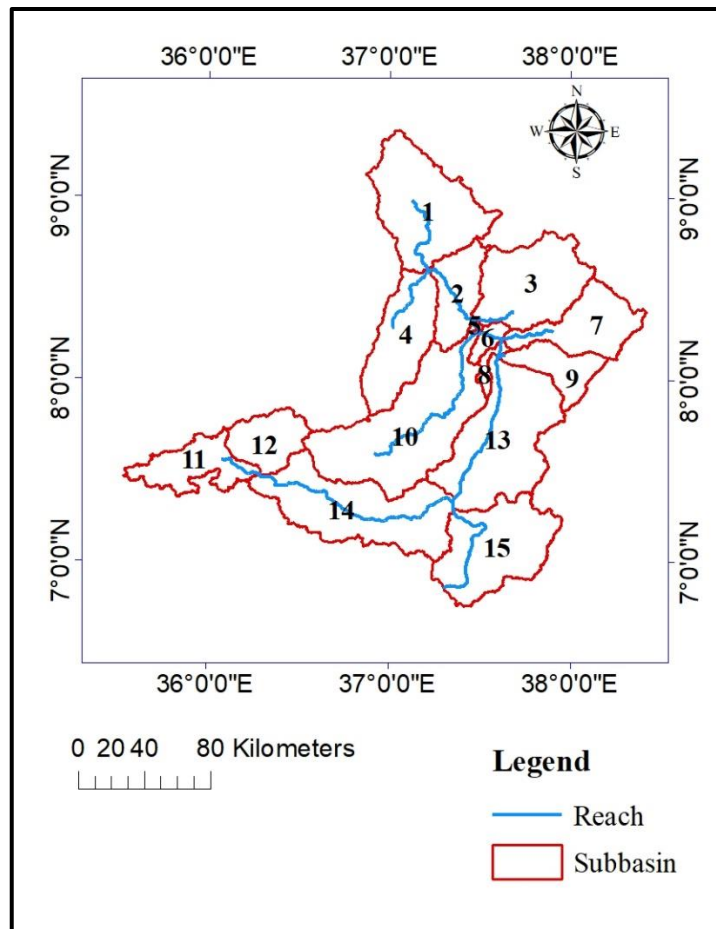


Figure 3-9 Delineated watershed and sub basins of Gibe III

By choosing the threshold area or minimum drainage area needed to shape the origin of the streams, the description of the stream and the size of the sub-basins were carefully determined. The topographic parameters (elevation, slope) of the watershed and its sub-watershed have also been created from the DEM data during the watershed delineation process. Classification of the slope was done on the basis of the DEM height range used during watershed delineation. The watershed slope values have been reclassified by percentage. It has been reclassified into five classes. Figure 3.11 shows slope classification of Gibe III watershed.

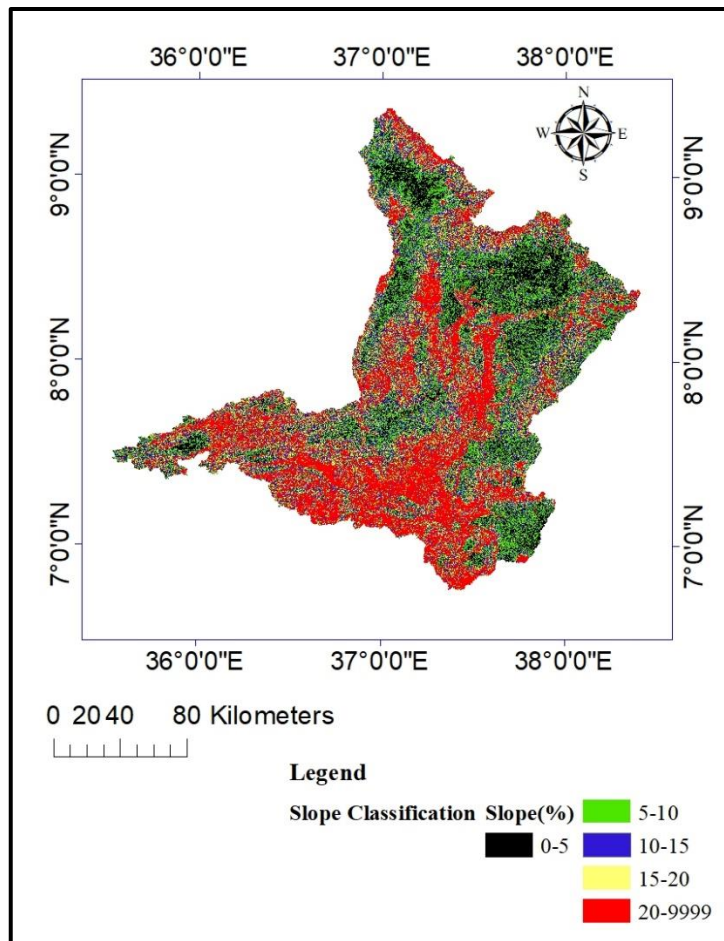


Figure 3-10 Slope class of Gibe III watershed

3.5.4 Hydrologic Response Unit Analysis

Hydrologic Response Units (HRUs) are sub-basin lumped land areas consisting of special combinations of land cover, soil and management. For various land covers and soils, HRUs enable the model to reflect variations in evapotranspiration and other hydrologic conditions. For each HRU, the runoff is independently measured and diverted to produce the overall runoff for the watershed. This boosts flow estimation accuracy and gives a much clearer physical representation of the water balance. To evaluate the area and hydrological parameters of each land-soil category simulated within each sub-watershed, the land use and soil data in a predicted shape file format were loaded into the SWAT interface. Using the look up chart, the land cover groups were established. In order to link the grid values to SWAT land cover/land use groups, a look-up table that defines the 4-letter SWAT code for the various types of land cover/land use was prepared. Calculation of the area occupied by each land use and reclassification is carried out after the land use SWAT code was assigned to all map groups. As for land use by loading the soil look-up table and reclassification applied, the soil layer in

the map was connected to the user soil database information. Also used for slope classification was the DEM data used during the watershed delineation. The soil overlay procedure was conducted during the reclassification of land usage.

The HRU definition was the last step in the HRU analysis. In this analysis, the HRU distribution was calculated by assigning many HRUs to each sub-watershed. A threshold standard has been used in several HRU definitions to exclude small land use, soil or slope groups in each sub-basin. Land use or soil occupying less than the threshold amount, is eliminated. The area of the residual land use or soil, was reassigned during the removal process so that 100 percent of the land area of the sub-basin is modelled. The threshold levels set are a function of the purpose and the amount of information needed for the project. The HRU concept offers a clearer estimate of runoff and sediment components with several choices that account for 20% land use, 10% soil and 20% slope threshold mix. Therefore, the HRU definition with multiple options to account for 20% land use, 10% soil and 20% slope threshold combination was used for this analysis. The justification for taking these threshold values was to keep the HRUs at a fair and achievable amount and also to take into account the necessary time for data processing. These thresholds remove the land use and the soils occupied in the sub-basins by comparatively small fields.

3.6 Weather Generator

There is a lack of complete and credible long-term climate data in Ethiopia. This dilemma is thus overcome by the weather generator by extracting data from the observed one (Danuso, 2002). Using monthly average data over a range of years, the Model needs the regular values of all climate variables from calculated data or produced from values.

In some of the factors, however the weather data collected for the stations in the Gilgel Gibe III watershed has missed records. These missing values were then filled with the weather generator utility from the weather generator parameter values in the Arc SWAT Model. As an input, weather data of the wolita sodo, wolkite and jimma stations with continuous records were used to evaluate the weather generator parameter values. Therefore, the WGN stations.txt weather generator data file was chosen first for the weather generator data description. The rainfall, temperature, relative humidity, solar radiation and wind speed data were subsequently selected and applied to the model.

The SWAT model contain the WXGEN (Shapley and Williams, 1990) weather generator model. In the SWAT model, it is used to produce climate data or fill in missed data using monthly statistics calculated from actual daily data. From the values of weather generator parameters, the weather generator first separately generates precipitation for the day. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated. Lastly, the wind speed is generated independently.

Using the weather parameter calculator WXPARM and dew point temperature calculator Dew02, which were downloaded from the SWAT website, weather parameters were generate the details. By reading the normal values of the Welaita Sodo station variables, the Pcp STAT software measures the monthly daily average and standard deviation, as well as the likelihood of rainy and dry days, the skew coefficient, and the average number of precipitation days in the month. The average daily Dew Point temperature was determined from the daily maximum temperature, daily minimum temperature and average relative humidity using the Dew Point calculator (Dew02). In addition, from the regular available sunshine hour results, daily solar radiation was estimated (Shapley and Williams, 1990).

3.6.1 Statistical parameters calculation for precipitation data

After the precipitation, data was checked for quality and the appropriate station selected the statistical parameters of precipitation data must be calculated before model set up. The statistical parameters for precipitation were calculated using the programme.

pcpSTAT.exe: This programme calculates the statistical parameters of daily precipitation data used by the weather generator of the SWAT model (Liersch, 2003).

3.6.2 Statistical parameters calculation for temperature data

The temperature data record was available from one weather station: welita sodo, the daily maximum and minimum air temperature was available with some missing data. The missing data was filled by filling -99.

Dew02.exe: is used to calculate the dew point temperature using minimum and maximum daily temperature and the average daily humidity. The data must be an ASCII text file format with three columns. The first column stores the maximum daily temperature data the second column the minimum temperature data and the third column the average daily humidity data is used to generate maximum and minimum temperature and relative humidity and dewpoint.

3.7 Sensitivity Analysis

The conditions of SWAT input parameters are process-based and must be kept within a reasonable spectrum of uncertainty. The identification of the most sensitive parameters for a given watershed or sub-watershed is the first step in the calibration and validation process in SWAT (Abbaspour, 2014). For the efficient use of these models, methods to reduce the number of parameters through sensitivity analysis are therefore necessary (Van Griensven, 2006).

Sensitivity analysis is the method of determining the model parameters that have the largest effect on the calibration of the model or the predictions of the model. The sensitivity of the model is defined as the change in model output per parameter input change (Abbaspour, 2014). A sensitivity analysis of parameters gives insights into the parameters, because of input uncertainty, contribute much to the output variance (Holvoet et.al., 2005). A parameter is then called sensitive if the change in that parameter induces a significant change in the performance of the model. In general, an essential goal of parameter sensitivity analysis is to allow the number of parameters to be calculated to be decreased, thus reducing the computational time needed for the calibration of the model. Algorithmic methods for sensitivity analysis are given in the latest iteration of the SWAT model, SWAT2012. When using SUFI2 (Sequential Uncertainty Fitting version 2), two types of sensitivity analysis are allowed. Global Exposure and Study of Sensitivity One-at-a-time (Van Griensven, 2006).

