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SEDIMENTATION PROBLEM AND MITIGATION MEASURE OF KOGA RESERVOIR



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The School of Civil and Environmental Engineering**

**Presented for Fulfillment of the Replacements for the Degree of Masters of Science
(Civil and Environmental Engineering)**

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CERTIFICATION

I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa Institute of Technology a thesis entitled **Sedimentation Problem and Mitigation Measure of Koga reservoir** in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (major Hydraulic Engineering).

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DEDICATED

I dedicated this thesis to my beloved mother, **Bogalech Haile** and her sister **Demekech Haile**, who poured me to this stage and who are not ... by now. God rest their soul in heaven!

ABSTRACT

Reservoir sedimentation originates from the catchment area and the river system then gradually, settles in reservoir. It is a major problem that endangers the performance and the life of the reservoirs by reducing water holding capacity. Inappropriate use of land, rapid population growth, and poor ecosystem management are the main causes of reservoir sedimentation. Since Koga dam is constructed on the outlet of degraded watershed, measurements of sediment load during the study have confirmed high rate of sedimentation. The aim of this study was to estimate sediment yield inflow in to the reservoir, to investigate the spatial variation of sediment yield and to recommend the appropriate sediment reduction measures. The ArcGIS interface Soil and Water Assessment Tool (ArcSWAT) was used with sediment data from rating curves to model the amount of sediment yield inflow in to Koga reservoir from catchment with an area of 155.75 km², located at the upper Blue Nile Basin, Amhara Region, Ethiopia. Primary data were used to identify the distribution, the grain size variation of sediment load of the reservoir. Secondary data were used as input for SWAT and SWAT CUP. For stream flow calibration, the most sensitive parameters were Base flow alpha factor for bank of storage (ALPHA_BNK.rte); and for sediment calibration, were SPEXP (Exponent parameter for calculating sediment restrained in channel sediment routing). The results indicated that stream flow calibration and validation period indicated that $R^2=0.81$, $NS=0.76$ and $R^2=0.77$, $NS=0.74$ respectively and sediment yield calibration and validation period indicated that $R^2=0.66$, $NS=0.61$ and $R^2=0.76$, $NS=0.70$ respectively. Both the calibration and validation result indicated good agreement between measured and simulated stream flow and sediment yield values. The simulated result shows that the average annual sediment yield is 158 ton/km²/year at the dam site. Sub-catchment 25 and 26 are the most erodible areas. The spatial variation of sediment ranges from 1.79 ton/ha to 62.53 ton/ha. The laboratory result indicated that relatively more clay soils are eroded from the upper catchment and enter in to the reservoir. These clay soils can be retained by suitable sediment detention mechanism to be used as nutrient input. For the identified erosion prone areas, Scenarios were developed for reduction of sediment yield in the Koga reservoir and S5 (changing 50% of agricultural land to forest mixed land) was the best scenario.

Key words: Reservoir sedimentation, Koga dam, ArcSWAT, SWAT CUP, SUFI-2, Calibration, Validation, Grain size variation, Scenario, erosion-prone, Blue Nile Basin

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LIST OF ABBREVIATIONS

ACRU	Agricultural Catchment Research Unit
AGNPS	Agricultural Non-point Source Pollution Model
AnnAGNPS	Annualized Agricultural Non-point Source pollution model
ARS	Agricultural Research Service
ARCS	Agricultural Research Conservation Service
CCHE2D	Center for Computational Hydro science and Engineering, 2 Dimensional
CFRF	Coarse Fragment Factor
CN	Curve Number
D	Difference for a quantity percentage
DEM	Digital Elevation Model
DR	Delivery Ratio
ECDSWC	Ethiopian Construction, Design and Supervision Works Corporation
EPIC	Erosion Productivity Impact Calculator
EHRS	Ethiopian Highland Reclamation Study
FAO	Food and Agricultural Organization
FEWS-SFM	Famine Early Warning System Stream Flow Model
GIS	Geographical Information System
GMT	Greenwich Mean Time
GPS	Global Positioning System
ha	Hectare
ham	Hectare meter
HEC 6	Hydrologic Engineering Center Version 6
HRU	Hydrologic Response Unit
HUSLE	Hydro-geomorphic Universal Soil Loss Equation
ITCZ	Inter-Tropical Convergence Zone
IWRM	Integrated Water Resource Management
LH	Latin Hypercube
LH-OAT	Latin Hypercube One-At –a-Time
masl	Meter above sea level

MCM	Million meter cube
Mount	Mountain
MoWIE	Ministry of Water, Irrigation and Electricity
MoNRA	Ministry of Natural Resource and Agriculture
MRS	Mean relative sensitivity
MUSLE	Modified Universal Soil Loss Equation
NMA	National Metrological Agency
NRCS	Natural Resources Conservation Service
NSE	Nash–Sutcliffe coefficient
OAT	One-At –a-Time
pcp STAT	Precipitation Statistics
PH	Potential of Hydrogen
R ²	Coefficient of Determination
RUSLE	Revised Universal Soil Loss Equation
SCS	Soil Conservation Service
SDR	Sediment Delivery Ratio
SSY	Suspended sediment yield
STAT	Statistics
SNAM	SWAT Code Name
SWAT	Soil and Water Assessment Tools
SWAT CUP	Soil and Water Assessment Tools, Calibration and Uncertainty Procedures
SWHISA	Sustainable Water Harvesting and Institutional Strengthening
SUFI-2	Sequential Uncertainty Fitting version 2
TIN	Triangular Irregular Networks
USDA	United State Development of Agriculture
USGS	United States Geographic system
USLE	Universal Soil Loss Equation
WEPP	Water Erosion Prediction Project
WMO	World Meteorological Organization
WXGEN	Weather Generator

CHAPTER ONE

INTRODUCTION

1.1 Background and Justification

Soil erosion occurs gradually with increase in population that requires land clearing for agricultural activities and urbanization. Land clearing and overgrazing changes the vegetation to desert that is the land without sufficient amount of water to stand life. The next problem is draught, humans took measure for this problem by building dams to produce enough food and water but immediately, the reservoir will be filled by sediment.

Reservoir sedimentation is the process of sediment deposition that occurs after a dam construction. A dam causes reduction in flow velocity and consequently in turbulence, which causes the settling process of sediments carried by the flowing water von George (2008). Sediment originates from catchment areas and passes through the river system then settles in reservoirs. As a river enters the reservoir, small sediment particles may be transferred through the reservoir without settling whereas larger particles may be retained depending on how completely suspended sediment settles into the reservoir. After the sediment deposited in the reservoir, it can come out through the dam out let system, so the problem continues towards the water distribution structures. The main impact of reservoirs sedimentation is the loss of storage capacity of the reservoir and downstream flooding.

Soil erosion by water occurs simultaneously in two steps: the detachment, individual particles from the soil mass which is principally caused by the falling kinetic energy of raindrop impact; and the transport of the detached particles by erosive agents, This causes gradual diminishing of reservoir storage capacity that obstructs the reservoir operation, and finally shortens the life span of the reservoir. According to Pimentel et al. (1995) sets soil erosion is not created only from the catchment area but it can also emerge from bed and banks of river channels. Sediment yield is the end product of erosion. All eroded soil particles from the upstream catchment area are not the sediment yield because; some sediment will be trapped before reaching the out let of the catchment, catchment, and some will deposit due to limited transport capacity of the flow. Sediment yield is directly proportional to the eroded soil particles which reaches the out let of the catchment.

According to Dereje (2010) soil erosion is a major problem in Ethiopia. Deforestation, overgrazing, and poor land management accelerates the rate of erosion. Many farmers in Ethiopian highlands cultivate sloped farm land. With the fast growing population and the density of livestock in the basin, there is pressure on the land resources, resulting in forest clearing and overgrazing. Increasingly mountainous and steeper slopes are cultivated, in many cases without protective measures against land erosion and degradation.

Previous studies on sediment yield and impacts, conducted mainly in northern parts of Ethiopia have shown that the spatial variability of sediment yield in that region is generally high. Aynekulu et al. (2006) reported that because of reservoir sedimentation, the life of dams in Ethiopia is almost five times shorter than that considered during the design phase.

According to Demesew Alemaw et al, 2014 study result showed that, because of the sediment accumulation in Koga reservoir, the storage volume shrunk from its design storage of 83.1 Mm³ in 2009 to 82.7 Mm³ in 2012.

1.2 Statement of the problem

Sediment deposition causes different impacts. The main impact of reservoir sedimentation is the loss of storage capacity of the reservoir due to sediment deposition in the reservoir which results in shorter reservoir life. The other impact is over topping and flooding. Due to loss of flood storage capacity, the reservoir spillway and the dam may become unsafe.

According to Birr Koga irrigation and watershed management project feasibility report, soil erosion and consequent land degradation are the most serious problems in the Koga catchment. The land is fully utilized for either grazing or agriculture which in turn affects the life expectancy of the Koga Dam reservoir.

Due to the confirmation of high rate of sediment load during feasibility study, IWRM was included and the project named as Koga Dam Construction and Integrated Watershed Management Project. This project was the first project that the construction of the dam and integrated watershed management is implemented simultaneously by the contractor, till the end of the project in 2011.

The construction project is implemented with watershed management practice but according to project report, 2011, the construction of the dam was well done but the watershed management has constraints like low level of achievements. So there is a gap between the ongoing watershed management practice and the planned watershed management.

Now, this study estimates the sediment inflow into the reservoir, indicate erosion prone areas of the catchment and recommend the mitigation measures to reduce the sediment problem on the reservoir, and compare the result with the feasibility report.

1.3 General objective

The general objective of this study is to estimate sediment inflow in to Koga reservoir from each catchment and recommend mitigation measures.

1.3.1 Specific objectives

- To determine the amount of sediment inflow in to the reservoir from the catchment
- Assess spatial variability of sediment yield in the catchment.
- To recommend the appropriate mitigation measures.

1.4 Research Questions

- How much sediment is produced in the catchment up to now?
- What is the pattern of the sub catchments sediment distribution?
- Among the all sub catchments which one is most erodible?
- How can the accumulation of sediment in the reservoir be reduced?

1.5 Significance of the study

Since, Koga dam constructed on degraded outlet, estimating of the sediment load of the reservoir after twelve years of feasibility study is essential to know the amount of sediment entered in to the reservoir till now. The results of the study would also be useful for policy makers and researchers to know where erosion prone areas occurred and implement effective sediment mitigation measures from this study engineering analysis that help prevention of water storage capacity reduction of the reservoir.

1.6 Scope of the study

This research attempts to estimate sediment yield in watershed of the study area after the feasibility study has been done in 2004. The scope of this section is broad and attempts to indicate the amount sediment transport and entering in to the reservoir by using physically based semi distributed model Soil Water Assessment Tools (SWAT) which can be calibrated and validated by SWAT CUP, identify erosion prone areas and recommend mitigating the sediment problem of Koga reservoir by developing different sediment mitigation measure scenarios using ARC SWAT.

1.7 Thesis Outline

This Thesis contained six chapters.

Chapter one presented the introduction, statement of problem, objective that include general and specific objective, significance of the study, scope of the study and thesis out line. Chapter two describes literature review. Chapter three provides a description of the study area and data availability that include model input data collection and data analysis method presented in detail. The chapter four deals with presentation of the research findings including identification of erosion prone areas and sediment yield distribution in the catchment assessing sediment reduction methods. The last chapter presented conclusion, recommendation, reference and appendix.

CHAPTER TWO

LITERATURE REVIEW

2.1 Soil erosion

Soil erosion is a process of detachment of soil particles due to raindrop energy and/or surface runoff, the transport of sediment by surface runoff and the deposition of sediments as the velocity of surface runoff decreases. Soil erosion causes worldwide environmental problems leading to degraded soil productivity and water quality, causes sedimentation in the reservoirs and increases the probability of floods as a result of reduction of flood storage capacity (Fasil, 2012).

2.1.1. Soil erosion in Ethiopia

Soil erosion by water has been a longstanding environmental problem in Ethiopia and is considered to be a critical economic problem (Bewket and Sterk, 2003). The annual rate of soil loss in the country is greater than the annual rate of soil formation (Tamene and Vlek, 2008). The rate of soil erosion is high due to a number of favoring factors that include erosive rains, steep gradients, deforestation, overgrazing, and poor agricultural techniques (Nyssen et al., 2004).

2.1.2. Soil erosion in highlands of Amhara region

The highlands of the Amhara Region suffer from accelerated soil erosion and overall land degradation, which resulted in considerable areas of cropland unable to provide reasonable crop yield. Estimates show that 1.1 billion tons of soils (58% of the nation's total loss) are lost from the Region each year (ARCS 1997). About 42% of the estimated soil loss is from only 10% of the Region, which is classified as very high erosion hazard category. These areas are located in the highlands of North and South Gondar, East and West Gojam, North and South Wollo, North Shewa and Waghamra 8 Zones. In terms of the extent of impacts, Gojam, Awi and surrounding areas of Lake Tana are most critical areas where the erosion hazard is very severe. These areas are known as surplus producing areas at both regional and national levels. A recent study by Tebebu et al. (2009) on hydrological controls of gully formation in the southern part of the basin indicated an average gully erosion rate of 24.8 t ha⁻¹year⁻¹. A modeling study found 18.4% of the basin highly susceptible to erosion with estimated sediment yield of 30 t ha⁻¹year⁻¹ (Setegn et al., 2009).

2.1.3 Types of erosion

Soil erosion types and erosion process

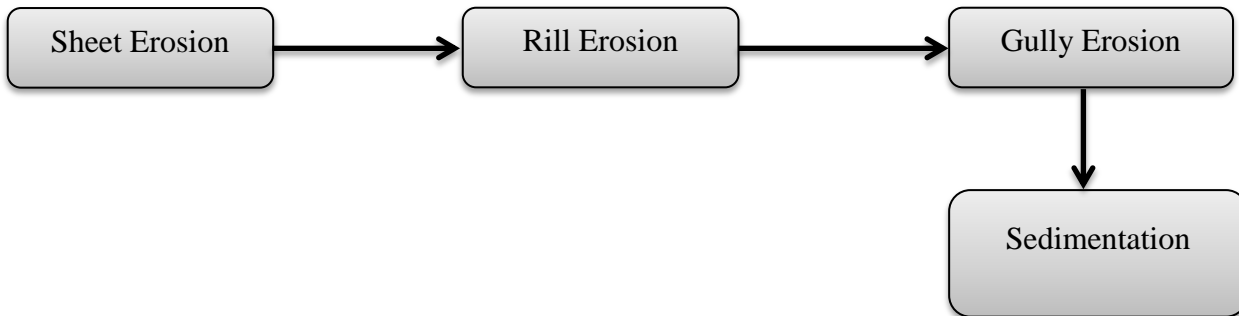


Figure 2.1 Conceptual frameworks of soil erosion types and process

According to study by William W. Doe III et.al the removal of a uniform thin layer of soil by raindrop splash or water runoff is called sheet erosion.