The two above methods of sensitivity analysis can produce different results, since one parameter's sensitivity depends on the value of other associated parameters. Global sensitivity analysis was conducted in this study and the rating of the parameters was compared. In order to allow a rigorous analysis, the principle of the Latin-Hypercube Simulation is based on the Monte Carlo Simulation, but uses a stratified sampling technique that enables efficient calculation of performance statistics, whereas the One-Factor-At-a-Time is an integration of a local to a global form of sensitivity (Van Griensven, 2006). In local methods, only one parameter is modified with each run. Sensitivity analysis is therefore useful not only for model growth, but also for model validation and uncertainty reduction as an instrument for evaluating the input parameters with regard to their effect on model performance (Lenhart et.al., 2002).

3.7.1 Local (one-at-a-time) sensitivity Analysis

Only by holding the value of other parameters stable is the one-at-a-time (OAT) sensitivity analysis was carried out with one parameter at a time. Study of OAT sensitivity reveals a

variable's sensitivity to changes in a parameter while all other parameters are kept constant at a fair value. The value of parameters from the best simulation (simulation with the best objective function value) of the last iteration can be this constant value. The downside of the OAT sensitivity analysis is that other parameters that are fixed are never considered to have the right value (Abbaspour, 2013). Sum of the squares of the difference of the calculated and simulated values after ranking (SSQR) was the objective function used in this project for ranking of the parameters based on OAT sensitivity analysis. The goal of the SSQR approach is to match the frequency distributions of the series observed and the series simulated (Abbaspour, 2013).

3.7.2 Global sensitivity analysis

Global sensitivity analysis performs the sensitivity of one parameter while the value of other related parameters is also changing. Global sensitivity analysis uses t-test and p-values to determine the sensitivity of each parameter. The t-stat provides a measure of the sensitivity (larger in absolute values are more sensitive) and the p-values determine the significance of the sensitivity. A p-value close to zero has more significance. This type of sensitivity can be performed after iteration. The main problem related to global sensitivity analysis is that it needs a large number of simulations (Abbaspour, 2013).

3.8 Model Calibration and Validation

Model calibration will be carried out by carefully choosing values for model input parameters (within their respective ranges of uncertainty) by matching model predictions (output) with observable results for the same conditions for a given set of assumed conditions (Arnold, 2012). This implies applying the calibrated model to replicate the response for a time other than the calibration period, without modifying the parameter values that were set during the calibration (Refsgaard, 1996, 1997). There are three types of methods of calibration (Refsgaard, 1996, 1997): the manual process of trial and error, the method of optimization of automated or numerical parameters, and a mixture of both methods. In this study, using SWAT CUP tools, the model calibration and validation process is carried out. The SWAT Calibration and uncertainty Program (SWAT-CUP) is a software program that provides SWAT models with calibration, validation and sensitivity analysis. It contains many techniques that can be selected for calibration and uncertainty analysis purposes, such as SUFI2, PSO, GLUE, ParaSol, and MCMC (Abbaspour et al., 2007). Manual adjustment for the values of parameters that were

physically inaccurate helped the auto-calibration process. The parameter values that are given during calibration by SWAT-CUP software as the best parameter value may not be physically accurate or may be beyond the recommended uncertainty range and need to be manually changed to better balance the current situation. Using SUFI2 (Sequential Uncertainty Fitting Version 2 program) in SWAT CUP, the model calibration and validation process was performed. SWAT CUP is a computer software for automated SWAT model calibration. The software ties the procedures for SUFI2 to SWAT. The parameters should be adjusted manually before the effects of the model simulation are appropriate as per the output measurements of the model. (Refsgaard, 1996, 1997) argued that the manual approach is preferred for the use of more complex models in which a good graphical representation is a requirement (Refsgaard, 1996, 1997). A two-step calibration technique has been proposed in sediment transport modeling (Neitsch, 2011). First check the contribution of water balance, then calibrate the stream flow and then calibrate the sediment. Next, the final parameter values can be used for the initial values for the auto-calibrations for the stream flow and sediment load in SWAT. Model validation is the final step for the components of interest (stream flow, sediment yield, and water quality).

Model validation is the method of proving that a given site-specific model is capable of producing predictions that are reasonably precise. This implies applying the calibrated model to replicate the response for a time other than the calibration period, without modifying the parameter values that were set during the calibration (Refsgaard, 1997).

The programs indicate that the parameters of the SWAT model can be edited using SUFI2 or other programs in the SWAT model for each iteration. It is important to upgrade the SWAT model with a new set of parameters and then run the SWAT model. The new SWAT performance must be used for the next version, and so forth, after the model has been run using the new set of parameters.

3.9 Model Performance Evaluation

For the evaluation of the calibration (and validation) performance of the model, two statistical parameters namely R^2 = the squared correlation coefficient between the observed and simulated output and NS = the Nash-Sutcliffe efficiency parameter, are evaluated. Values of $R^2 > 0.6$ and $NS > 0.5$ for the calibration of the daily and monthly simulated stream flow are usually considered as adequate for an acceptable calibration (Santhi et. al., 2001).

1. Coefficient of determination (R²) is calculated as

The range of values of coefficient of determination between observed discharge (Q_m) and simulation discharge (Q_s) is 1.0 (best) to 0.0 (worst). This coefficient measures the fraction of the variation in the measured data that is replicated in the simulated model results. A value of 0.0 for R means that none of the variance in the measured data is replicated by the model predictions. On the other hand, a value of 1.0 indicates that all of the variance in the measured data is replicated by the model predictions.

$$R^2 = \frac{(\sum_{i=1}^n (Q_{m,i} - \bar{Q}_m) \times (Q_{s,i} - \bar{Q}_s))^2}{\sqrt{\sum_{i=1}^n (Q_{m,i} - \bar{Q}_m)^2} * \sqrt{\sum_{i=1}^n (Q_{s,i} - \bar{Q}_s)^2}} \dots \dots \dots \text{Equation 3.24}$$

2. NS: Nash-Sutcliffe (1970) coefficient calculated as

The statistical index of modelling efficiency (NS) values ranges from 1.0 (best) to negative infinity. NS is a more tough test of performance than R² and is never larger than R². NS measures how well the simulated (Q_s) results predict the measured data (Q_m) relative to simply predicting the quantity of interest by using the average of the measured data over the period. A value of 0.0 for NS means that the model predictions are just as accurate as using the measured data average (\bar{Q}_m) to predict the measured data. NS values less than 0.0 indicate the measured data average is a better predictor of the measured data than the model predictions while a value greater than 0.0 indicates the model is a better predictor of the measured data than the measured data average. This measure is highly affected by a few extreme errors and can be biased if a wide range of flow events is experienced.

$$NS = 1 - \frac{\sum_{i=1}^n (Q_m - Q_{si})^2}{\sum (Q_m - \bar{Q}_m)^2} \dots \dots \dots \text{Equation 3.25}$$

3.10 Conceptual Frame Work of the study

It is important to consider the conceptual frame work of each step-in order to understand how each segment operates within the modelling process, as well as what data is used and how it is implemented into Arc SWAT. The key steps used for SWAT model simulation and calibration and validation of SWAT CUP are therefore seen below.

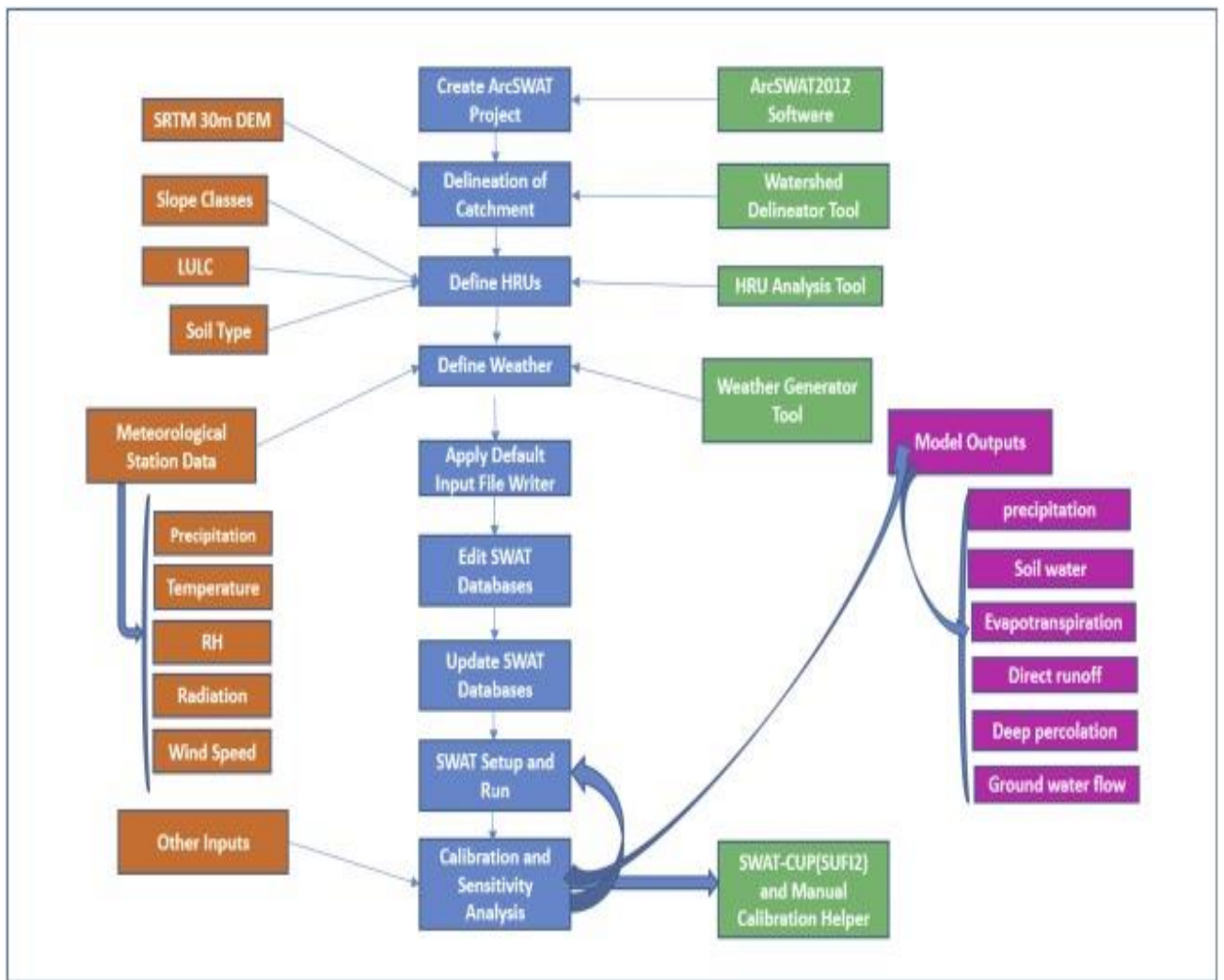


Figure3-11 Steps on SWAT model Simulation

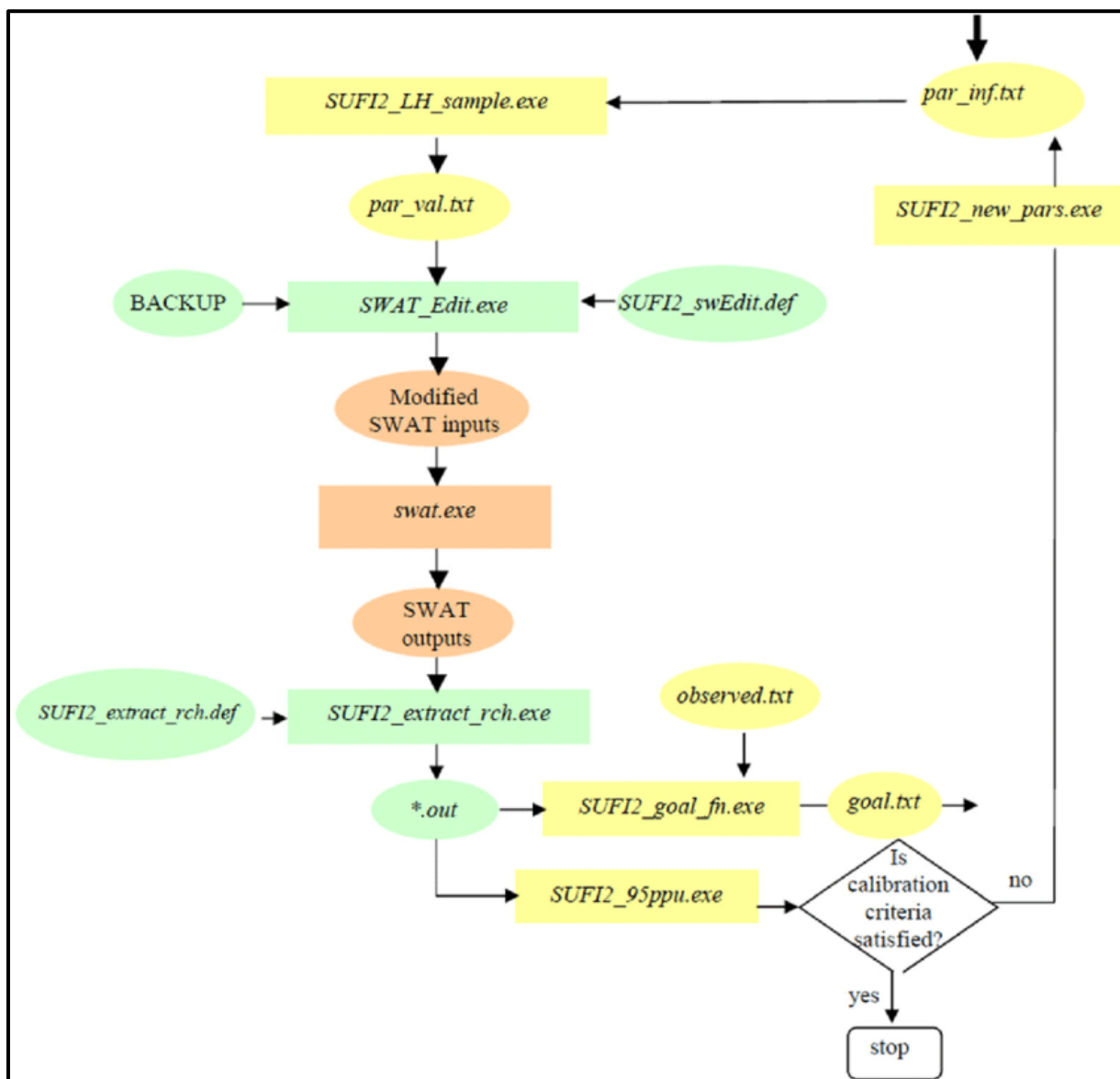


Figure 3-12 Schematic of linkage between SWAT, SWAT-CUP (SUFI-2) Optimization program

4.RESULTS AND DISCUSSIONS

4.1 Land Cover Classification

Before beginning a study of land use and land cover change, it is normally necessary to construct and define homogenous land use and land cover units. These must be distinguished utilizing the available data sources, such as remote sensing, as well as any other pertinent information and prior local knowledge. For these study, land use/cover of 2009 and 2019 were used for analysis of impact of land use/cover change through the consecutive periods. Hence, based on spatial data and additional information from previous research in the study area, five different types of land use and land cover have been identified for the Gibe III catchment. The descriptions of these land use and land covers are given as follows:

Cultivated land: Areas used for crop cultivation, both annuals and perennials, and the scattered rural settlement that are closely associated with the cultivated fields. Due to the difficulty encountered to identifying the dispersed rural settlements this kind of land cover was combined with the cultivated land during classification.

Forest land: Land covered with dense trees which includes ever green forest land, mixed forest and plantation forests.

Shrub land: Areas with shrubs, bushes and small trees, with little wood, mixed with some grasses.

Grass land: Areas covered with grass used for grazing, as well as bare lands that have little grass or no grass cover. It also includes other small seized plant species.

Wood land: Land covered with low-dense trees.

Table 4-1 2009 Land use Classification

LULC Classification	SWAT Code	Area(ha)	Area Coverage (%)
Plantation and farrow	AGRC	12,149.00	0.36
Wetland	WETF	40,111.65	1.18
Residential	URML	21,534.90	0.63
Forest	FRSE	380,357.67	11.19
Cultivation	AGRL	1,931,750.24	56.81
Water body	WATR	4,859.16	0.14
Grassland	RNGE	280,141.17	8.24
Shrub land	RRGB	190,317.74	5.6
Bare land	BARR	1,660.06	0.05
Woodland	FRSD	537,258.26	15.8
Total		3,400,139.85	100

Table 4-2: 2019 Land use Classification

LULC Classification	SWAT Code	Area(ha)	Area Coverage (%)
Plantation and farrow	AGRC	12,118.09	0.36
Residential	URML	49,634.33	1.46
Grassland	RNGE	156,245.58	4.6
Forest	FRSE	347,423.01	10.2
Water body	WATR	13,380.87	0.39
Bare land	BARR	2,654.46	0.08
Wetland	WETF	6,655.95	0.2

Cultivation	AGRL	2,168,598.63	63.78
Shrub land	RNGB	118,170.49	3.48
Woodland	FRSD	525,258.45	15.45
Total		3,400,139.85	100

Table 4-3 Summary of Land use change 2009 and 2019

No.	LULC Classification	Years		Land use change detection
		2009	2019	(2009-2019)
1	Plantation and farrow	0.36	0.36	-
2	Residential	0.63	1.46	0.83
3	Grassland	8.34	4.6	-3.74
4	Forest	11.19	10.2	-0.99
5	Water body	0.14	0.39	0.25
6	Bare land	0.05	0.08	0.03
7	Wetland	1.18	0.2	-0.98
8	Cultivation	56.81	63.78	6.97
9	Shrub land	5.6	3.48	-2.12
10	Woodland	15.8	15.45	-0.35

4.2 Stream flow Modeling

4.2.1 Stream flow sensitivity analysis

Before model calibration, a sensitivity analysis was performed to identify SWAT factors that have a substantial impact on certain model outputs such as stream flow and sediment yield. Because land use change affects the sensitivity of flow parameters, a stream flow sensitivity analysis was conducted independently for the two LULC reference times (2009 and 2019). A total of 27 flow parameters were subjected to sensitivity analysis for all reference land uses. Hence, analysis was done with 324 iterations (27 flow parameter * 12 iteration per parameter) for a period ten years (2003 to 2012) for 2009 LULC and eight years (2013-2020) for 2019 LULC. Sensitivity analysis was carried out at sub basin 15 which was the outlet of the Gibe III watershed. The results of sensitive flow parameters for SWAT application in Gibe watershed are described in Table 4.4 below for 2009 LULC. Depending on the sensitivity index eight flow parameters which their index value ranges from medium to high for 2009 LULC was selected for calibration. Initial SCS CN2 value, Soil evaporation compensation and Threshold depth of water in the shallow aquifer required for return flow to occur were the most sensitive of all, the most top three sensitive flow parameters were the same for both 2009 and 2019 LULC. For the two-reference land use, the change in sensitivity of flow parameters occurs for those parameters with a sensitivity index in the medium sensitivity class. The amount of flow from the catchment is calculated using these flow parameters. Because the amount of runoff that joins the stream flow is mostly determined by the properties of the soil infiltration capacity, flow was shown to be the most sensitive to soil properties. Runoff will be low if the soil's infiltration capacity is high.

Similar study done at Gilgel-Abbay watershed, Lake Tana basin by Asmamaw (2013) Alpha_BF, CN2, ESCO, CH_N2 (Manning roughness coefficient) and CH_k2 (effective hydraulic conductivity of main canal) are most top sensitive parameter for flow. Another similar study done at Gojeb watershed, Omo Gibe basin by Mesganaw (2017) Alpha_BF, Gwqmn and CN2 are most top sensitive parameter for flow. Table 4.5 shows the default value of parameters and rank of sensitivity of 2009 LULC.