Watersheds, or catchments, are commonly divided into the upland areas and channels. In the upland areas, Sheet and rill erosion classification and description are based on a concept of progressive erosion severity. Sheet erosion, which is a uniform removal of soil from the surface, is assumed to be the first phase of the erosion process, and sheet erosion rates are assumed to be low. Sheet and rill erosion occurs particularly in grazing and cultivated areas of mild slope where runoff is not concentrated in well-defined channel (Morris and Fan, 1998; Vanoni, 2006). And overland flow is conceptually divided between rill flow mechanisms and inter-rill flow mechanisms, which occur on hill slopes. As overland flow converges from various portions of the upland area and becomes more concentrated, it becomes sufficiently erosive to form shallow channels, referred to as rills.

In channels areas, Additional soil particles may become detached as water flows through these rills. In the inter-rill areas, runoff occurs as a very thin, broad sheet, sometimes referred to as sheet flow. Both detachment and transport may occur in the rill and inter-rill areas. As erosive power increases, the small rills may converge to form larger surface channels, called gully (figure 2.1).

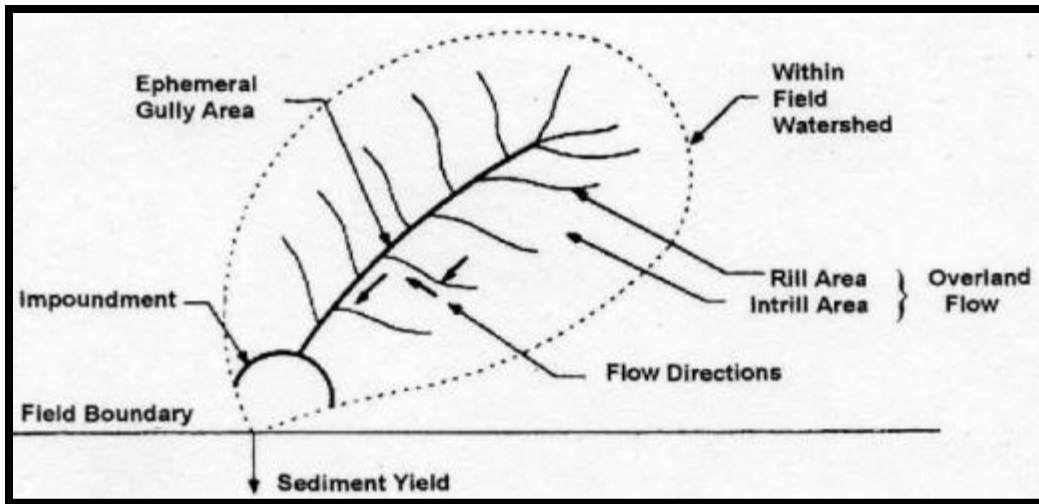


Figure 2.2 Schematic representations of rill, inter-rill areas and gully on a sub-watershed (Foster GR., 1990)

Finally, if sufficient amount of water continues to move down slope, it will reach well-defined channels, through which both water and sediment will be carried downstream towards the watershed outlet (figure 2.2).

If at any point along the water flow path the velocity is decreased (e.g., change in slope), some soil particles may be deposited because the reduced flows cannot carry as much sediment. The transport capacity is the maximum amount of sediment that a given flow can carry without net deposition occurring. The detachment capacity, which is the ability of the overland flow overcoming the interconnecting forces holding the soil particles together, and transport capacity are interrelated and it is their interaction that controls the patterns and magnitudes of erosion and deposition. The character of the processes is closely linked to which capacity is the limiting factor.

The amount of sediment actually leaving a site or watershed is a function of the erosional and depositional processes – both surface and channel – that occur up slope of the discharge point.

The amount (mass) of sediment being carried is called the sediment load. The velocity of entrained sediment passing a given point is the sediment rate. Sediment yield is the amount of eroded soil that is delivered to a point in the watershed that is remote from the origin of the detached soil particles. In a watershed, sediment yield includes erosion from slopes, channels and mass wasting (slumping, sliding, falling, etc.), minus the

sediment that is deposited after it is eroded, but before it reaches the point of interest (Dilnesaw Alamirew Chekol, 2006).

Based on the study by L. Van Rijn there are two major types of erosion are accelerated erosion and geologic erosion.

Accelerated erosion is soil loss in excess of geologic erosion. It is normally associated with changes in natural cover or soil conditions and is caused primarily by water and wind. The forces involved in accelerated erosion are

- (1) Attacking forces which remove and transport the soil particles and
- (2) Resisting forces which retard erosion. Hereafter, accelerated erosion will be referred to as soil erosion or simply erosion.

Geologic erosion, usually referred to as natural erosion acting over long geological periods, occurs when the soil is in its natural environment. Natural erosion rates exist under natural or undisturbed environmental conditions. Usually under natural geologic erosion rates, soil properties and soil profiles develop to approach equilibrium condition (Dilnesaw Alamirew Chekol, 2006). This type of erosion has contributed to the formation of soils and their distribution on the surface of the earth. This long-time eroding process caused most of the present topographic features.

2.2 Erosion and Sediment Yield relationships

According to Julien, (1998), Sediment yield directly depends on the intensity of erosion but all eroded soil particles from the upstream catchment area is not the sediment yield because, by infiltration structure or limited transport capacity, some sediments will be trapped before reaching the out let of the catchment. So, sediment yield is not an accurate measure of all the products of erosion. Sediment yield is directly proportional to the eroded soil particles which reaches the out let of the catchment. From above description, sediment yield can be defined as; the total amount of sediment transported and reached the catchment outlet over a period of time. Sediment yield is the end product of erosion

The other relationship between erosion and sediment yield is described by

$$SY = AT * SDR \qquad \text{Equation 2.1}$$

Sediment delivery ratio (**SDR**) is the ratio of the sediment yield (**SY**) at a given stream cross section to the gross erosion (**AT**) from the watershed upstream from the measuring point.

Sediment delivery ratio can only be applied to catchments that are homogeneous with respect to hydrology, erosion and sediment characteristics and it is also depend up on the size of the catchment area.

2.3 Sedimentation

2.3.1 Sedimentation process

Sedimentation process stages:-

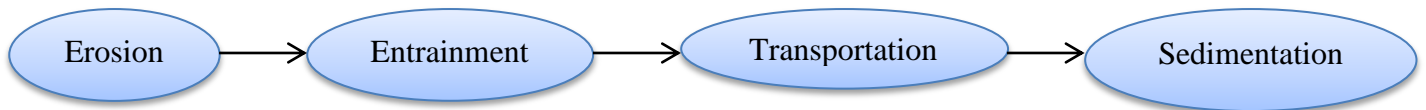


Figure 2.3 Conceptual framework of sedimentation process

As shown in figure 2.3 the processes of sedimentation are highly complex. The detachment of particles in the erosion process occurs through the kinetic energy of raindrop impact, or by the flowing water. Once a particle has been eroded it must entrain before it can be transported away. According to Pidwirny (2008) entrainment is the process of particle lifting by the agent of erosion and there is a thin line between entrainment and detachment so much so that it is somehow hard to distinguish between entrainment and detachment.

2.3.2 Sediment transport

According to Pidwirny (2008), the different ways in which transport can occur in the transporting medium:

- Saltation is where the particle moves from the surface to the medium in quick continuous repeated cycles. The action of returning to the surface usually has enough force to cause the entrainment of new particles. This process is only active in air and water.
- Traction is the movement of particles by rolling, sliding, and shuffling along the eroded surface. This occurs in all media of erosion sediment transport.
- Solution is a transport mechanism that occurs only in aqueous environment and it mainly involves the eroded material being dissolved and carried along in water as individual ions.

2.3.2.1 Modes of sediment particle motion

- Rolling and/ or sliding particle motion,
- Saltating or hopping particle motion,
- Suspended particle motion

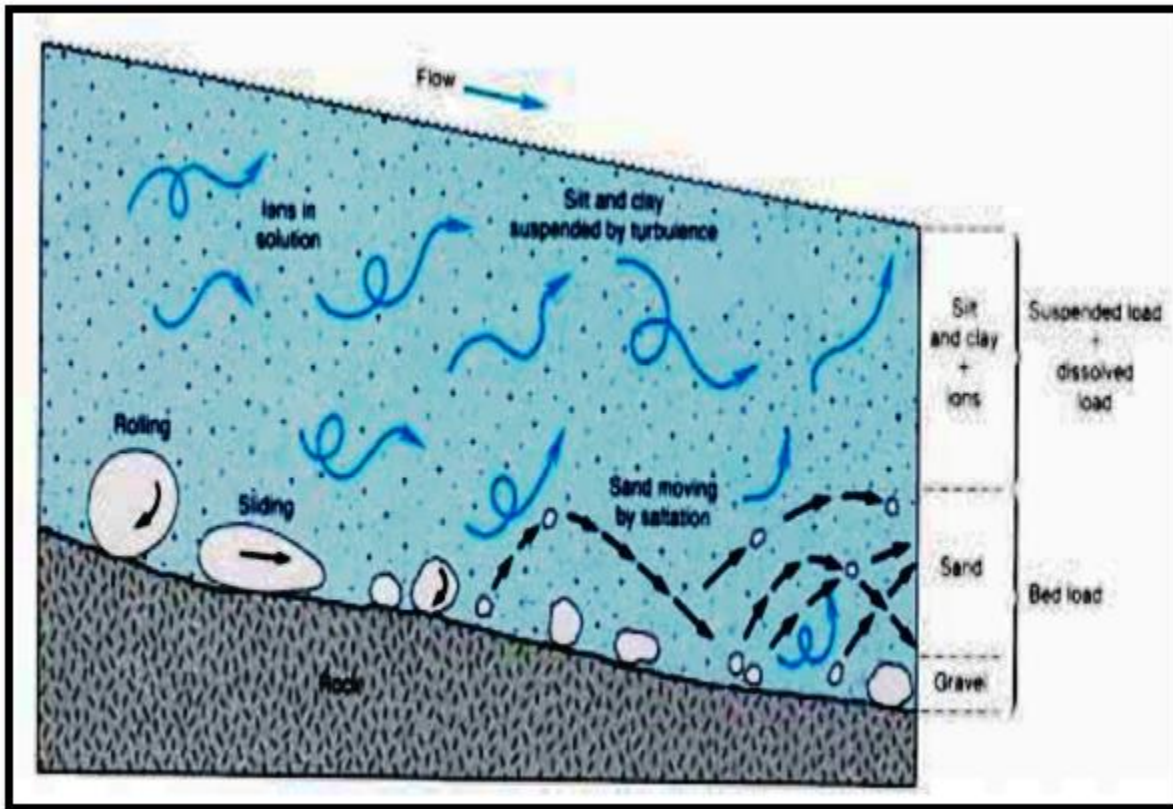


Figure 2.4 Movement of sediment within the stream (Wang, et al 2004)

According to the mechanisms of transport, the total sediment load can be subdivided (a) by source (b) by mode of transport (figure 2.4).

(a) For source; the total load is split between the bed material load and wash load. The bed material load is derived from the river bed and is typically sand-sized or gravel-sized. The wash load consists of sediment that has been flushed into the river from upland source and is sufficiently fine-grained that the river is always able to carry it in suspension.

(b) For mode of transport, sediment after joining streams based on its transport mechanism can be classified as bed load or suspended load.

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

When the value of the bed-shear velocity begins to exceed the fall velocity of the particles, the sediment particles can be lifted to a level at which the upward turbulent forces will be of comparable or higher order than the submerged weight of the particles and as a result the particles may go into suspension. Usually, the transport of particles by rolling, sliding and saltating is called bed-load transport, while the suspended particles are transport as suspended load transport.

The suspended load may also include the fine silt particles brought into suspension from the catchment area rather than from streambed material (bed material load) and is called the wash load. Bed load and suspended load may occur simultaneously, but the transition zone between both modes of transport is not well-defined.

2.3.2.2 Sediment transport capacity and sediment load

According to Julian (1998), Every sediment particle that passes a given stream cross-section must satisfy the two conditions below:

- It must be eroded somewhere in the catchment above the cross section
- It must be transported by the flow from the place of erosion to the cross section

It was concluded from the above conditions that the rate of sediment transport depends on the transport capacity of the stream and availability of sediment. , the amounts of transported material in the stream depend on two variables. These are

a) Characteristics and quantity of material made available for transport (characteristic variables): catchment topography, geology, rainfall intensity, magnitude and duration, weathering, vegetation, surface erosion, sediment supply from tributaries, mineralogy, soil type and land use.

b) Sediment transport capacity (defining variables): channel geometry, width, depth, shape, wetted perimeter, slope, vegetation, roughness, velocity distribution, turbulence and uniformity of discharge.

The sediment that is transported by the river has varying sizes in terms of diameter. In regions where the sediment transported in the river is relatively coarse consisting of sand, gravel or coarser particles it is possible to hydraulically determine the sediment yield (Basson, 2008). Sediment yield is the quantity of sediment that has been mobilized from a known catchment area size which his passing through a river channel's reference point in a given time interval. Sediment quantitative analysis is sometimes expressed as total sediment load in a stream. The sediment transport capacity is determined as function of hydraulic conditions and the shape of the stream cross section.

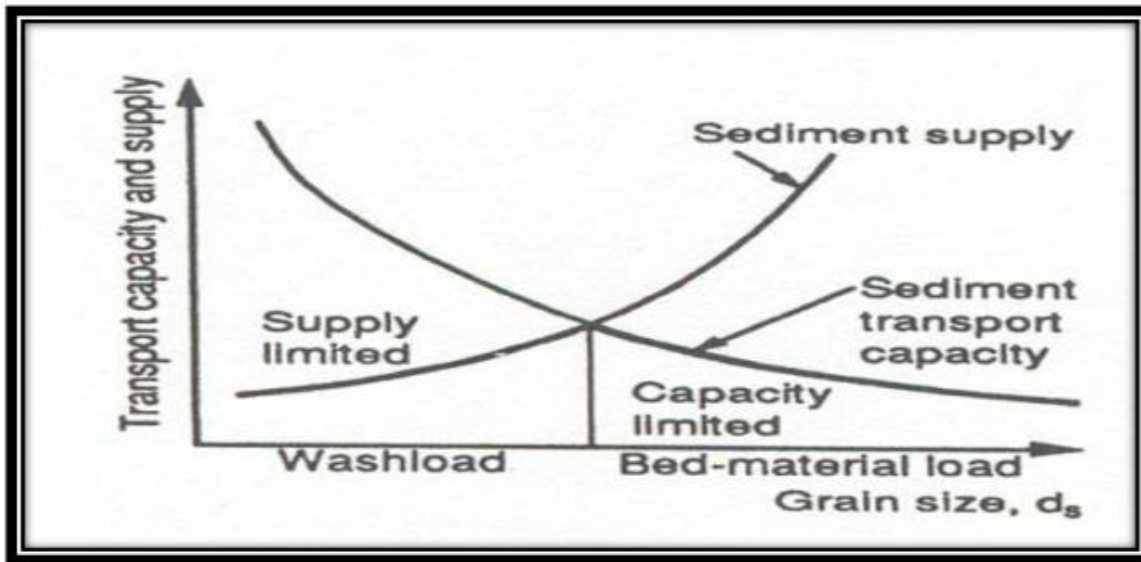


Figure 2.5 Sediment transport capacity and supply relationship (Julien, 1998).