Table 4-4 flow parameter sensitivity analysis result for 2009 LULC

SWAT Code	Flow Parameter Description	Default Values	Rank	Sensitivity Class
CN2	Initial SCS curve number	Default*	1	High
Esco	Soil evaporation compensation factor	0.95	2	High
Gwqmn	Threshold depth of water in the shallow aquifer required for return flow to occur	0	3	High
Sol_Z	Plant uptake compensation factor	Default*	4	Medium
Revapmn	Threshold depth of water in the shallow aquifer for revap to occur	1	5	Medium
Sol_Awc	Available water capacity of soil layer (m/m)	Default*	6	Medium
Canmx	Maximum canopy storage	0	7	Medium
Alpha_Bf	Alpha base flow factor	0.0048	8	Medium

4.2.2 Stream flow calibration

The model's performance was evaluated at each stage of the simulation, with the parameters printed out at each stage. Before starting the calibration process, the model's performance was assessed using the model's default parameter values in the initial simulation. Since the default SWAT simulation resulted in a difference between measured data and simulated outputs, automatic calibration was performed with swat cup 5.1.6.2. The model allows for automatic calibration by altering the parameters repeatedly up to 300 times, however the greatest fit was found at 38 simulation numbers. At the end of automatic model calibration, the model performance test was taken and the following result was obtained. The coefficient of determination (R^2) of 0.71 & 0.74, Nash Sutcliffe Coefficient (NSE) 0.63, 0.60 and percent of bias (PBIAS) of -44 and -32 for 2009 and 2019 LULCs respectively. But all the SWAT model

performance indicators were out of the recommended acceptable range. This shows still there was the need of further adjusting the parameter values by varying iteratively in their allowable range until satisfactory agreement between measured and simulated stream flow was obtained. At this stage the manual calibration was used by taking the characteristics of one parameter and their respective allowable range in to consideration. The periods 2006-2011 and 2015-2017 were used for stream flow calibration of 2009 LULC and 2019 LULC respectively.

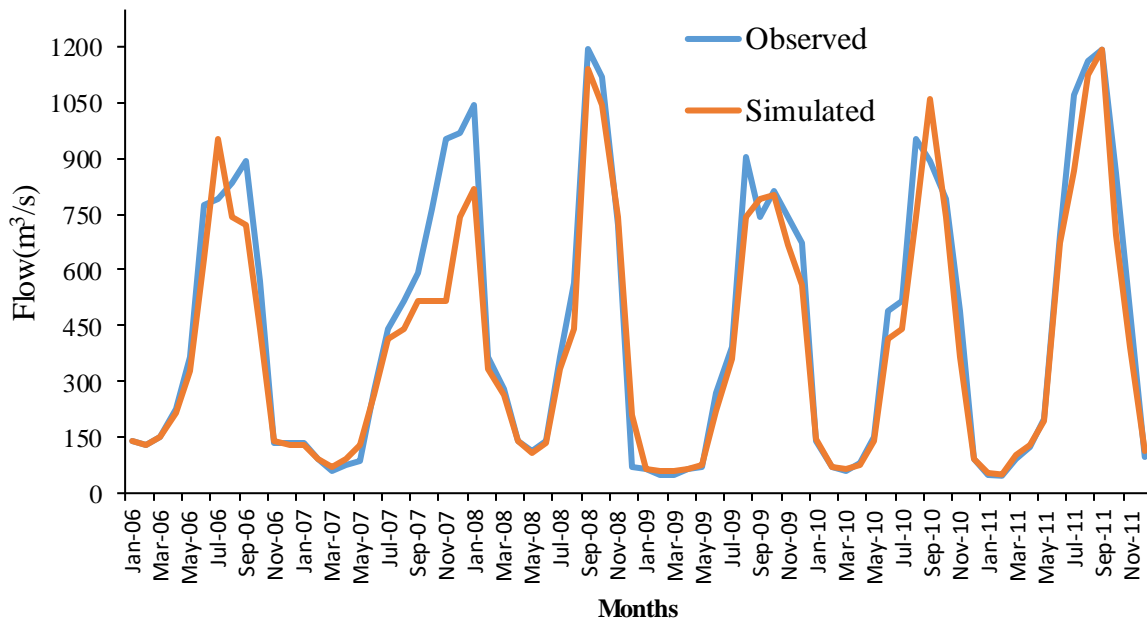
These periods were selected for model calibration because both the meteorological and stream flow records were consistent and they presented both low and high flow conditions comparatively. These periods were thus suitable for training the model to efficiently depict the hydrological processes in the watershed. The parameter ranges were automatically changed based on the correlation between the simulated and observed stream flow, ensuring enough parameter space and fast convergence. The final results of the calibration were acquired by multiplying, adding, or subtracting the default values by the necessary factor led by the manual calibration helper after they had been automatically calibrated.

Table 4-5 Calibration value of stream flow parameters of 2009 and 2019 LULC

SWAT Code	Flow Parameter Description	Range	Default Values	Calibration Values	
				2009 LULC	2019 LULC
				CN2	Initial SCS curve number
Esco	Soil evaporation compensation factor	0-1	0.95	0.95	0.95
Gwqmn	Threshold depth of water in the shallow aquifer required for return flow to occur	0-5000	0	450	500
Sol_Z	Plant uptake compensation factor	±25%	Default*	4.4%	3.9%

Revapmn	Threshold depth of water in the shallow aquifer for revap to occur	0-500	1	235	255
Sol_Awc	Available water capacity of soil layer (m/m)	±25%	Default*	+18%	+14%
Canmx	Maximum canopy storage	0-1	0	0.72	0.75
Alpha_Bf	Alpha base flow factor	0-1	0.0048	0.05	0.51

Even though the calibration for the stream flow was first done for the mean annual condition but the model goodness fit was evaluated on the monthly basis to test the performance of the model. The result of the model test shows that R^2 , NSE, PBIAS of 0.72, 0.81 and -4.3% respectively for 2009 LULC as shown Table 4.11, which satisfy the objective function. Figure 4.1 shows Monthly Stream flow Calibration for 2009LULC and 2019LULC



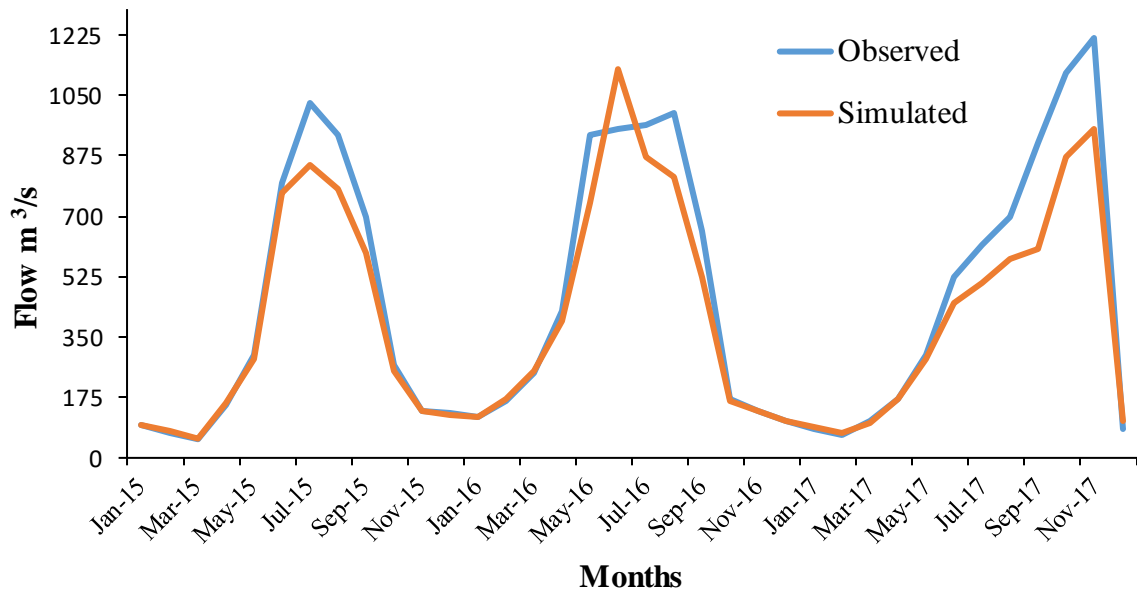


Figure 4-1 Monthly Calibration result of observed and simulated stream flow for 2009LULC and 2019LULC

4.2.3 Stream flow validation

Calibrated parameters were used to check the model capability of reproducing simulated results related to the measured value of stream flow. Validation of the model was carried out using an independent set of measured flow data without further adjustment of the calibrated flow parameter. During the validation period (2012-2014) and (2018-2019) for 2009 LULC and 2019LULC respectively, the performance of the model was evaluated using performance indicators. For 2009 LULC the model shows good performance with 0.81, 0.85% and -5.5% of R^2 , NSE and PBIAS values. The model underestimate peak flow periods but still it was in the recommended range. Figure 4.2 shows Stream flow validation for 2009LULC and 2019LULC.

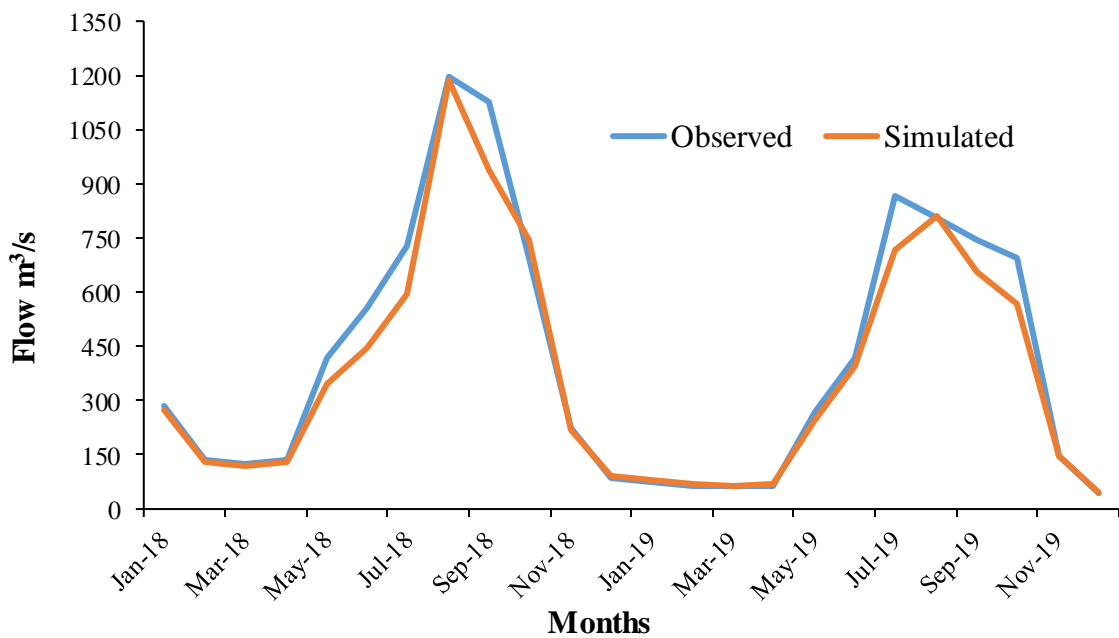
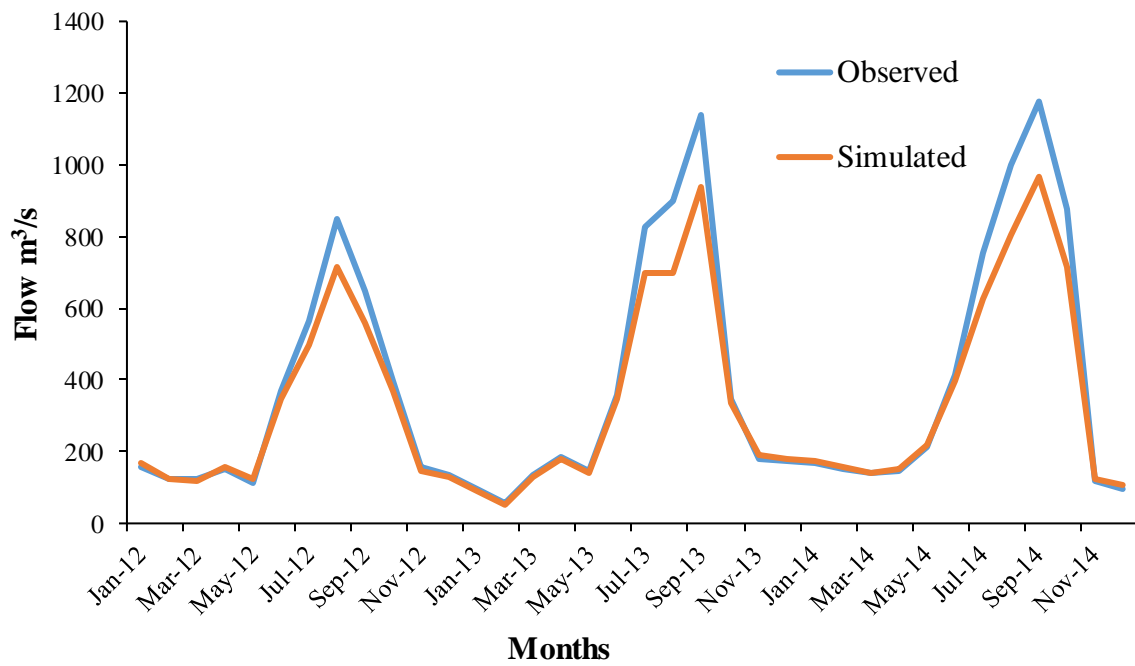


Figure 4-2 Monthly validation result of observed and simulated stream flow for 2009LULC and 2019LULC

Depending on the model performance indicators, correlation coefficient (R^2), Nash-Sutcliffe simulation efficiency (NSE) and percent of bias (PBIAS) summarized in the Table 4.7 below, reasonable stream flow results of the model simulation provide confidence for the further application of the model to assess stream flow hydrologic response analysis .

Table 4-6. Performance evaluation of calibrated and validated stream flow

Performance Evaluation	2009LULC		2019LULC	
	Calibration (2006-2011)	Validation (2012-2014)	Calibration (2015-2017)	Validation (2018-2019)
R^2	0.72	0.81	0.83	0.85
NS	0.81	0.85	0.79	0.81
PBIAS (%)	-4.3	-5.5	-3.43	1.68

4.2.4 Evaluation of stream flow due to land use land cover change

According to Land use land cover changes detection of the two different years satellite image results showed an effect on stream flow of the watershed. The calibrated and validated results of simulated annual average stream flow for the 2009 and 2019 land use are presented in table 4.7. The results have shown that there is an increase of stream flow in both of the calibration and validation periods.

Table 4-7 Mean annual stream flow results for the calibration and validation period

Year	2009 LULC	2019 LULC	Stream flow change detection
			2009-2019
Calibration	436.4	441.1	4.7
Validation	438.1	445.3	7.2

Generally speaking, stream flows has increased throughout the study period with a magnitude of 4.7 m^3/s . The increase of cultivated land use/cover decrease the amount of water which infiltrate to the soil. Therefore, the amount of runoff which join the stream flow will increase.

4.3 Sediment yield Modeling

4.3.1. Sediment yield sensitivity analysis

Sensitivity analysis for sediment yield was carried out for 2009 LULC and 2019 LULC separately like stream flow sensitivity analysis. Model sediment parameter analysis for study watershed was done at the outlet sub basin (sub basin 15) through 240 iterations (12 parameters * 20 iteration per parameter) for each LULC maps.

Table 4-8 Sensitivity analysis result for sediment parameters of 2009 LULC

SWAT Code	Sediment Parameters	Default values	Rank	Sensitivity
USLE_P	USLE support practice factor	1	1	High
Spcon	Linear factor for channel sediment	0.001	2	High
Spexp	Exponential factor for sediment routing	1.75	3	High
SOL_K	Soil Conductivity (mm/hr.)	0.1	4	Medium
USLE_C	USLE cover factor	0.003	5	Medium
Ch_erod	Channel erodibility factor	0.23	6	Low

From the above Tables six parameters for 2009 LULC were selected according their sensitivity index which their class of sensitivity ranges from high to low class for calibration. Table 4.9 indicates that USLE_P, Spexp and Spcon are more sensitive than other parameters (Channel erodibility factor, USLE cover factor and Soil conductivity (mm/hr)).

4.3.2. Sediment yield calibration

Because soil, hydrologic, and hydraulic parameters such as soil erodibility, surface runoff, stream discharge, and stream flow velocity are the main determinant of sediment outflow from each HRU and sub basin, SWAT cup calibration and validation for monthly sediment yield were conducted after the model was calibrated and validated for stream flow. As a result, prior to sediment calibration, the watershed's stream flow must be calibrated (Holvoet, 2004). Like

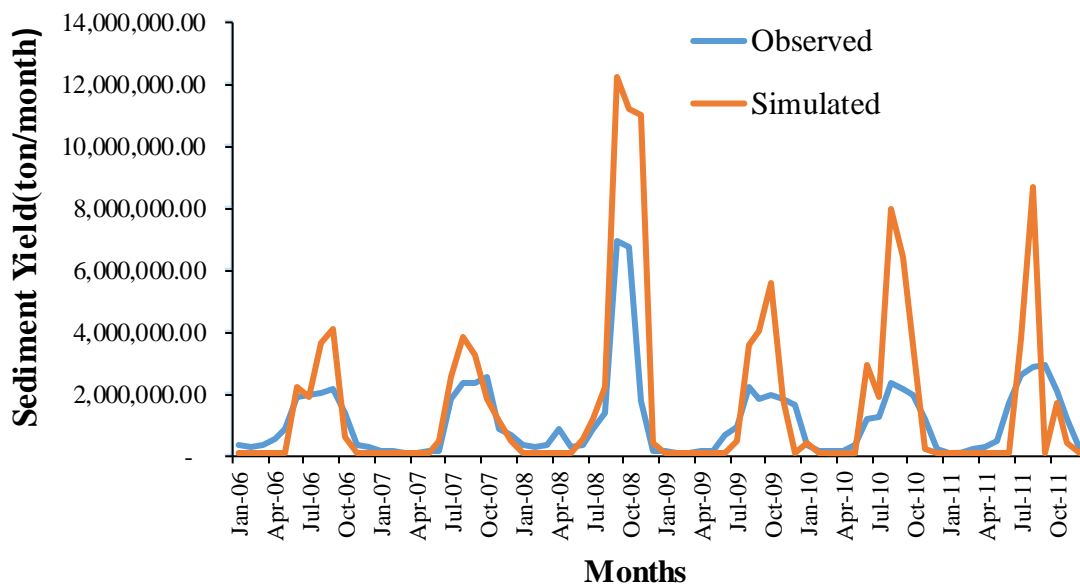
stream flow calibration, the model was also calibrated for sediment yield from 2006 to 2011 for 2009 LULC. The sediment calibration was done with automatic calibration and followed by manual calibration in monthly time setup based on the sensitive sediment parameters identified after sediment sensitivity analysis. The following final sediment parameter values (Table 4.9) were accepted after respective modification and adjustment of the default/initial values. The linear parameter for calculating the maximum amount of sediment that can be re-entered during sediment routing (Spcon) were adjusted to 0.03 for 2009 LULC. SWAT calculates the actual C factor based on the amount of soil cover and minimum C factor defined for the plan/land cover. The minimum C factor quantifies the maximum decrease in erosion possible for the plan/land cover. Because of the USLE C factor is influenced by management, this variable has to be adjusted by the user to reflect management conditions in watershed of interest. Accordingly, USLE_C factor was modified to 0.28 for 2009 LULC.

Table 4-9 Calibration value of sediment parameter of 2009 and 2019 LULC

SWAT Code	Sediment Parameters	Range	Default values	Calibration Values	
				2009 LULC	2019 LULC
USLE_P	USLE support practice factor	0-1	1	0.65	0.56
Spcon	Linear factor for channel sediment	0.0001-0.01	0.001	0.03	0.022
Spexp	Exponential factor for sediment routing	1.0-2.0	1.75	1.56	1.53
SOL_K	Soil Conductivity (mm/hr.)	0-1	0.1	0.21	0.2
USLE_C	USLE cover factor	0.001-0.5	0.003	0.28	0.24
Ch_erod	Channel erodibility factor	0-1	0.23	0.015	0.021

Calibrated parameter values of sediment parameters model performance indicators (R^2 , NSE and PBIAS) were used for evaluating of model prediction efficiency. Accordingly, coefficient of determination (R^2), Nash – Sutcliffe coefficient (NSE) and percent of bias were 0.77, 0.56 and -16.3% respectively for 2009 LULC. All values of the Statistical indicators are above the lower acceptable limit. This shows the model performs well in sediment calibration. Hence the objective function was obtained.

Monthly time setup of sediment yield hydrograph was developed to compare the observed and simulated sediment load values for calibration period (2006-2011) for 2009 LULC and (2015-2017) for 2019 LULC respectively. Figure 4.3 shows monthly Calibration result of simulated and observed sediment yield for 2009 LULC and 2019 LULC.