From Figure 2.5 The wash load availability is limited and it can be seen that for finer sized sediment, the transport capacity of the stream is much higher than the sediment supplied (up to some limiting grain size).

2.3.2.3 Grain size Vs. Sediment Deposition Vs Sediment Transport

Sediment particles range in size from large boulders to colloidal size fragments and vary in shape from rounded to angular. Once the particles have been detached and/or entrained, they continue to be transported in the given transporting media. Some of the particles become deposited while in transit. Renard (1997) noted that sediment transport is largely a function of topography and runoff velocity while deposition is a function of runoff velocity and sediment particle sizes. Deposition occurs when particle flow velocity is reduced and the forces propelling the particle to move are less than the forces of resistance to transport. The interaction between flow velocity and particle erosion, transport, and deposition is illustrated by (Pidwirny, 2008) using Figure 2.1 (Pidwirny,2008) states that the curved line marked "erosion velocity" describes the velocity required to entrain particles from the surface and further explains that the entrainment of silt and clay needs great velocities than larger sand particles owing to the fact that silt and clay have the ability to form cohesive bounds between particles. Therefore, greater flow velocities are required to break the bonds and move these particles.

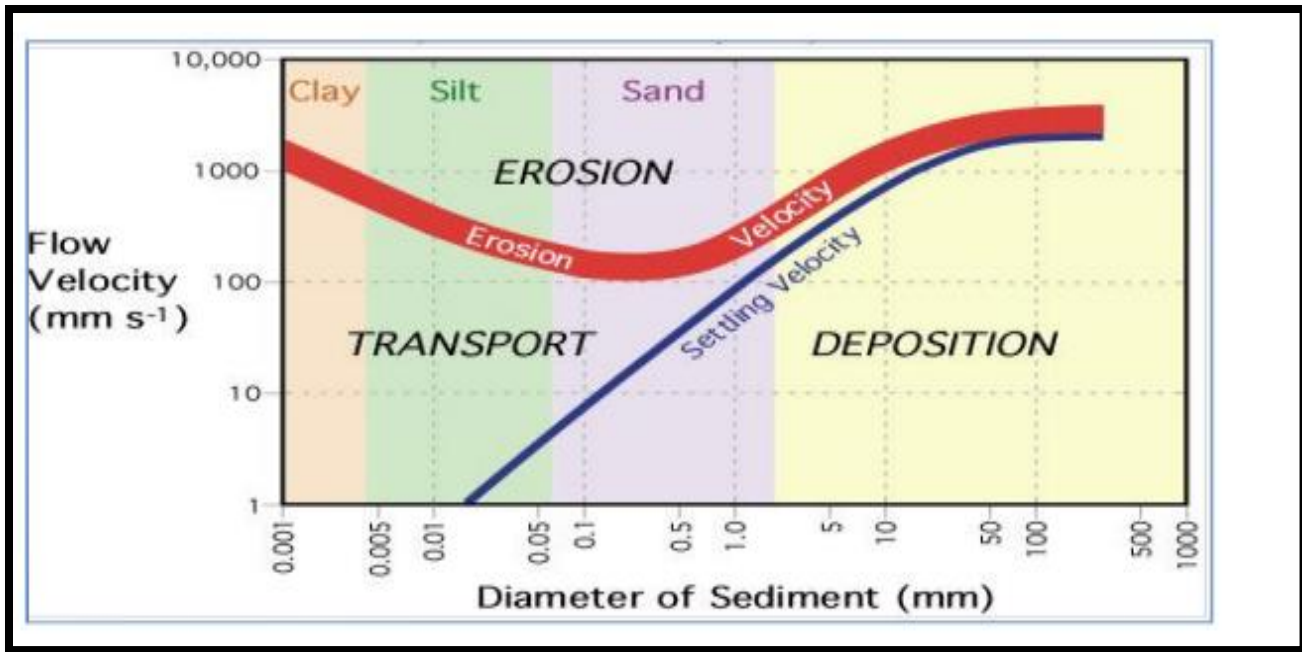


Figure 2.6 The relationship between flow velocity and diameter of sediment (Pedwirny, 2008).

From Figure 2.6 above, the line labeled settling velocity shows at what velocity certain sized particles fall out of transport and are deposited (Pidwirny, 2008). The illustration shows the interaction between flow velocity, erosion, transport, settling velocity and deposition of particles of varying sizes in the form of clay, silt or sand.

The yellow band describes the relationship between erosion velocity and settling velocity for larger sized particles. The curves indicate that greater flow velocities are required to entrain larger sized particles from the stream's bed and banks and also to make them fall out of transport and be deposited. The erosion velocity is slightly lower than the settling velocity for similar larger sized particles.

2.3.2.4 Cohesive and Non-cohesive sediments

As confirmed by study of (Grabowski et al, 2011), cohesive sediments are a heterogeneous mixture composed of clay, silt and organic matter in solid, liquid or gaseous phases with a particle diameter of less than 60 μm whereas non-cohesive sediments are primarily composed of fine and medium sands and have a particle diameter of more than 60 μm .

Cohesive sediments widely exist in rivers, lakes, reservoirs and stick together due to the action of electrostatic force or flocculation; they act at very small distances and are affected by the clay mineralogy,

ion content and composition, pH and temperature. The major transportation method of cohesive sediments is in suspension state by convection, turbulent diffusion and gravity settling. Generally, flocculation increases the settling velocity of cohesive sediments, thus being responsible for deposition (Sarkkula J, Koponen J, Lauri H, Virtanen M., 2010).

2.3.2.5 Deposition at river banks

Not all eroded sediment join the river due to filtration by vegetation and sediment transport capacity loss of the runoff before it joins the river. The part of eroded sediment that joins the river starts making some deposition pattern. Finer particles keep in suspension until the flow velocity falls below threshold while coarse sands and boulders start deposition near the river banks.

2.4 Reservoir Sedimentation

2.4.1 General concepts of reservoir sedimentation

Reservoir sedimentation is a gradual accumulation of the incoming sediment load from a river. It is a universal and natural phenomenon. The eroded soil from the upper catchment area is carried into water courses by flood and storm waters resulting in tremendous sediment movement. Uncontrolled deforestation, forest fires, overgrazing, improper method of tillage, and unwise agricultural and land use practices accelerate soil erosions resulting in a large increase of sediment inflow into streams and ultimately entering into lakes and artificial reservoirs (Ouyang et al., 2010).

Sediment particles are originated from catchment area and river systems. As a river enters the reservoir, its cross section of inflow is enlarged due to the effect of the back water curve. Thus, it causes a decrease in flow velocity; subsequently the sediments carrying capacity of the water is reduced too. The deposition of sediment in reservoirs creates a variety of problems, such as depletion of storage capacity, increased flood risks, interruption in hydropower generation and downstream river bed degradation; other problems such as degradation of water quality, increased complexity in reservoir operation and maintenance leads a consequent increase in their associated costs (Kothyari et al., 2002).

The accumulation of sediment in the reservoir results different consequences, like; (a) increase the evaporation losses for a given storage capacity firstly, due to increase in area of exposed water surface in fan shaped reservoir and Secondly, due to increase in transpiration losses of water from vegetation growing

on the sediments deposited at the periphery of reservoirs. (b) Deposition of sediment in the river valley above the reservoirs; this results in a rise in bed level and may lead to water logging and formation of swamps.

Generally, Deposition occurs when the forces are diminished enough leading to a reduction or cessation of transport. Therefore, when a river flow enters a reservoir, its velocity and transport capacity are reduced and its sediment load is eventually deposited.

The amount and rate of deposition in a reservoir are determined mainly by:-

- Detention storage time
- The shape of the reservoir
- The operating procedure of the reservoir

The depositional pattern usually starts with the coarser material depositing towards the reservoir headwater, while finer sediment is transported further into the reservoir.

2.4.2 World experience on reservoir sedimentation

Sedimentation is a problem for many dams around the world and considered as an invisible enemy. It has tremendous economic and environmental impacts. The gradual loss of reservoir capacity reduces the effective life of dams. For each year up to 1% of the world's reservoir capacity is lost due to sedimentation (Howard, 2000). Jurack K.E. (2002) conducted studies on reservoir sedimentation in Kansas, USA. He found that water storage capacity had been decreased due to sedimentation. Reduction in storage capacity is less than 5% at Hillsdale Lake in northeast Kansas and Webster Reservoir in North central Kansas is 50% at Cedar Lake.

2.4.3 Reservoir sedimentation in Ethiopia

The existing and the newly constructed reservoirs of Ethiopia are under similar threat of sedimentation problems (Siyam et al., 2005); (Haregeweyn et al., 2012). Previous studies on sediment yield and impacts, conducted mainly in northern parts of Ethiopia have shown that the spatial variability of sediment yield in that region is generally high. The frequent power cuts and rationing based electric power distribution recently experienced in the country are partially attributed to storage losses due to sedimentation (Haregeweyn et al., 2006). A number of efforts have been made to estimate sediment yield throughout the world, though few in Ethiopia. Aynekulu et al., (2006) reported that the life of dams in Ethiopia is almost five times shorter than that considered during the design phase. Tamene (2005) in Tigray region northern

part of Ethiopia studied reservoir siltation and siltation rate on 11 small reservoirs. He found that annual average rate of capacity loss varies from 0.1 to 7.4% due to the wide contrast in environmental variables of catchments. In addition to this, his result showed that most of the reservoirs would be filled with sediment within less than 50% of their projected service time.

Mulugeta (2013) studied the impact of sedimentation on the hydrological status of Lake Hawassa, in southern Ethiopia with bathymetry survey methods using echo sounder for depth measurement by 500mx500m grid spaces. He found out that the annual reduction in storage capacity of Lake Hawassa due to siltation is about 0.08% and the specific sediment yield is estimated to be 9.67m³/ha/year.

Angereb Dam, which was constructed in early 1980 on Angereb River, a tributary of the Blue Nile, was primarily built to adequately supply drinking water to Gondar town (Musa et al., 2005). Nevertheless, the Angereb Reservoir has not lived up to the design expectations because of siltation, in which about 1.4Mm³ sediment has been accumulated (Amare, 2005); (Hathaway, 2008). According to Musa et al., (2005); Haregeweyn et al., (2006, 2011) the specific sediment yield of Angereb reservoir is 2,927 tons/km²/year. They predicted that the reservoir will lose 68% of its volume by the year 2015.

Many dams constructed to store water for irrigation and for drinking purposes were being silted up while under construction (Amare, 2005). There were extreme sedimentation cases in Ethiopia such as Borkena Dam in Wollo, which cost \$35 million US dollars in 1991 and Adrako Dam (Ebinat, South Gondar) where the dead storage volume of the reservoirs silted up before their construction ended (Haregeweyn et al., 2006).

Adrako irrigation project is a failed project immediately after construction due to violation of the technical procedures that were followed, and mismanagement of watershed (Bitew, 2013). The Bathymetry survey done by SWHISA (2006) on Gomit, near Istie and Zana, near Guhala Belesa reservoir in the Upper Blue Nile basin with the main aim for estimating the present water holding capacity and sediment accumulation in the reservoirs. They took 3,183 survey data points at the Gomit reservoir, and the result showed that Gomit reservoir reduced by 26.62 ham means that from the total volume of 102.08 ham reduced to 75.4685 ham within 4 year. On the other hand Zana reservoir lost its capacity by 27.9915 ham (81.64 ham from 109.6365 ham) within 11 year between 1995 to 2006.

To mitigate agricultural crisis from recurrent drought and erratic rainfall the government of Ethiopia in collaboration with other organizations, constructed more than 50 micro dams for irrigation purpose in

Tigray region between 1994 and 2002 (Haregeweyn et al., 2006). Investigation of these micro dams by Tamene, (2005) showed that the area specific sediment yield of the reservoirs ranged between 345 and 4935 tons/km²/year with a mean of 1900 tons/km²/year. A related study in this region by Haregeweyn et al., (2006) showed that 50% of the studied micro dams have a siltation problem that will shorten the economic life by half of the design period and another 20% of the reservoir will lose their effectiveness between half and 100% of the design life. This is indicator of the fact that sedimentation is a challenging problem in the reservoirs of Ethiopia. The existing condition of previously constructed reservoirs showed that significant portion of their storage capacities is lost due to sedimentation every year. The realization of the objectives was highly affected, unless possible mitigation measures are taken during the planning, construction and operation stages.

2.4.4 Reservoir sedimentation in Koga reservoir

According to Demesew Alemaw et al, 2014 study, the sediment accumulation (Figure 2.7) in the reservoir is obtained as the difference between the TIN derived from the topographic map and the TIN derived from the bathymetric survey the result showed that the storage volume shrunk from its design storage of 83.1 Mm³ in 2009 to 82.7 Mm³ in 2012, i.e., sediment inflow volume of 339,500m³.

Annual average sediment inflow rate was 84,800m³. Taking the average density of clay soil of 1.2tons/m³ annual sediment yield is estimated to be 101,500 ton/year or (500 tons/km²/year). The dead storage for Koga reservoir is 393,000 m³ (MacDonald, 2004). Based on the annual sediment inflow rate of 84,800m³ obtained through DEM differencing the dead storage is about 4.6 years of sediment accumulation and represents the loss of 0.4% of the total storage of the reservoir.