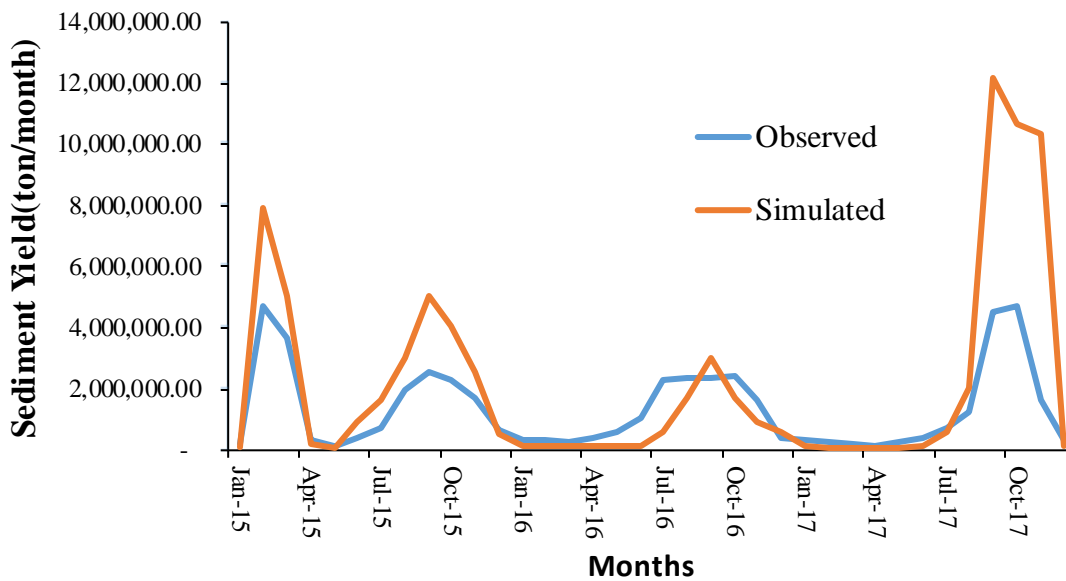


Figure 4-3 Monthly Calibration result observed and simulated sediment yield for 2009 LULC and 2019 LULC

4.3.3. Sediment yield validation

The sediment yield hydrograph of calibration period was validated using independent data set of observed sediment yield without adjusting calibrated sediment parameters for each land use and land cover reference years. Like the calibration period, the sediment yield hydrograph of measured and simulated output in monthly time setup during the validation period (2012-2014) for 2009 LULC and (2018-2019) for 2019 LULC, respectively shows a good agreement for both reference land uses. Figure 4.4 shows monthly Validation of simulated and observed sediment yield for 2009 LULC and 2019 LULC.

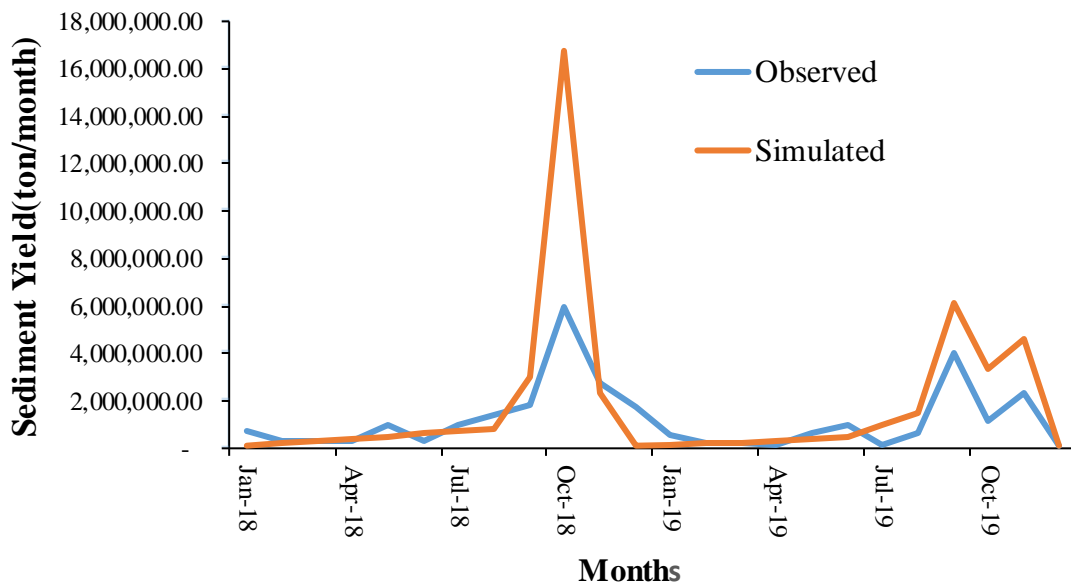
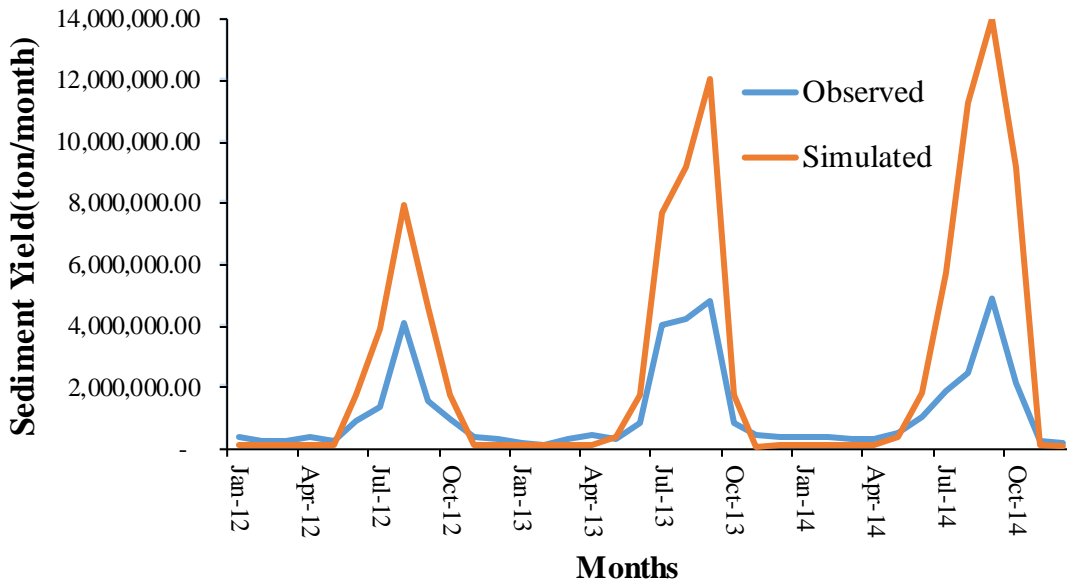


Figure 4-4 Monthly Validation result of observed and simulated sediment yield for 2009 LULC and 2019 LULC.

Depending correlation coefficient (R^2), Nash-Sutcliffe simulation efficiency (ENS) and percent of bias (PBIAS) summarized in the Table 4.11 below, confirms of reasonable monthly sediment yield results of the model simulation (both calibration and validation period) provided confidence that the further application of the model to assess sediment yield hydrologic response analysis due to spatial temporal variability of the watershed.

Table 4-10 Performance evaluation of calibrated and validated sediment yield

Performance Evaluation	2009LULC		2019 LULC	
	Calibration (2006-2011)	Validation (2012-2014)	Calibration (2015-2017)	Validation (2018-2019)
R ²	0.77	0.68	0.63	0.74
NSE	0.56	0.512	0.531	0.60
PBIAS	-16.3	-17.3	-19.4	-6.45

4.3.4 Evaluation of sediment yield due to land use land cover change

The land use cover change on sediment yield of the watershed were evaluated using the validated sediment yield results for the two different land cover changes. The annual sediment yield of Gibe III watershed was increased from year to year due to land use cover changes.

Table 4-11 Calibrated and validated sediment yield (ton/ha/year) results of watershed

Year	Simulated sediment Yield (ton/ha/year)		Sediment change detection (ton/ha/year)
	2009	2019	2009-2019
Calibration	15.78	16.31	0.53
Validation	17.60	18.06	0.46

An increase of cultivated area (2009 – 2019) by 6.97 % resulted in an increase of sediment yield by 0.53 ton/ha/year.

The land use change was an increase of cultivated land throughout the study period, and decrease of Forest, wood and shrub land which in turn caused an increase of sediment yield. This was due to cultivation caused loosening of soil layer sequentially resulting movement of a soil layer easily through water especially during peak flow periods, since sediment transport has a direct relationship with the river discharge.

4.4 Best Management Practices

4.4.1 Prioritization of critical sub-basins for sedimentation management

A few places in a broad watershed may be more critical, causing significant runoff and soil losses. Identification of these important locations is critical for the effective and efficient application of watershed management practices. The Resource considerations for implementation of watershed management programs related to administration or even political considerations may limit the implementation of management programs to a few sub-basins of a watershed only. Hence, it is always better to begin management measures from the most critical sub-basins, which makes it mandatory to prioritize the sub-basins available. In other word, identification of these critical areas is essential for an effective and efficient implementation of watershed management programs.

Watershed prioritization is thus the ranking of different critical sub-basins of a watershed according to the order in which they have to be taken up for treatment and soil conservation measures. Based on sediment yield result the sub basin were classified into 5 class. The critical sub watersheds were identified and prioritized on the basis of average annual sediment yield simulated using the SWAT model from the sub watersheds for the period 2015 to 2019 of the recent land use land cover (2019 LULC). Annual sediment yields were simulated for each sub watershed of the study watershed. 15 sub watersheds were identified during watershed delineation step. Hence, priorities among the 15 sub watersheds were fixed on the basis of ranks assigned to each critical sub watershed according to ranges of sediment yield. The spatial distribution sediment yield in the whole study watershed showed in Figure 4.5 results, 16.31 ton/ha/year of average annual sediment yield from whole catchment of Gibe III watershed.