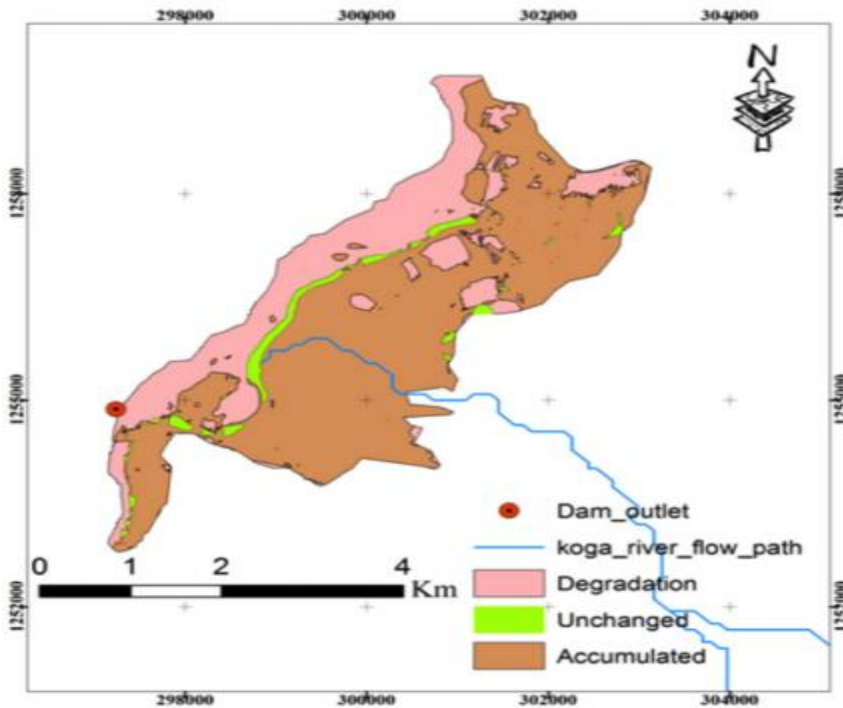


Figure 2.7 Sediment distributions in Koga reservoir using bathymetry survey, (Demeseew Alemaw et al, 2014)

2.4.5 Trap efficiency of reservoirs

Trap efficiency of reservoir is the ratio of incoming sediment load that is retained in the reservoir to the total inflow of river sediments. The trap efficiency mainly depends on (Graf, 1984):

- The characteristics of the watershed
- Water and sediment inflow
- Reservoir storage (dimensions, configurations, retention period, etc...)
- Water and sediment outflow

For large reservoirs the trap efficiency is almost 100% (C.J. Sloff et al, 1991)

2.4.6 Distribution of Sediment Deposits in the Reservoir

Determining how the distribution of Sediment Deposits in the reservoir is used for reservoir operation. Mainly the coarse sediment fractions are deposited in the head of the reservoir by backwater effects during high discharges, forming delta. The delta may be divided into two zones, the topset bed and the foreset bed. And then point at which coarse sediments are deposited moves gradually towards the reservoir in time,

forming fore set beds that slope down into the reservoir. Fine sediment particles are transported in suspension further beyond the delta into the reservoir and settle on the floor of the reservoir area forming bottom set beds. Sediments will settle out of the density current and be deposited along the length of the reservoir as the current moves toward the dam.

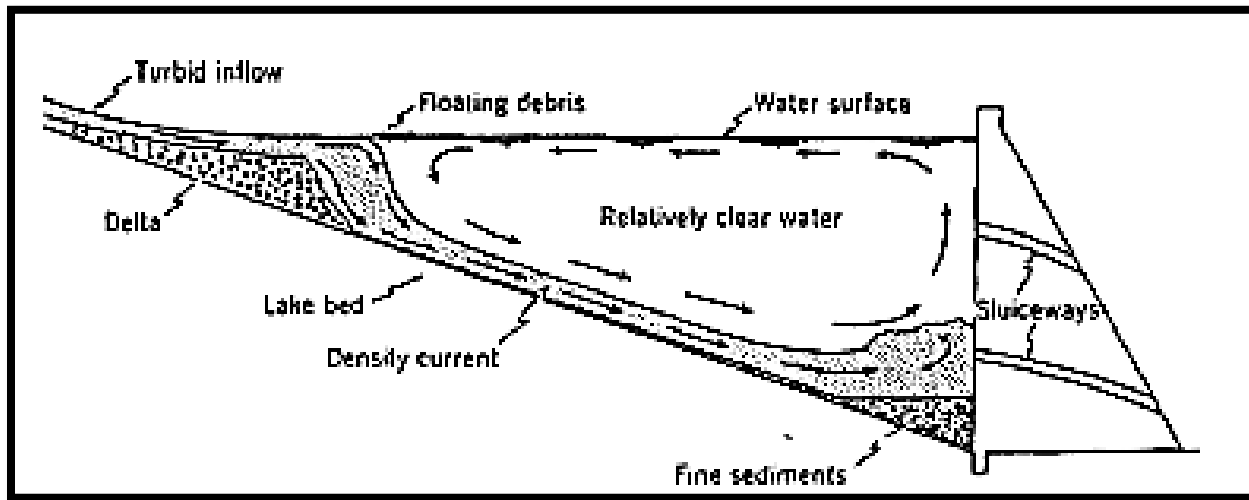


Figure 2.8 Sedimentation in reservoirs (C.J. Sloff, 1991)

2.4.7 Main impacts of reservoirs sedimentation

The main impact of reservoir sedimentation are discussed below: (C.J. Sloff et al, 1991)

1. Storage loss

The main effect of sedimentation is the loss of storage capacity in the reservoir. Deposition in the upper part of the reservoir directly affects the active storage. The benefit of dams is quite proportional to the storage.

2. Downstream impacts

The presence of dam imposing reservoir results, river reaches found at the downstream of dams suffers large environmental impacts due to flow changes which lead to produces clear water without sediment. The clear water released from the reservoir will cause downstream erosion and possibly bank failures.

2.5 Hydrological modeling

Modeling of the rainfall-runoff processes of hydrology is needed for many different reasons the main reasons being limited range of hydrological measurement techniques and limited range of measurements in space and time (Beven, 2000).

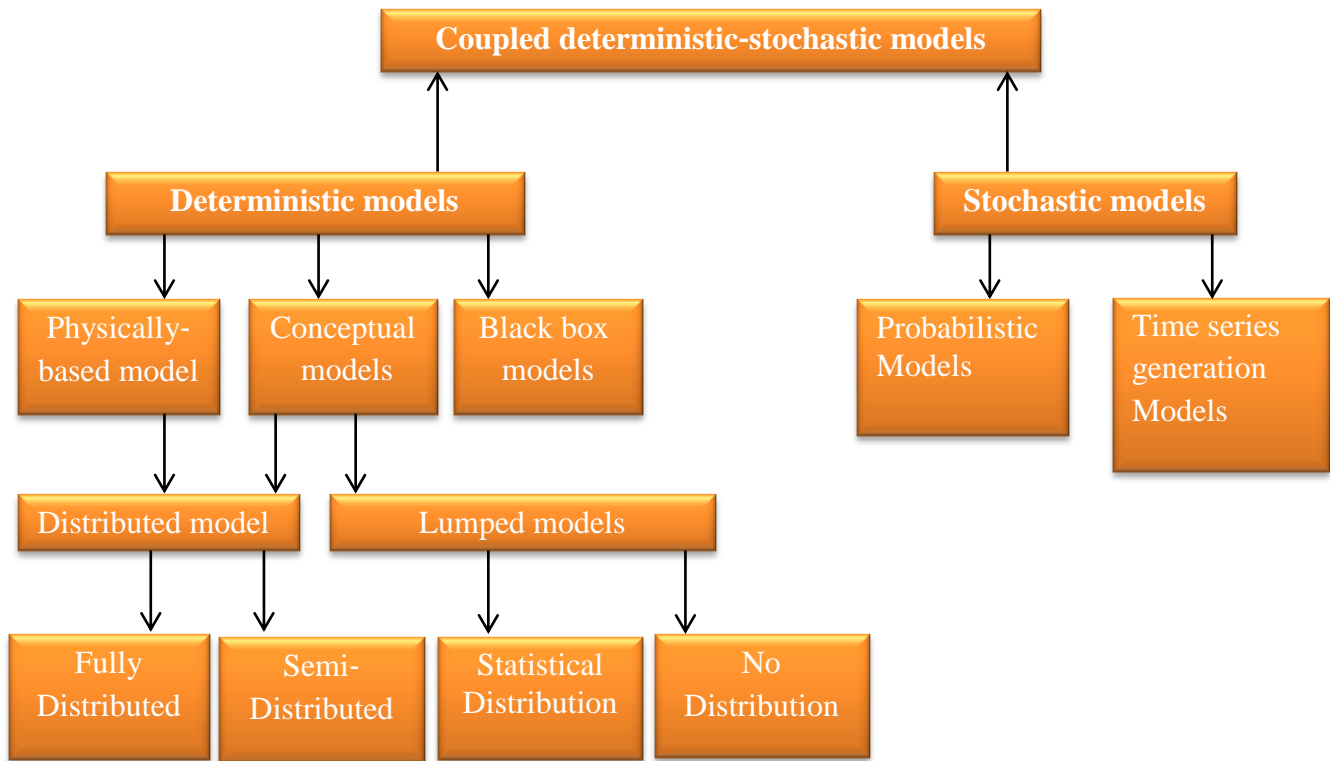


Figure 2.9 Classification of hydrological models, based on Becker and Serban (1990)

Models can also be classified as deterministic or stochastic depending on the character of the model outputs (figure 2.9).

Deterministic model: these are models in which no random variables are used; a given input always produces the same output. If all the input data, parameters, and processes are considered free of random variation and known with certainty, then the model is referred to as a deterministic model (Dwarakish and Ganasri, 2015). Deterministic models widely used in watershed management activities.

Stochastic models: these allow for some random and variable in time output due to uncertainty in input variables, boundary conditions or model parameters, a given input always do not produces the same output (Beven, 2001).

Physically-based models: these are based on physical and theoretical interrelationships between erosion and sediment yield controlling processes. The models have ability to give reliable detailed simulated description in time and space of the sediment yield. Some of the available physically based models includes:

SHETRAN (Ewen et al., 2000) and Water Erosion Prediction Project (WEPP) (Nearing et al., 1989), SHE (Abbott et al., 1986) and SHETRAN (Ewen et al., 2000).

Empirical models: or black box models are those that are based entirely on data not derived from relationship between variables and they are not based on physical parameters. Empirical equations are developed using data collected from specific geographical areas of long-term data, measurement, experiments and statistical methods (Petter, 1992). The application of these equations should be limited to areas represented in the base data (Randle et al., 2006). Empirical models: contain non physically-based transfer functions to transform input data to output data mathematically. Some example empirical models of are; the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965), the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991), Erosion Productivity Impact Calculator (EPIC) (Williams et al., 1975) and Agricultural Non-point Source Pollution Model (AGNPS) (Young et al., 1987) are examples of commonly used watershed models based on USLE methodology to compute soil erosion.

Models can also be classified as deterministic or stochastic depending on considering spatial variability.

Lumped models: these types of models treat an entire watershed as one unit and take no account of the spatial variability in processes. Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub basins. Lumped models do not provide any information regarding the spatial behavior of the outputs. The whole catchment is assumed to be homogeneous degree of accuracy (Huggins and Monke, 1966).

Distributed models: these types of models takes account the spatial variability of watershed characteristics. It divides the watershed into units which are assumed homogeneous. All the hydrologic, climatic and management parameters are assumed homogeneous within each cell, but may vary from cell to cell. Distributed is capable of predicting multiple points within a river (Beven, 1985). Distributed models can be fully distributed models or semi-distributed models.

a) **Fully Distributed models:** Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user.

b) **Semi-distributed models:** Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into a number of smaller sub basins. Models can also be classified as based on scale and time.

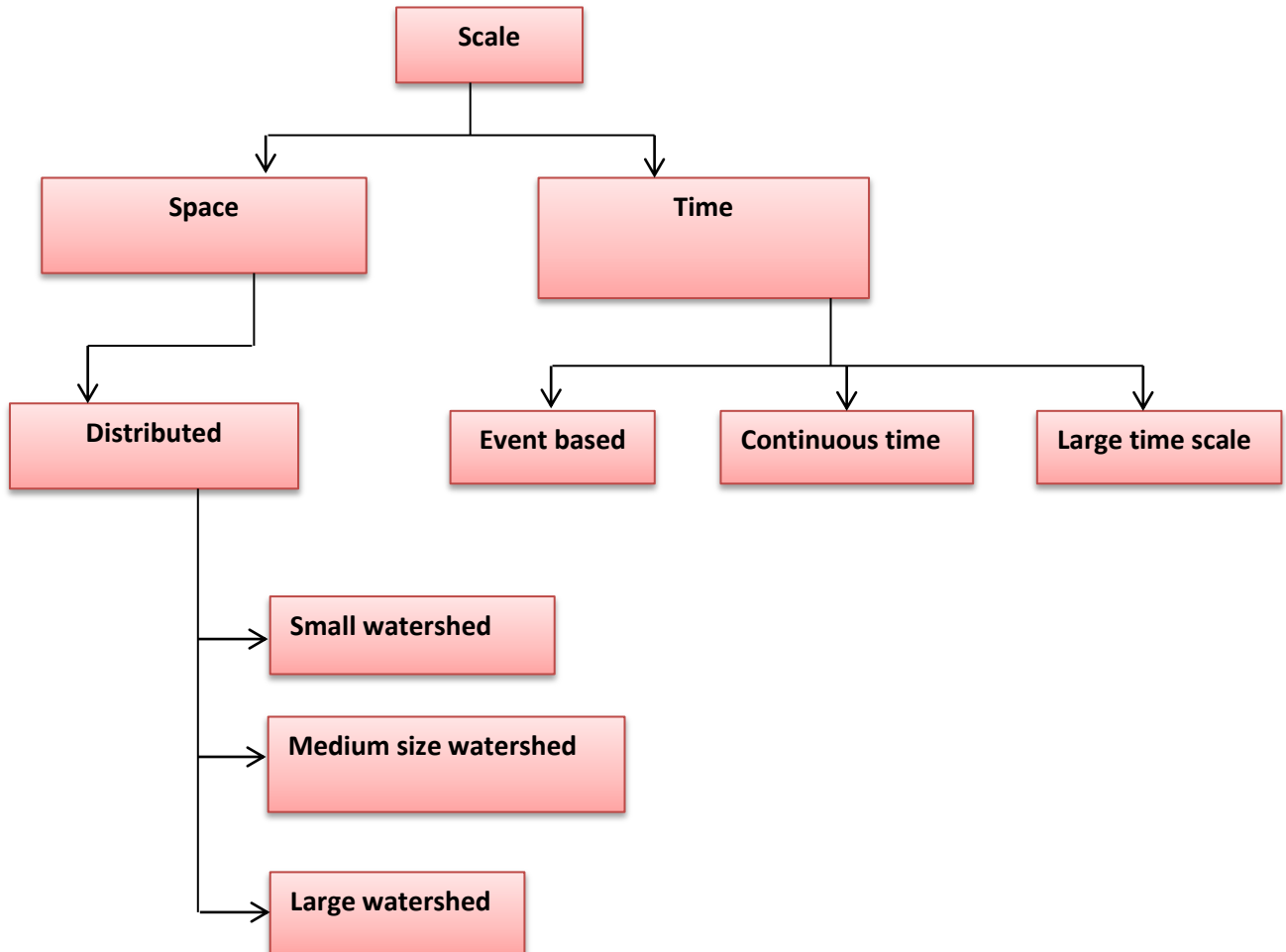


Figure 2.10 Classification of hydrological models based on space and time (Borah and Bera, 2003)

Event based models may be employed for storm events of relatively short duration. Continuous simulation models are used to analyze the long-term effects of hydrological changes and agricultural management practices whereas event based models are useful for analysis of storm events and may also be used to evaluate structural best management practices (Borah and Bera, 2003). The principal advantage of continuous modeling is that it can provide long-term series of water and pollutants loadings. Long-term series provides information the long period of time information.

2.6 Comparing sediment yield estimation methods

Based on different literatures, some of mostly used sediment analysis methods were selected and evaluated with related to the objectives of this study.

2.6.1. Bathymetric Survey

Bathymetric surveys provide a mean for determining sediment deposition in lakes and reservoirs, which depends on measuring changes in bed elevation of water body over time and linking them to an accurate base map. Basically, general procedure of the method consists of building up the bathymetric map for the lake bottom and compared it from previously prepared map.

Bathymetric measurement is to determine the volume and distribution of sediment accumulated during a specific period of time. It is a direct measurement procedure to assess the volume of deposit along its pattern in the reservoirs.

Bathymetric survey methods is more accurate as compared to other methods, the survey has some limitation due to water quality of the reservoir and the instrument used to survey. Bathymetric survey methods is expensive therefore cannot be carried out regularly at shorter intervals for the purpose of monitoring reservoir sedimentation.

2.6.2. Satellite Remote Sensing Method for Estimating Reservoir Sedimentation

Satellite remote sensing method is suitable for estimation of reservoir sedimentation located in remote regions.

Remote sensing resources that are freely available nowadays represent a great opportunity to support the study and monitoring of hydrological and hydraulic processes (Liebe, 2009).

Satellite Remote Sensing techniques provide a relatively cost and time effective method for assessing reservoir sedimentation during the operation stages. Remote sensing technology allows a fast and accurate estimation of the live storage capacity loss due sedimentation (Goel et al., 2002).

Even if, Jain and Singh (2003) described that, it is important to note that the amount of sediments deposited below the lowest observed water level can't be determined through remote sensing and thus, it is not possible to estimate the actual sedimentation rate in the whole reservoir.

Input data are satellite data, topographical Maps, digital elevation models (DEM), metrological Station Data, field Surveying and livestock Data.

2.6.3 AnnAGNPS Model

AnnAGNPS (Bingner and Theurer, 2001) is a distributed parameter, physically based, continuous simulation, daily time step model, developed initially in 1998 through a partnering project between the USDA Agricultural Research Service (ARS) and the Natural Resources Conservation Service (NRCS).

AnnAGNPS model (Bingner and Theurer, 2001) can predict runoff and sediment from agricultural land better because of the following reasons, i) AnnAGNPS model is a continuous-simulation, agricultural-related, non-point source, pollutant loading watershed model, it has the ability to predict the sediment yield (clay, silt, and sand) by sheet and rill erosion from the watershed landscape. ii) It can predict sediment yield from gullies, bed, and bank erosion and delivery ratio for the sheet and rill erosion to determine sediment yield to receiving reaches of the stream system by using Hydro-geomorphic Universal Soil Loss Equation (HUSLE); and particle-size distribution for the delivered sediment yield to the stream system from sheet and rill erosion.

AnnAGNPS model spatial scale application is limited by data availability, computer memory and drainage areas up to 300,000 ha.

2.6.4 SWAT model

SWAT (Soil and Water Assessment Tool) model is a river basin, or watershed, scale physically based semi distributed hydrological model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time (Arnold et al., 2012).

2.6.4.1 Theoretical description of SWAT model

SWAT allows a number of different physical processes to be simulated in a watershed. In order to adequately simulate hydrologic processes in a basin, the basin is divided into sub basins through which streams are routed. The subunits of the sub basins are referred to as hydrologic response units (HRU's) which are the unique combination of soil and land use characteristics and are considered to be hydrologically homogeneous.

The model calculations are performed on a HRU basis and flow and water quality variables are routed from HRU to sub basin and subsequently to the watershed outlet. The model splits hydrological simulations of a watershed into two major phases: land phase (upland processes) and the routing phase (channel processes).

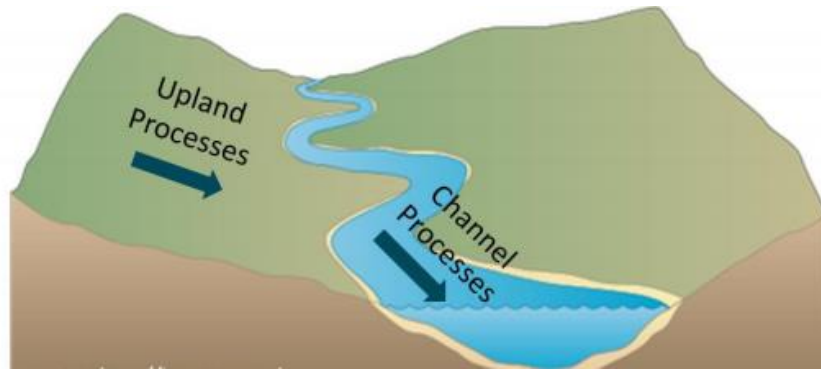


Figure 2.11 Conceptual model of the hydrology simulation in SWAT model (Schürz, 2015)

1. The land phase of the hydrologic cycle

The land phase (upland processes) control the amount of water, sediment and nutrients loadings to the main channel in each sub basin (Neitsch et al. 2011).

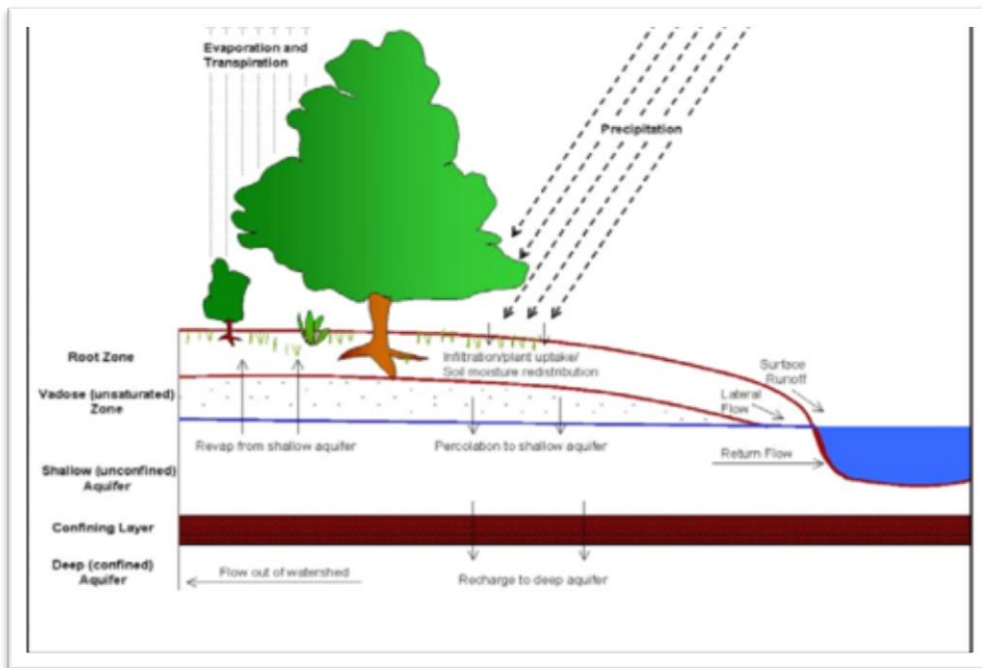


Figure 2.12 Schematic representation of land phase of the hydrologic cycle (upland processes)

2. Routing phase of the hydrological cycle

The routing phase (channel processes) describe the movement of water, sediments etc. through the channel network of the watershed to the outlet (Neitsch et al. 2011).

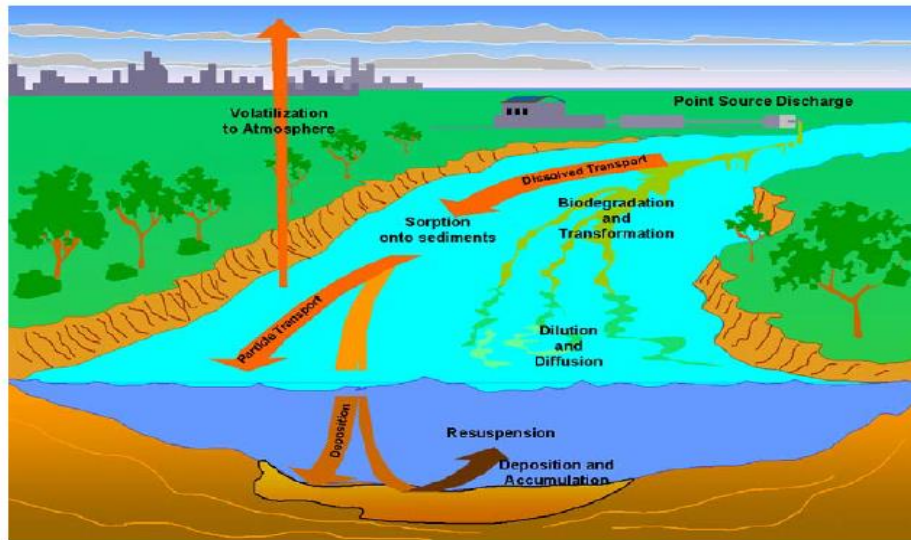


Figure 2.13 Schematic representation of routing phase of the hydrological cycle (channel processes)

2.6.4.2 SWAT strength and limitation

The major strengths of the SWAT model in this study

SWAT model is freely availability to download. The foundational strength of SWAT in this study is that it is combination of upland and channel processes that are incorporated into one simulation package. However every one of these processes is a simplification of reality thus subject to the need for improvement. It is physically based means that allows considerable spatial detail for basin scale modeling.

SWAT model can consider using meteorological data obtained from outside the watershed area. Merawi and Adet meteorological stations are found outside Koga watershed but the model used the data to simulate stream flow and sediment yield in flow in to Koga reservoir.

The model uses readily available inputs to simulates for long period in any size watershed effectively. And also, it can identify vulnerable sub watershed and adopt best management strategies practice using different scenarios to be implemented by government bodies.

The major limitations of the SWAT model in this study

In this study meteorological data obtained from outside the watershed area and far apart from the outlet of the catchment that some of them were not considered by the model. Out of five collected metrological station data (Bahire Dar, Merawi, Adet, Dangila, Wetet Abay), two of them (Merawi, Adet), were used and three of them (Bahire Dar, Dangila, Wetet Abay), were rejected by the model. Shortage of observation stations in the watershed affects the model output and can overcome model uncertainty. Over parameterization or over-estimation of sediment load was obtained and so parameter values needed to be adjusted more closely to match with the result of the model. SWAT model doesn't account sediment leaving the reservoir, so does this study.

2.6.4.3 Previous sediment estimation studies using SWAT model

A study in Rift Valley Basin, Mengist Abate (2017) used SWAT model to estimation sediment yield in the Gelana catchment (area of 644.28 km²), located in Abaya-Chamo sub-basin, rift valley, Ethiopia. Both the calibration and validation result indicated that good agreement between observed and simulated stream flow and sediment yield. The model simulated result shows that the average annual sediment yield is 89.14 ton/km²/year, at the dam site. At the same Basin, Tufa Feyissa (2016) study which drains 3602 km² to Gilgel Gibe-I dam reservoir outlet, estimated the sediment yield. The result indicates that the observed values show good agreement with simulated value for both flow and sediment yield. In this study the SWAT model yields average annual sediment of 106.178 ton/km²/yr. or (10617.8 ton/ha/yr.) at Gilgel Gibe-I outlet dam site. For both studies SWAT model performed good and similar sediment yield predictions due to having the same physiographic and climate characteristics.

Previous studies on upper Blue Nile basin specifically on Ribb dam sediment modeling using SWAT model indicated that annual sediment yield at the outlet is in the range of 35.80 to 106.97 tons per km² from 1985 to 2004 with annual average yield of 72.79 tons/km² (Tensay Getnet 2011). Another study in Gumera watershed by Mequanint Tenaw and Seleshi Bekele Awulachew (2010) on Gumera watershed SWAT model result shows that about 72% of the Gumera watershed is erosion potential area with an average annual sediment load ranging from 11 to 22 tons/ha/year exceeding tolerable soil loss rates in the study area. Since, both studies were taken in the upper Blue Nile basin SWAT model performed good sediment yield predictions due.

CHAPTER THREE

MATERIAL AND METHOD

3.1 Description of the Upper Blue Nile

The Upper Blue Nile lies in west Ethiopia between latitudes of 7° 45' N and 12° 46' N; and longitudes of 34° 05' E and 39° 45' E. The basin has a catchment area of about 199,812 km² at the border with Sudan, covering parts of Amhara, Oromiya and Benishangul-Gumuz Regional states. It covers about 17.5 percent of Ethiopia's land area, about 50% of its total average annual runoff and 25 % of its population. It has an irrigation potential of 815,581ha and a hydro potential of 78,820 GWH/yr. The basin has an average annual run-off estimated to 54.8 BCM (Awulachew et.al. 2007).

An altitude ranging from 590 meters to more than 4000 meters dominates the climate of Abbay basin. The influence of this factor determines the variation in local climates ranging from hot to desert-like climate along the Sudan boarder, to temperate on the high plateau, and cold on the mountain peaks. The annual rainfall varies between about 800mm to 2,220 mm with a mean of about 1420mm. (Master Plan of UBNRB Main Report, 1999).

3.2 Description of the Study Area

Koga watershed is located in Mecha Woreda which is approximately 35km southwest of Bahir Dar, the capital of west Gojam zone administration, in Amhara National Regional State, Ethiopia. Koga catchment is a typical catchment for Ethiopian highlands. It is situated between 11°10' and 11°32' N and 37°04' to 37°17'E with an altitude range from 1925 at the dam site to 3089 masl at Wezem mountain which is the source of the Koga River. The catchment area to the dam is 155.75 km². According to Mott MacDonald (2004) it has a narrow steep upper catchment draining the flanks of the Mount Adama range, and the lower catchment has relatively flat plateau sloping gently northwestwards.