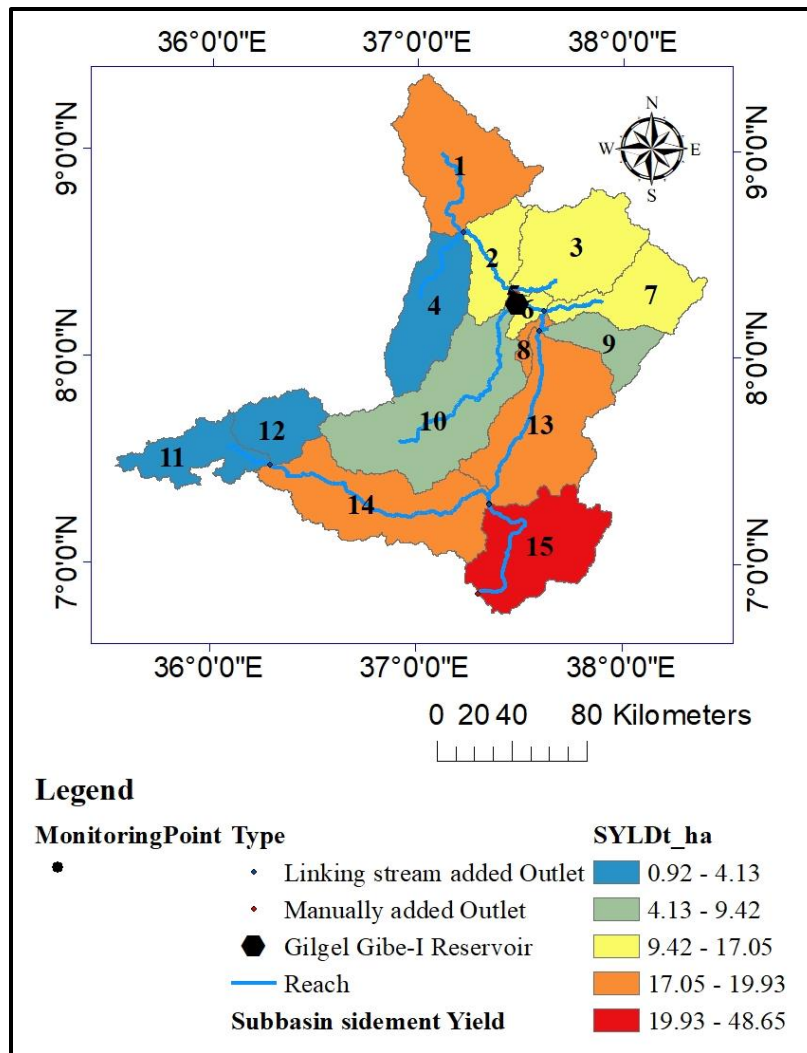


Figure 4-5 Spatial variability of sediment yield (t/ha/yr) in watershed

Table 4-12 Classification of severity of sediment yield

Class	Area(ha)	Area (%)	Sediment Yield (ton/ha/yr.)	Sensitivity
1	534,250.40	15.7126	0.92-4.13	Low
2	631,068.83	18.5601	4.13-9.41	Moderate
3	672,363.94	19.7746	9.41-17.053	High
4	1,231,702.34	36.225	17.93-19.92	Sever
5	330,754.31	9.72767	19.92-48.65	Very Sever

The overall simulation result for 15 sub watersheds of annual sediment yield using 2019 LULC for the period of (2015-209) used for prioritization sub watershed. But ten (10) sub watersheds (Very sever, sever and high) which their annual value ranges above the tolerable limit are prioritized according their sediment yield for watershed management efforts.

4.4.2 Best Sediment management scenario development and analysis

After the model has been validated and the results are considered acceptable, the model is ready to be parameterized to the conditions of interest (e.g., to develop management and conservation option for runoff and sediment yield). Evaluation of the performance of management and conservation practices on a watershed scale can be facilitated by utilizing distributed parameter watershed models that partition the watershed into fields (HRUs) and channel segments for computations. The impact attributed to each individual practice can be simulated and predicted by SWAT model (Dilnesaw, 2006). During this study three different scenarios were developed and compared according to their effectiveness of soil conservation or sediment reduction. Those scenarios were S0, S1, S2 and S3, the details of the management options of each scenario are described below:

1. In Scenario 1, when the watershed existing conditions is considered.
2. In Scenario 2, when different width of filter strips was placed on all agricultural HRUs that are the combination of dry land cropland, all soil types and slope classes since the effect of the filter strip is to filter the runoff and trap the sediment in a given plot (Bracmort et al, 2006). Thus, for this study 5 m wide filter strip was used.
3. In Scenario 3, when parallel terraces with different slope length and stone bunds were placed on agricultural HRUs that are the combination of dry land cropland, all soil types and slope classes. Thus, for this study 75% reduction of slope length was used.
4. In Scenario 4, Reforestation

Table 4-13: Scenario’s description and SWAT parameters used to represent BMPs

Scenarios	Description	SWAT Parameters used			
		Parameter name	Input file	Calibration Value	Modified Value
S0	Base case	-	-	-	-
S1	Filter Strip	FILTERW (.hru)	5m	0	5m
			Slope (0-5%)	91	23m
S1	Parallel Terrace/Stone bund(75% SL Reduction)	SLSUBBSN (.hru)	Slope (5-10%)	61	15m
			Slope (10-20%)	24	9.1m
			Slope (>20%)	9.1	9.1m
			CN2(.mgt)	Default*	**Average
		USLE_P(.mgt)		0.8	0.4
S3	Reforestation			*	*

Scenario 1: Current/Baseline Condition

A baseline scenario, which was assumed to reflect current conditions, was initially executed prior to performing the scenario simulations. Each scenario was then run for the same simulation period, except with modified management inputs, to provide a consistent basis for comparison of the scenario impacts. After calibration was completed for flow and sediment, this simulation was re-run for the 15-year period. This simulation represented the current conditions or is a baseline, which will be used as a point of reference. The baseline scenario corresponds to 2019 LULC management practices without conservation measures or without use of best management practices.

Scenario 2: Introducing different width of filter strips

Filter strips are vegetated regions that connect surface water bodies (such as wetlands, streams, and lakes) to cropland, grazing land, forestland, or disturbed land. They're usually located near where runoff water exits a field, with the goal of filtering sediment, organic matter, nutrients, and pollutants out of the water. Filter strips are sometimes known as buffer strips or vegetative filter strips. Filter strips were placed on all agricultural HRUs that are the combination of dry land cropland, all soil types and slope classes. The filter strip's function is to filter runoff and trap silt in a specific plot (Bracmort et al, 2006). The width of the filter strip is an appropriate model parameter for representing the effect of filter strips (FILTERW). The HRU (.hru) input table was edited to change this value. Based on local research experience in the Ethiopian highlands (Hurni, 1985), the filter width value was assigned (Herweg and Ludi, 1999).

These scenarios were analyzed using an empirical formula with varying width filter strips as a biological soil and water conservation measure and tested as a remedial to slow soil erosion and reduce sediment yields in the Gibe watershed's critical area. Hydrologic response units can be used to define the edge of field filter strips. As the surface runoff flows through the filter strip, the sediment, nutrient, pesticide, and bacterial loads are reduced. The filter strip's sediment, nutrient, and pesticide trapping efficiency is calculated as follows: (Neitsch et al., 2005).

$$\text{Trap ef} = 0.367 * (\text{Width of filtstrip})^{0.2967} \dots \dots \dots \text{Equation 4.1}$$

Where Trap ef is the fraction of the constituent loading trapped by the filter strip, and width filtstrip is the width of the filter strip (m).

In evaluating impact of the use of filter strips, two management scenarios were considered and simulated.

- Base Case (no filter Strip)
- Filter strip 5 m wide on all HRUs in selected sub watersheds; and

As mentioned in above, sub basin with sediment yield exceeding the tolerable soil loss (>9.41 t/ha/y) were considered in this scenario analysis. The selected Sub watershed included 1,2,3,5,6,7,8,13,14 and 15.

Table 4-14 Mean annual change in sediment yield due to implementation of vegetation (filter strips) of 5 m widths.

Selected Critical Sub basin	Mean Annual Sediment Yield (t/ha/yr.)		Percent Reduction in sediment	
	Filter Strip (5m wide)			
	Base case	Filter Strip	Fraction	percent
1	19.57	7.65	0.61	61.00
2	16.40	8.10	0.51	50.6
3	15.38	6.71	0.56	56.00
5	48.65	19.56	0.6	60.00
6	17.05	8.4	0.52	50.73
7	13.42	6.32	0.52	52.9
8	19.23	7.89	0.58	58.97
13	19.93	8.36	0.58	58.05
14	18.49	7.86	0.57	57.49
15	33.53	14.93	0.55	55.47

With implementation of vegetation strips - an average annual sediment yields were reduced by 50 % to 61% for 5m buffer strip. Thus, an average sediment yield is reduced to 9.53 t/ha/yr. from baseline condition that is 41.56% reduction.

Scenario 3: Parallel Terraces with different Slope Length and Stone Bund

Because there is so much stone in the area, physical conservation structures such as terracing and stone bund measurement are used more frequently, but most of the existing terraces and stone bunds are no longer functional. So, on agricultural HRUs with a mix of dry land cropland,

all soil types, and slope classes, parallel terraces and stone bunds were built. By lowering the slope length, this approach lowers overland flow and soil erosion (Bracmort et al, 2006). Therefore, Slope length and steepness greatly influence both the volume and velocity of surface runoff. Long slopes deliver more runoff to the base of slopes and steep slopes increase runoff velocity. Both conditions enhance the potential for erosion to occur. Naturally, the steeper the slope of a field, the greater the amount of soil loss from erosion by water. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff and sediment yield.

Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased velocity of water which permits a greater degree of scouring (carrying capacity for sediment). Shortening the length of the slope reduces erosion. The shorter the slope length, the less chance there is for runoff to build enough momentum to cause excessive erosion. This measure is one of the most widely used practices to reduce erosion on cropland. With some types of terraces, stone bund more than 95 percent of the detached soil particles remains on the land. In these scenarios it is intended to evaluate the impact of reduction of slope length by 75 % on the reduction of sediment yield. The slope lengths were reduced for HRU with crop field then simulations were done for these scenarios. Also, appropriate parameters for representing the effect of parallel terrace and stone bunds are the Curve Number (CN2), average slope length (SLSUBBSN) and the USLE support practice factor (USLE_P). We modified SLSUBBSN value by editing the HRU (.hru) input table, whereas USLE_P and CN2 values were modified by editing Management (.mgt) input table. The SWAT model assigns the SLSUBBSN parameter value based on the slope classes. In this application, the SWAT assigned SLSUBBSN parameter value based on the slope classes. In this application, the SWAT assigned values were 91 m, 61 m, 24 m and 9.1 m for slope classes 0–5%, 5–10%, 10-20% and over 20%, respectively. Thus, for the reduction of Slope length by 75% the SWAT assigned value were changed to 23 m, 15.25 m, 9.1 m, and 9.1m for the above slope classes. After all the parameter value for the scenario in addition to Curve Number (CN2) and USLE support practice factor (USLE_P) were change and simulated for the period the result shows that annual sediment yield reduction of 32.49% from the baseline condition. As well as the reduction of Slope length by 75% for the selected critical sub basin shows that annual sediment yield of 36% to 64% reduction can be achieved, this is because of the increasing infiltration as a result of reducing slope length. The surface runoff was reduced by

26.56%. This scenario can potentially reduce sediment to 11.01 t/ha/yr., which is 32.49% reduction.

Table 4-15 Mean annual change in sediment yield due to conservation structure by reducing slope length to 75%.