3.2.1 Location of Study Area

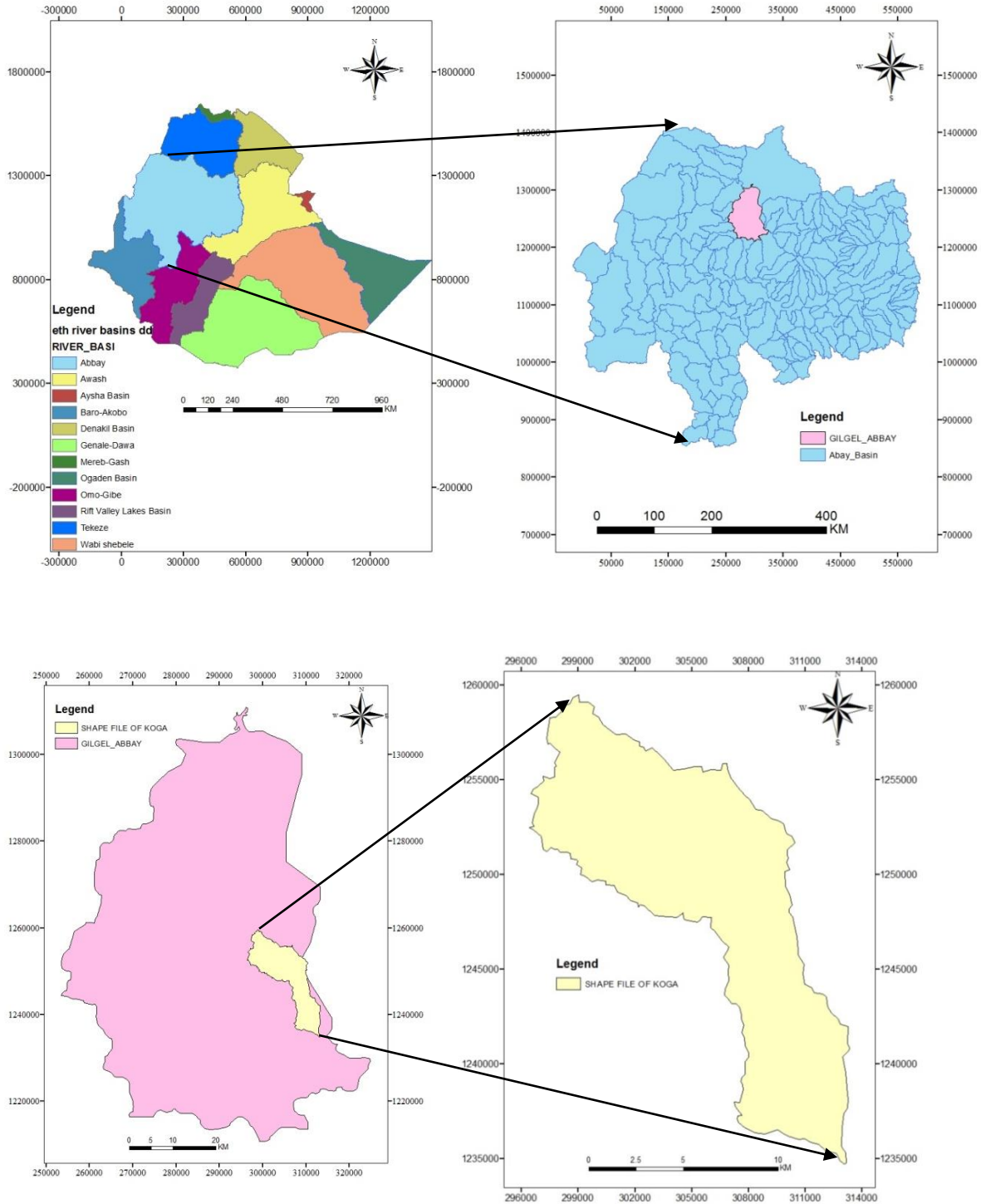


Figure 3.1 Location of study area

3.2.2 Koga Reservoir

Koga reservoir has a capacity to impound a total volume of 83.1 MCM of water at full supply level with an elevation 2015.25 masl by inundating 18.56 km² to irrigate 7,000 ha command area. Figure 3.2 shows site and aerial view of Koga Reservoir. The impoundment is formed by the damming of Koga river which is a second order stream flowing to Lake Tana (Mott MacDonald, 2004).



Figure 3.2 Site and Aerial view of Koga Reservoir (source from site visit and Google earth respectively)

3.2.3 Koga River

As shown in figure 3. 3, Koga River is 64 km long which is flowing into the Gilgel Abay River, the major tributary of Lake Tana. Koga River is the only river that flows into the reservoir (Mott MacDonald, 2004).



Figure 3.3 Koga River at January (source from site visit)

SEDIMENTATION PROBLEM AND MITIGATION MEASURE OF KOGA RESERVOIR

Table 3.1 Salient Features of the Koga dam (Mott MacDonald 2006) interim report

Item	Unit	Koga dam
Crest elevation	m	2019.5
Crest length of earth dam	m	1730
River bed elevation	m	1998
Maximum height	m	21
Spillway type	-	Overflow ogee type
Spillway crest elevation,		2015.25
Crest length	m	21.5
Spillway gates	-	Uncontrolled crest
Full supply level (FSL)	m	2015.25
Dead storage	CM	393000
Live storage	MCM	79.4
Dead storage level (DSL)	m	2007.5
Maximum water level	m	2016.94
Maximum storage	MCM	83.1
Maximum submergence	ha	2041
Diversion work and low level outlet	-	3m gate conduit on the left bank of the river
Design discharge of outlet works	m ³ /s	9.1

3.2.4 Topography

Topography is an important determining factor for reservoir sedimentation determination. It is characterized by the slope angles and the length and the shape of the slopes. The greater of the slope angle of the land and the length of the slopes, the more severe is the soil erosion that may occur. Increased slope angle cause increased runoff velocity, and with this, the kinetic energy of water causes more erosion. Long slopes allow the runoff to build up, increasing its volume and causing yet more series erosion.

The Koga watershed has two watershed parts, the upper and the lower part. The upper part is narrow steep valleys draining the flanks of the Mount Adama range. The lower catchment, where the irrigation scheme is located, comprises a much flatter plateau with some undulating topography in places and extensive flood plains bordering the Koga River during the rainy season, though they are otherwise mainly used as grazing lands (Figure 3. 4) (Mott MacDonald, 2004).

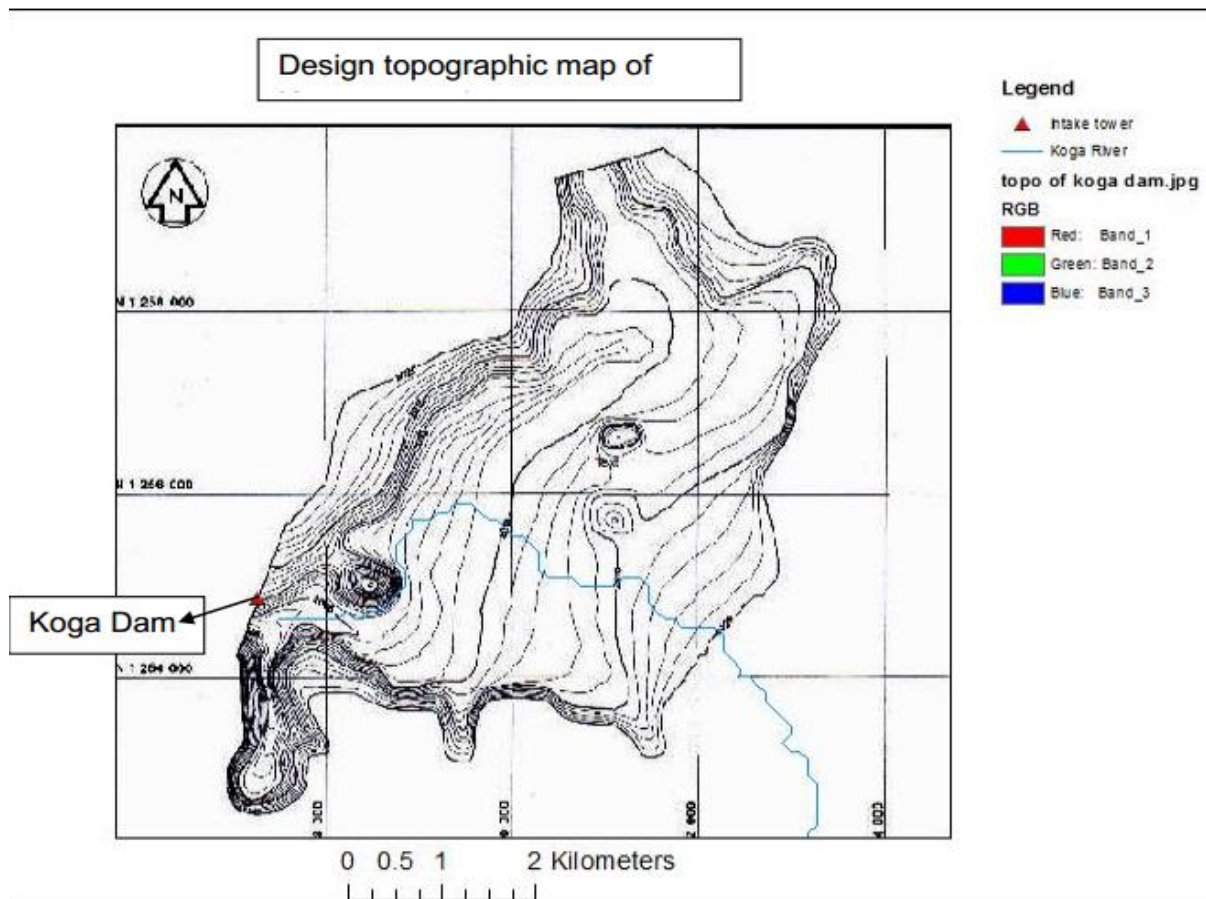


Figure 3.4 Design topographic map of Koga reservoir (source: MoWIE)

3.2.5 Climate

The climate of the Koga catchment falls within the Woina Dega and Dega zones. The majorities of the catchment are allies with in the Woina Dega zone (Mott MacDonald, 2004)

The climate of the catchment is largely controlled by the movement of air masses associated with the Inter-Tropical Convergence Zone (ITCZ). The Inter-Tropical Convergence Zone (ITCZ), a low-pressure zone at the meeting point between the dry northeasterly and moist southwesterly winds, is the major rainfall mechanism in the area (Mott MacDonald, 2004)

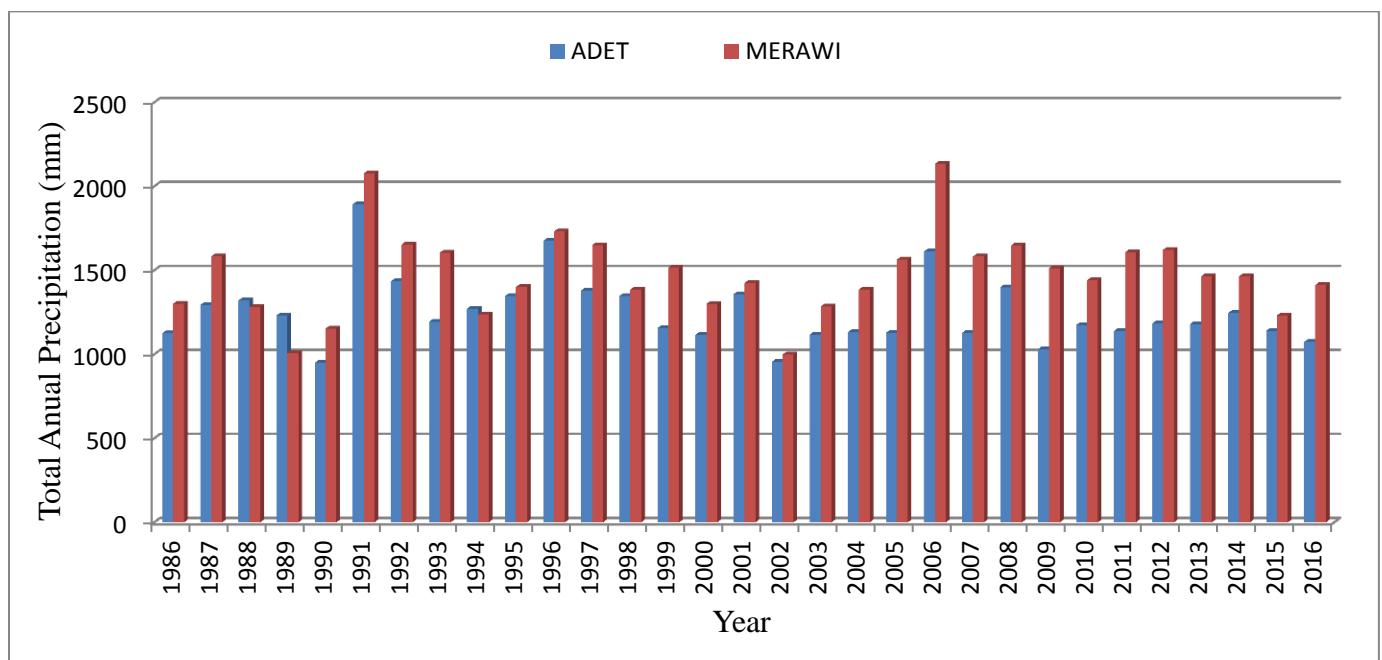


Figure 3.5 Total annual precipitation of Koga catchment

Koga watershed has uni-modal rainfall characteristics, with one rainy and one dry season (Figure 3.5). The dry season, called the Bega, occurs between November and April while the Kirement or rainy season is between May and October. More than 90% of the annual rainfall occurs in the wet season months. A high concentration of rainfall occurs in July and August when the ITCZ is to the north of the project area, rainfall is at a maximum. The precipitation exceeds 2134.4 mm/year in some areas, whilst at the lowest precipitation of Koga catchment is often below 949.7mm/year.

3.2.6 Geology

The regional geology comprises flow type rocks of Tertiary origin. The Koga catchment is underlain primarily with basalt inter bedded with pyroclastic deposits. Rocky outcrops occur primarily at higher elevations. Most of the catchment covered by highly weathered red clay soils, with alluvial deposits bordering the river at lower elevations (AfDB, 2000).

The regional geology of the Koga catchment comprises extensive flow type, volcanic (extrusive) rocks mainly of the Ashangi Group; these were deposited during the palaeocene-Oligocene-Miocene (tertiary) stages of geological time. The Ashangi group comprises the older volcanic rocks, which were formed by lava and debris, ejected from fissural volcanic eruptions. The choke shield volcanic group, deposited during the Miocene and Pliocene, has covered a small area of the upper Koga catchment in the eastern part. The shield volcanic group consists mainly of pyroclastic basalt and is petro graphically similar to the Ashangi group (Eleni Yeshaneh, et al 2013).

3.2.7 Soils

There are two types of soil in Koga catchment. These are Euvetisols and chluvisols. According to Agizew Nigussie Engida (2010) Euvetisols are deep clayey soils that expand upon wetting and shrink upon drying. They are found in level to undulating terrain with distinct wet and dry periods. They are poorly drained and largely have good water holding capacity. Chluvisols: These are soils developed in fluvial, alluvial, lacustrine or marine deposits and are common along rivers and lakes, in floodplains and deltaic areas. Chluvisols in upstream parts of river systems are normally confined to narrow strips of land adjacent to the actual riverbed. Figure 3.7 show the Koga catchment soil.

3.2.8 Land Use and Land Cover

Land use is the most important factor affecting reservoir sedimentation and it is strongly affected by the human activities. Human disturbs the natural environment, for the purpose of farming activity and building houses dramatically increase erosion. Figure 3.8 show land use land cover of Koga catchment.

Land use of Koga catchment is dominated by agricultural land. The farming system is traditional and depends on use of oxen for land preparation, rain dependent, subsistence farming.

3.3 Materials and Methods

The materials used for the study are Sediment sample kit and GPS. Arc SWAT 2012 version 2012.10_3.19 Arc GIS 10.3.1 interface which was developed by Stone Environmental, Inc. used to simulate the sediment yield inflow from the catchment in to Koga reservoir. SWAT CUP 2012 version 5.1.6.2, SUFI-2 algorithm was used to calibrate and validate the simulated model results. Model selection was based on;

- The performance of the model when tested in different watersheds in Ethiopia.
- The performance of the model to carry out required output to meet the objective of the thesis.
- The availability of input data
- The complexity or simplicity of model analysis
- The availability of the model to download freely
- The time required to do the thesis work (based on the thesis schedule)

SWAT model was selected by fulfilling the criteria mentioned above. As shown on figure 3.7, from Koga catchment and reservoir sediment samples were collected as primary data and analyzed using laboratory, finally the results are interpreted. Including previous research works, secondary data metrological data (rainfall data, temperature data, solar radiation data, wind speed data and relative humidity data) and spatial data (DEM, land use data and soil data) were collected for SWAT input. Hydrological data (stream flow data and sediment data) were collected for SWAT CUP input. Metrological data and hydrological data were analyzed and imported to SWAT model as per required, Swat project set up, watershed delineation, create HRUs, defining weather data, SWAT model setup, were the steps to run the SWAT model. To calibrate and validate the simulated SWAT model results, sensitive parameters were selected as SWAT CUP input. Out of those total Hydrological data two-third used for calibration purpose and one-third used for validation purpose. Model performance is evaluated by coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE). From calibrated SWAT model result, the most vulnerable prone-areas were identified. By re-running the SWAT model and taking suggestion from the farmers at Koga catchment, different scenarios were developed to reduce sediment depositing in Koga reservoir. Finally, the laboratory result and the calibrated model result were interpreted to identify the distribution, the grain size variation of sediment load and develop the appropriate catchment rehabilitation measures.

The detail methodology explained in the following flow chart (figure 3.6).

SEDIMENTATION PROBLEM AND MITIGATION MEASURE OF KOGA RESERVOIR

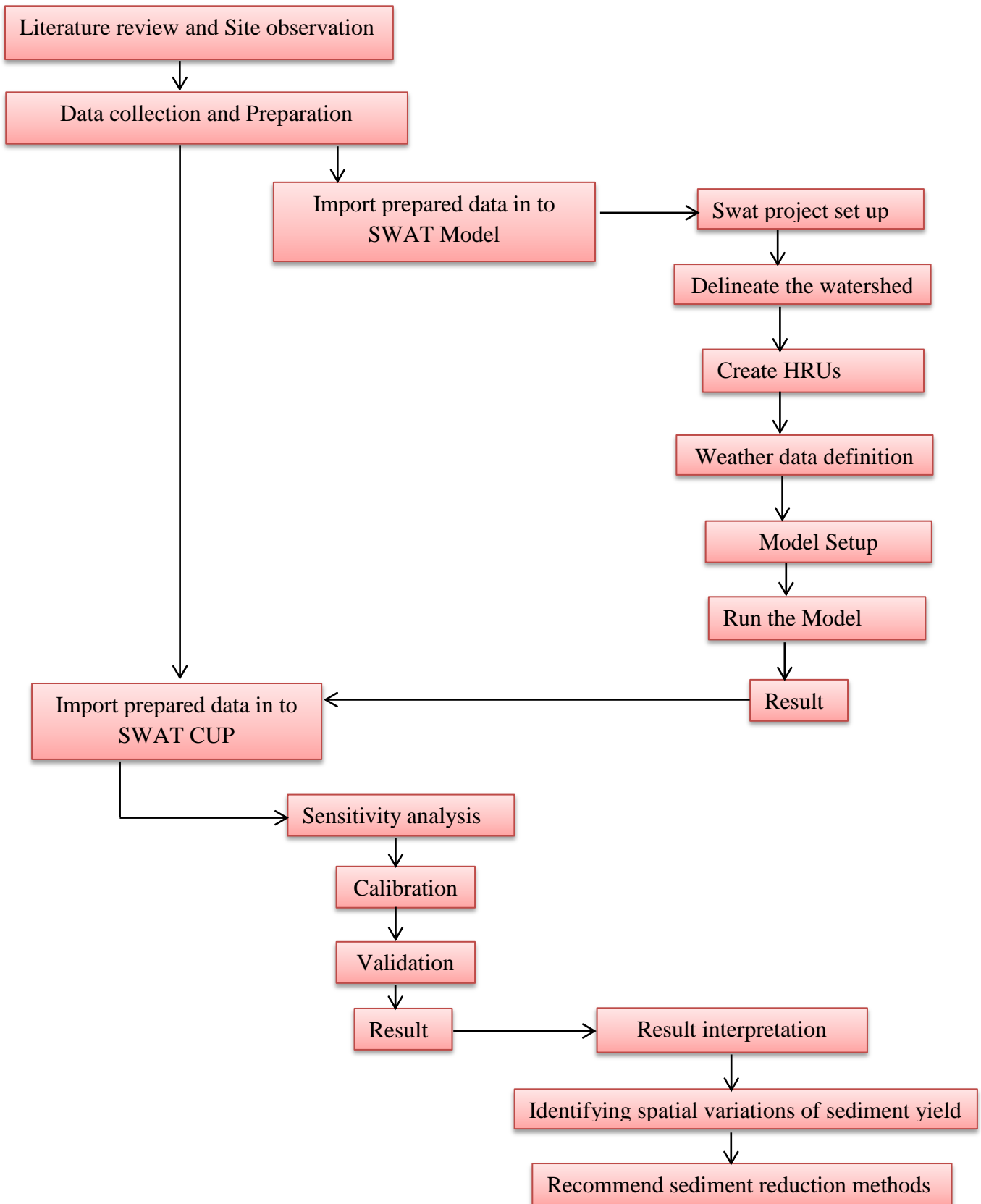


Figure 3.6 Conceptual framework of the methodology

3.3.1 Data collection and analysis

The general method of this study is collecting primary data from site and secondary data from different organizations that used to estimate the sediment yield of Koga reservoir using SWAT model which is used to identifying the most vulnerable watershed to develop the sediment reduction measures. The detail data collection explained in the following flow chart (figure 3.7).

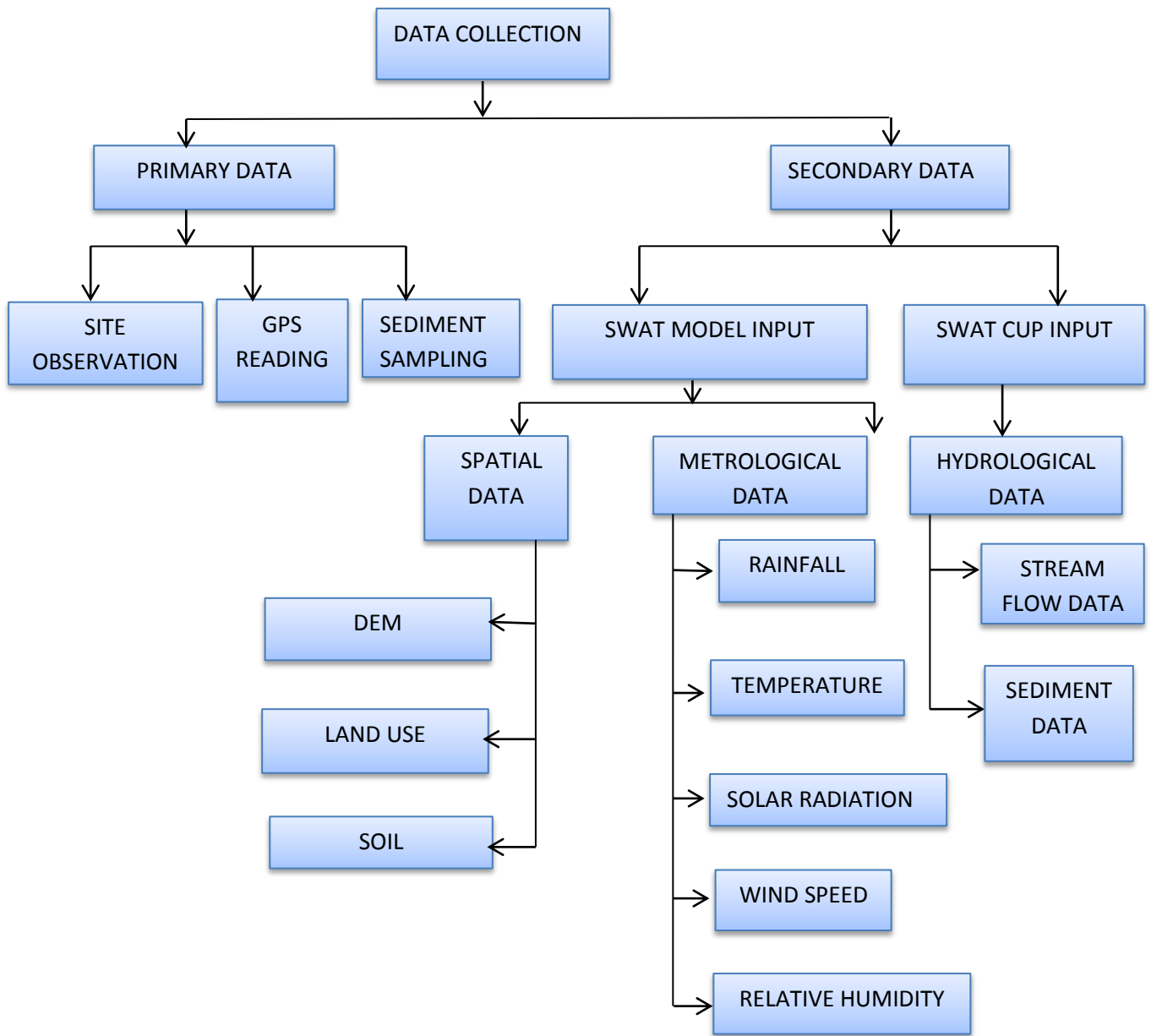


Figure 3.7 Conceptual framework of the data collection

3.3.2 Primary data collection

Sediment data was collected (figure 3.8) from site to identify the distribution, the grain size variation of sediment load and as an input for soil and water conservation analysis. The samples were collected from two different locations, one from reservoir inlet and the other from the side of the reservoir.

The field investigation is also made for the observation of hydro geological features, the confirmation of the secondary data collected from different organization for confidential conceptual model. GPS reading was made at the dam site and it has 37°08' E and 11°20' N coordinate.



Figure 3.8 primary data collection

3.3.3 Secondary data collection

Secondary data were collected as input for this study. It includes previous research works, metrological data (rainfall data, temperature data, solar radiation data, wind speed data and relative humidity data), hydrological data (stream flow data and sediment data), and spatial data (DEM, land use data and soil data).

3.3.3.1 Meteorological data

Meteorological data including daily data of rainfall, minimum and maximum temperature, relative humidity, wind speed and sunshine hours were collected from National Metrological Agency (NMA).

Based on national meteorological agency, there are four types of station classes. These are:

Class 1: These are principal stations where meteorological observations are made for Climatological purposes every three hours from 03:00 to 15:00 GMT hours. There are more than 150 principal stations in

Ethiopia. Observed climatological variables include rainfall, maximum and minimum temperatures, sunshine hour, relative humidity, wind speed at 2m and 10m heights, pitch evaporation and soil temperature.

Class 2: These are synoptic stations at which meteorological observations are made for synoptic meteorology purpose every hour for 24 hours a day at full GMT hours. There are 22 Synoptic stations in Ethiopia.

Class 3: These are ordinary stations at which only minimum and maximum air temperatures of the day and total rainfall amount in 24 hours are observed. Minimum temperature observation is taken at 06:00 and maximum temperature is observed at 15:00 hours.

Class 4: These are stations at which only total daily rainfall is observed (Source NMA, 2009).

3.3.3.2 Hydrological data

Stream flow data were collected from Ministry of Water, Irrigation and Electricity (MoWIE) and Ethiopian Construction, Design and Supervision Works Cooperation.

3.3.3.3 Sediment data

Eleven years (2004-2014) Seven years for calibration and four years for validation purpose, yearly sediment concentration data were collected from MWIE, Hydrology and Water Quality Directorate and ECDSWC at Koga dam site station (37⁰ 08' E and 11⁰ 20' N).

3.3.3.4 Spatial data

Soil shape file, land use/land cover shape file and 30m by 30m resolution digital elevation model were collected from Ministry of Water, Irrigation and Electricity (MoWIE).

3.3.3.5 Meteorological Data Collection and Analysis

Metrological data was collected from National Metrological Agency including Rainfall, Maximum and Minimum air Temperature, Wind speed, Solar Radiation and Relative Humidity of two stations in and outside the Watershed. The data was collected starting from 1986 up to 2016. If the missing than is more than two months in a year the data is considered as unavailable or missed data.

Merawi metrological station is class 3 meteorological station with (37⁰09' E and 11⁰25' N), and at an altitude of about 2020 m. The available data contains only daily rainfall, and average monthly minimum and

maximum temperatures. From the beginning of 1996 up to 2004 the station has not operated. A number of gaps are found within the period of record. The mean annual rainfall for Merawi is 1473mm.

Adet metrological station is Class 1 meteorological station with 37°49’ E and 11°27’ N, and at an altitude of about 2016m. The available data includes Wind speed, Solar Radiation and Relative Humidity, additional to daily rainfall, and average monthly minimum and maximum temperatures data. The station has better recorded precipitation and temperature data, but lack of sunshine hour has been observed. The mean annual rainfall for Adet is 1250 mm.

Based on from 1986 up to 2016 collected metrological data, the maximum precipitation occurs during June, July and August (figure 3. 9) (Table 3. 2). The precipitation characteristic of Koga catchment is uni-modal pattern. The mean annual rainfall for the catchment is 1361.65mm.