Selected Critical Sub basin	Mean Annual Sediment Yield (t/ha/yr.)		Percent Reduction in sediment
	Base case	75% Reduction in slope length	
1	19.57	9.54	51.20
2	16.40	8.62	47.43
3	15.38	8.67	43.00
5	48.65	27.23	44.00
6	17.05	8.32	51.20
7	13.42	8.55	36.28
8	19.23	7.4	61.51
13	19.93	7.12	64.37
14	18.49	9.45	48.89
15	33.53	20.55	38.71

Scenario 4: Reforestations

Within the Gibe III catchment increase in population and the resulting need for farming, opening up the vegetation for various uses, and other infrastructure need accelerated land degradation. And also, it was observed because of the risk of malaria and Trypanosomiasis

humans and livestock do not inhabit most of the hill-slope of the watershed. Since accelerated soil erosion is caused by the activities of man and is responsible for depleting soil productivity, destroying land and filling reservoirs with sediment. This scenario, simulated the impact of reforestation on soil erosion. The reforestation has a function to reduce overland flow and rainfall erosivity. The reforestation effect was simulated by introducing land use change, not by parameters changes. Thus, we replaced 30% of the area occupied by Grass land, shrub land and cultivated into forest or woodlands. The associated parameters (e.g., plant, hydrological and erosion) for the new land use were changed by the SWAT model from the database. The objectives of this component are to conserve and restore the remnant areas of the woodlands that are scattered on the steep slopes along the valley reservoir which are not used for agricultural production. Through this intervention, the existing woodland resources that are not submerged by the reservoir will be rehabilitated through the active participation of concerned communities. They will be involved in the planning and implementation of the restoration of the woodlands and shrub lands in collaboration with the respective agricultural offices at Wereda levels. Therefore, the implementation of reforestation scenario reduces the sediment yield by 53.77 % from the baseline scenario which is 7.54 t/ha/yr. this scenario was most effective than the other scenario as shown in the table 4.16.

Table 4-16 Mean annual change in sediment yield due to reforestation.

Selected Critical Sub basin	Mean Annual Sediment Yield (t/ha/yr.)		Percent Reduction in sediment
	Base case	Reforestation	Reforestation percent
1	19.57	5.02	74.34
2	16.40	6.67	59.32
3	15.38	6.02	60.85
5	48.65	8.35	82.83
6	17.05	6.93	52.49
7	13.42	6.62	50.67

8	19.23	5.23	72.8
13	19.93	7.4	62.87
14	18.49	5.42	70.69
15	33.53	8.12	75.78

4.4.3. Comparison of the Above BMPs Scenario

The impact of BMPs at the selected critical sub basin level showed a wider spatial variability on sediment reduction from baseline conditions as is shown below in table 4.17. The sediment reductions for selected critical sub basin ranged from 50.6% to 61% under filter strips scenario, 36.28% to 64.37% under conservation structure (parallel terrace and stone bunds) scenario and 50.67% to 82.83% under reforestation scenario. That means, the mean annual sediment was reduced to 9.53 t/ha/yr, 11.01 t/ha/yr, and 7.54 t/ha/yr by using filter strip scenario, conservation structure scenario and reforestation scenario respectively as shown in the table 4.17. Thus, reforestation measure was more effective to reduce sediment than another scenario which is up to 53.57%.

Table 4-17: Mean annual reduced sediment yield of different scenarios

Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2019 LULC mean Annual sediment (ton/ha/yr.)	16.31	9.53	11.01	7.54
Mean Percent reduction from base line condition	-	41.56%	32.49%	53.77%

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

From this study it can be concluded that Gibe III watershed has experienced a significant change in land use/cover over the past 10 years. It is clear to understand that deforestation and increase of agricultural lands was exhibited by rapid increase of human population which changes the whole Gibe III Watershed in general and some sub watersheds in particular. For the last one consecutive decays (2009 – 2019) forest lands and woodland were changed to cultivated lands in a significant amount. The magnitudes of the cultivated land were increased by 6.97% from 2009 – 2019 and the magnitude of Forest and woodland decrease by 0.99% and 0.35 respectively. The changes in land use (increased cultivated land and deceased forest and wood land) have resulted changes in stream flow, increase of surface runoff and decrease lateral and ground water flow. The significant changes of stream were occurred in wet periods than dry periods. The water yield was also increased with an increase of cultivated land. Sediment yield transported through rivers out of the watershed simulated using SWAT, and calibrated manually and automatically using SWAT CUP. Sediment yield was dependent of land use cover changes; hence in Gibe III watershed which has showed a significant land use cover change implied a change to the amount of sediment yield flows out of the watershed. Over 10 years period (2009 – 2019) an increase of cultivated land by 6.97% resulted in an increase of sediment yield by 0.53 t/ha/yr. Generally, sediment yield has showed a direct relationship with cultivated land. The spatial and temporal variability of sediment source areas was identified and mapped using Arc GIS. As a result, sub watersheds of 1,2,3,5,6,7,8,13,14 and 15 were identified as more potential sediment source areas (Very sever, sever and highly erodible). Those sub watersheds indicated that, it requires attention for best management practices in the watershed. The temporal variability of sediment yield at the outlet was done using the calibrated sediment yield; hence the highest number of sediments was occurred during wet months. The simulation results showed that applying filter strips, conservation structure (parallel terrace and stone bunds) and reforestation scenarios reduced the current sediment yields both at the sub basins and the basin outlets. The effectiveness of each BMP, however, depends upon the percentage of land available, and local topographical conditions in the basin. The potential effect of the BMPs could be obtained by implementing reforestation in steep areas, and filter strips and stone bunds in low slope areas of the catchment. BMPs were

designed and their sediment reduction efficiencies on Gibe III Watershed had been compared between them. As the result reforestation (30% of shrub land, grass land and cultivated land to forest land) was more effective means of watershed management in terms of sediment reduction. Filter strips has showed 41.56%, terraces and stone bunds 32.49% and reforestation 53.77% Sediment yield reduction efficiencies. The results indicate that land use change may cause a great deal of sediment yield increase. This is mainly attributed to land degradation (conversion of forest to agricultural land) due to intense human activities, especially deforestation. The Watershed has increased about 236,848 ha agricultural land and decreased about 32,934 ha forest land between 2009 and 2019. According to the model results, it is necessary to prescribe appropriate soil and water conservation practices to control the stream flow and sedimentation problems in this Watershed. The SWAT model is also capable of identifying areas within the basin with high water and sediment yield. This provides a useful guide for formulating policies and developing plans to reduce erosion effects, to optimize land use, and to achieve sustainable land development.

SWAT was estimated the sediment yield from the watershed to the reservoir for 2019 land use/cover maps. Therefore 55.5 M tone annual sediment load was entered to the reservoir during 2019. The reservoir dead load storage is 1040 million tonnes. Then it shows that there increment of sediment yield in 2039 the reservoir full to dead storage. Based on the model output at the HRU level, high erosion areas may be easily identified within the basin. Subsequent land development should avoid such areas because of the need to adequately protect them with appropriate conservation strategies. Human activities deserve more attention when assessing soil and water losses because of their inevitable impacts. How to avoid residents' illegal development activities will be the future important task of Gibe III Watershed. Re-evaluation of the existing laws and regulations, strengthening Watershed inspection, and plans for land use change detection using satellite images minimize deterioration of the invaluable environment condition in this Watershed.

5.2 Recommendations

It is evident that an increase of cultivated land (reduction of forests and wood lands) was a results of population growth. Therefore, there should have practice/adopt an effective family planning throughout the community in order to control exponential growth of the community living within the watershed.

Most of the gauging stations in this catchment are located at upper parts of the watershed which is a challenge for calibration and validation of hydrologic characteristics (stream flow and sediment yield) at the outlet. Therefore, a greater number of meteorological and hydrological stations should have to be installed at the watershed, in order to implement integrated water resource and soil conservation management.

Best Sediment management practices should have to be encouraged for reducing sediment loads that flows to Outlet of Gibe III Reservoir. Moreover, reforestation (5% of shrub lands, grass lands and some parts of agricultural lands mainly at lower parts of the watershed) with other soil conservation measures should have to be implemented for further reduction of sediment. So, land use changes need effective participatory integrated watershed development.

More Watershed intervention or management activities especially on Sub-watersheds 1,5, 8,13,14 and 15) should have to be designed and implement for sustainability of proposed Gibe III Watershed; Gibe III reservoir will be filled within some years since it is located downstream of these critical sub watersheds.

This research work was mainly depending on the secondary data and some primary data collected from different organizations and field survey as its input and simulation of the final result. But the quality and representativeness of these data should be tested with the primary data. Therefore, for further study on sediment yield of this study area, it is recommended that the use of primary data, especially the data related with soil and suspended sediment, will greatly refine the sediment yield modeling.

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7. APPENDICES

Appendix 1: 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 ₂ O)
PCPSTD	Standard Deviation for daily precipitation in month (mm H ₂ O/day)
PCPSKW	Skew Coefficient 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 2: Definition of weather generator parameters

Parameters	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TMPMX	28.36	29.20	29.61	28.84	28.60	26.86	24.88	24.58	25.69	27.38	27.75	28.03
TMPMN	13.42	13.63	13.88	13.49	13.81	13.39	13.67	13.66	13.40	13.22	13.15	13.01
TMPSTMX	1.97	2.18	2.44	2.32	2.24	3.16	3.08	2.49	2.34	1.93	1.91	2.17
TMPSTDMN	1.50	1.53	1.70	3.03	1.52	1.33	1.20	1.03	1.35	1.37	1.52	1.70
PCPMM	27.10	21.67	74.71	104.13	120.49	195.76	280.22	231.35	140.42	51.89	19.56	9.42
PCPSTD	3.03	2.86	5.41	7.22	7.93	8.90	11.11	10.32	7.76	5.42	2.96	2.05
PCPSKW	5.11	5.65	3.67	3.44	3.54	2.22	1.79	2.42	2.73	5.70	7.20	11.96
PR_W(1)	0.11	0.08	0.18	0.27	0.31	0.60	0.55	0.55	0.40	0.12	0.06	0.05
PR_W(2)	0.47	0.57	0.67	0.60	0.63	0.63	0.77	0.68	0.64	0.59	0.70	0.60
PCPD	5.18	4.47	10.65	11.82	14.00	18.41	21.53	20.06	15.88	7.53	4.88	3.82
RAINHHMX	0	0	0	0	0	0	0	0	0	0	0	0
SOLARAV	20.616	20.269	22.159	20.945	21.487	19.440	16.538	18.519	19.165	21.209	22.216	21.253
DEWPT	12.64	13.17	13.72	15.88	17.48	17.04	16.74	16.23	15.2	14.69	12.79	12.21
WINDAV	2.1258	2.1148	2.1002	2.1132	2.1557	1.8378	1.6444	1.4808	1.4426	1.8164	1.9163	2.1123