Table 3.2 Mean monthly precipitations of Merawi and Adet meteorological stations

Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Merawi	2.74	4.76	19.3	44.3	120.9	263.8	357.8	324.9	211.4	94.21	24.79	4.08
Adet	7.75	9.26	31.78	54.02	111.6	154	315.3	260.5	160.8	111.1	24.3	9.14

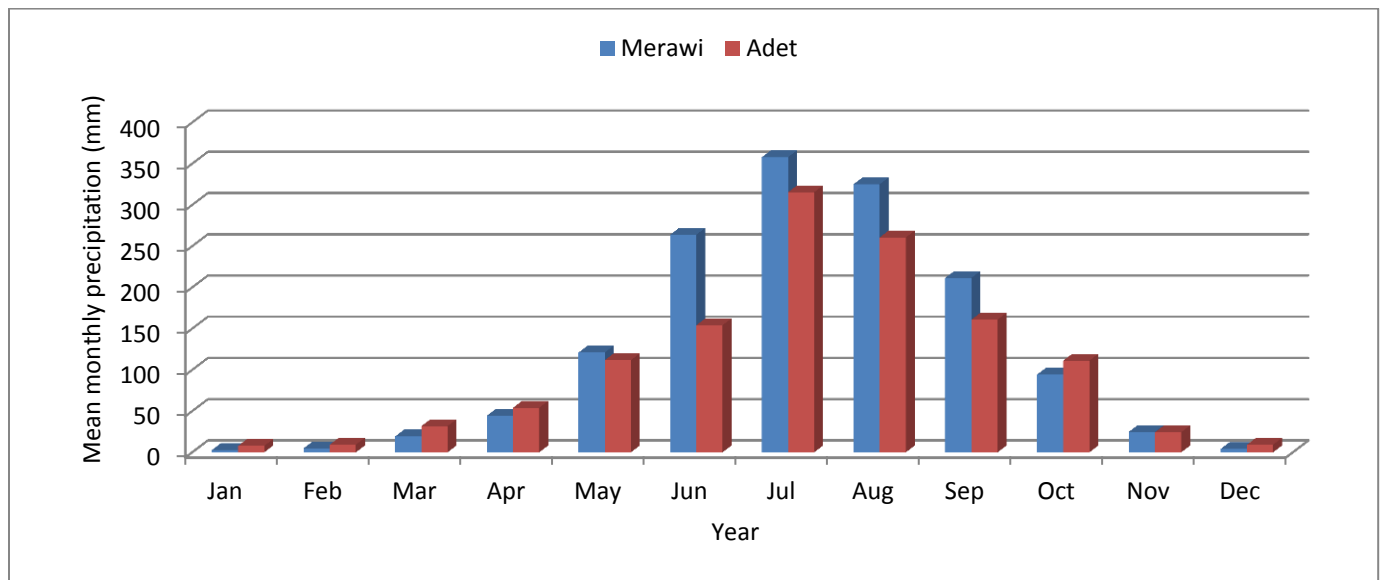


Figure 3.9 Mean monthly precipitation of Koga catchment

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The temperature and rainfall graphs were made using data from both Merawi and Adet meteorological stations. The daily minimum and maximum temperature values of Merawi & Adet are closely related because temperature has a relation with altitude. When temperature increases, altitude decreases.

In the Koga catchment, the average monthly maximum temperature varies from 27.6°C to 26.2°C and the average monthly minimum temperature varies from 9.9°C to 9.8°C. Figure 3.10 and 3.11 shows the average monthly maximum and minimum temperature each station, respectively.

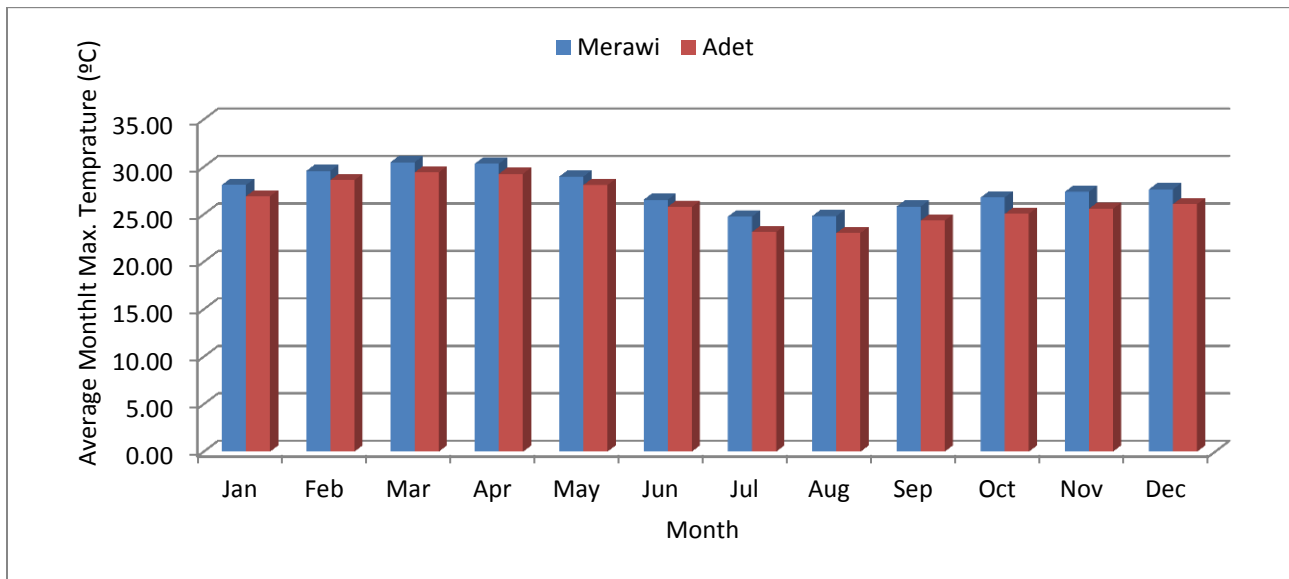


Figure 3.10 Mean monthly maximum temperature of Koga catchment

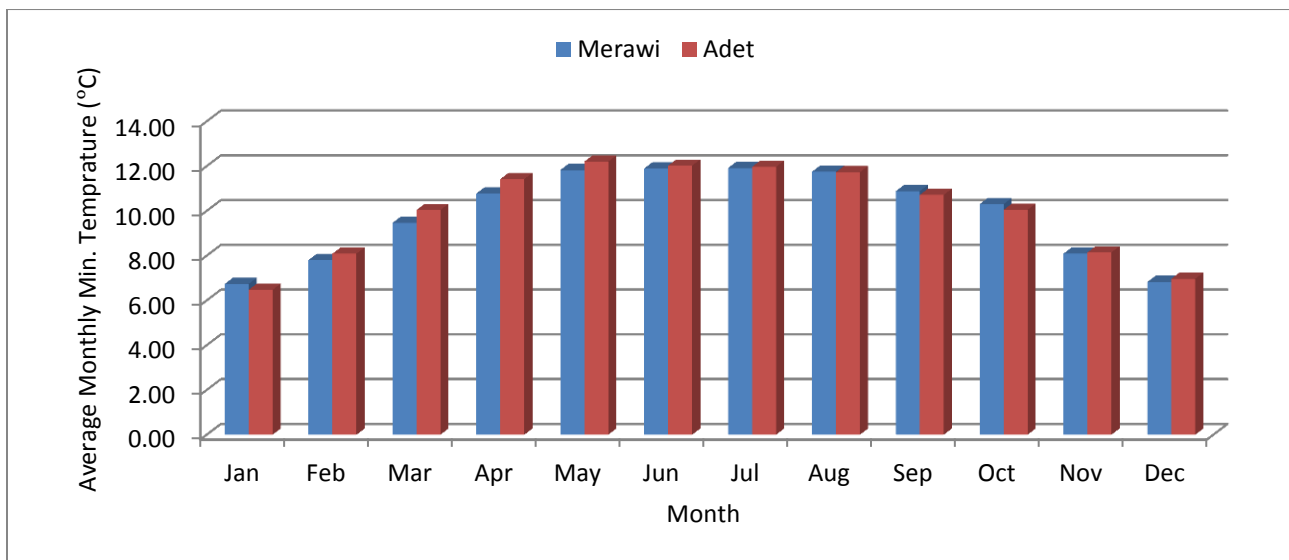


Figure 3.11 Mean monthly minimum temperature of Koga catchment

3.3.3.6 Meteorological data availability

The data availability of daily meteorological record is checked for and the results are discussed below.

Rainfall

Rainfall is the most important climatic factors determining reservoir sedimentation. High sedimentation will occur related to higher rainfall intensities. The daily rainfall data which was obtained from Merawi ordinary metrological stations has some years of data gap. The available data is also fragmented (table 3. 3). Overall, the station data coverage starting from 2005 appeared to be good. Adet is principal station. It has very good rainfall data, so it used to fill the missing gap of Merawi rainfall data using weather generator.

Table 3.3 Rainfall data availability for Merawi and Adet meteorological station

Station/year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Merawi	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
Adet	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█

█ shows data availability whereas □ shows data unavailability at that time

The rainfall data coverage in the basin was checked by recommended minimum precipitation network density by the World Meteorological Organization (WMO) indicated in Table 3.4. Koga catchment is 100% covered by Merawi metrological gauging station.

Table 3.4 Recommended minimum precipitation network density (WMO, 1994)

No.	Physiographic unit	Minimum area per station (km ² per station)	
		Non-recording	Recording
1	Mountainous	250	2500
2	Interior plains	575	5750
3	Hilly/undulating	575	5750

Temperature

Table 3.5 shows, the Merawi daily minimum and maximum temperature data availability was checked, and it is relatively poor up to the year 2005 whereas Adet has very good quantity of data with some month missing data.

Table 3.5 Temperature data availability for Merawi and Adet meteorological station

Station/year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
Merawi																																
Adet																																

■ shows data availability whereas □ shows data unavailability at that time

Relative humidity

Table 3.6 shows, only Adet metrological station has fragmented and has no data from 1996 up to 2000 and from 2006 up to 2014 which must be filled by data gap filling method for weather generation purpose.

Table 3.6 Relative humidity data availability for Merawi and Adet meteorological station

Station/year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Adet																															

■ shows data availability whereas □ shows data unavailability at that time

Wind speed

Table 3.7 shows, Adet metrological station has almost full wind speed data except for the year 1991, 2004 and 2012. These data gap is filled with data method as an input for weather generator.

Table 3.7 Wind speed data availability for Merawi and Adet meteorological station

Station/year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Adet																															

■ shows data availability whereas □ shows data unavailability at that time

Sunshine hours

Table 3.8 shows, sunshine hour data is found only from 2005 up to 2009. The other years will be filled for an input for weather generator.

Table 3.8 Sunshine hour data availability for Merawi and Adet meteorological station

Station/year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Adet																															

████████ shows data availability whereas shows data unavailability at that time

3.4 Data Analysis

3.4.1 Data quality and consistency

The daily rainfall data of Merawi and Adet metrological stations quality control was done to detect outliers. The inconsistency of record data at a given weather station can be caused by instrumental error and/or human errors. The data must be checked whether it is consistent and homogeneous or not before using it as an input for SWAT model otherwise, it could give erroneous output.

The first step involved quality control checks by visual inspection to ensure that data is with invalid ranges and no strange values are entered.

Based on national metrological agency standard the following valid range data checking was done.

Daily precipitation must be less than or equal to 250 mm, the minimum temperature must be greater than or equal to -10 °C, for maximum temperature must be greater than or equal to 55°C was taken. Sunshine hours must be between 0 - 13 hours, Daily wind speed must be less than or equal to 15 m/s, the relative humidity must be between 0 -100 percent.

Some unrealistic observed values of rainfall data was there and taken as no data to be filled later. No obvious deviations in wind speed could be detected. The result showed no significant inconsistency in the observed minimum and maximum temperatures. The majority of the observed Wind speed data were found to be within the specified minimum and maximum limits but few records did not meet the requirement. Sunshine data did not have quality problem.

The second data quality control was tested by double mass curve analysis in which precipitation data is plotted against the mean value of all neighborhood stations. The double mass curve method helped in identifying gaps or unphysical peaks in data series and correcting them before the data is used as input for the model. This technique is based on the principle by Subramanya, 2008 each recorded data from the same parent population is consistent. The precipitation data must be checked for continuity and consistency before it is used for further analysis. The quality control can be done by visual inspection, filling of missing data if there is any gap, accumulated plot and double mass curve (figure 3.12). Using inaccurate data as input to the model will give wrong output from the model.

Correct precipitation can be obtained as;

$$Pcx = Px \left(\frac{Mc}{Ma} \right) \tag{Equation 3.1}$$

Where: Cumulative average annual rainfall for neighboring station (mm)

Pcx = correct precipitation at any time t_1 at station x

Px = original record precipitation at any time t_1 at station x

Mc = correct slope of the double mass curve

Ma = original slope of double mass curve

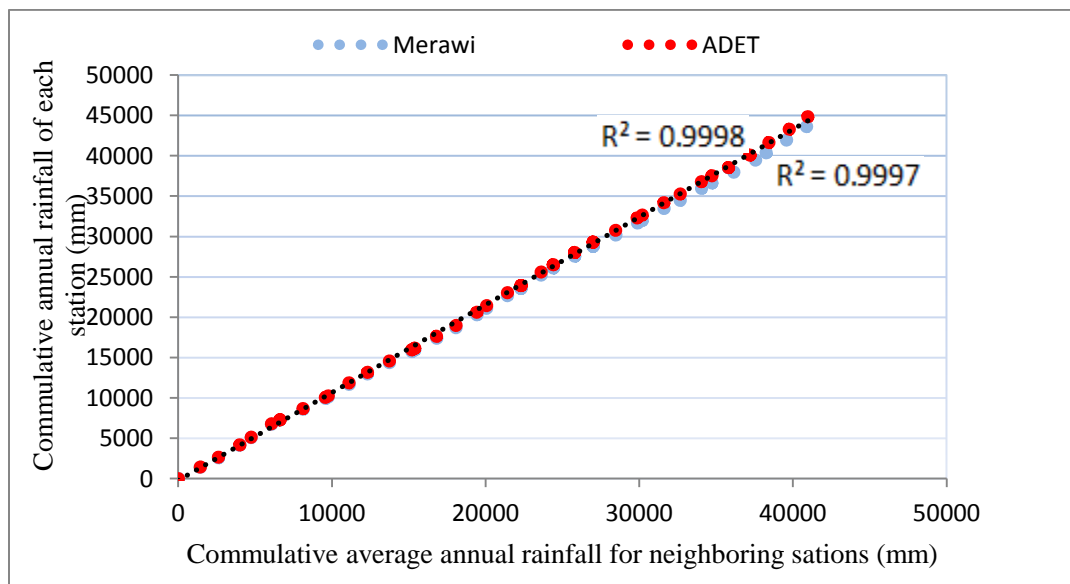


Figure 3.12 Double mass curve plots for selected metrological station

3.4.2 Filling Missing data

All weather stations do not have full time series observation data because of measurement error. Therefore, it is necessary to fill this missing gap. The missing precipitation data gap is calculated from the observations of nearby stations. There are some methods that used to fill the missing data. Some of them are arithmetic means method, normal ration method, and inverse distance weighing method and regression method.

According to Richard H. (1998) Arithmetic mean method can be used to fill the missing data when the normal annual precipitation is below or equal to 10% of the station which data are being recorded. The normal ration method is used when the normal annual precipitation any of index station different from that of precipitation station by more than 10%. When there is no normal annual precipitation for the station, inverse distance weighing method can be used to fill the missing data. Another method is regression/Excel STAT used to fill the missed data from nearest station. For this study Excel STAT, normal ratio method and arithmetic mean is used (Equation 3.2). The two formulas are described below.

Arithmetic mean method

$$P_x = \frac{(P_1 + P_2 + P_3 \dots P_n)}{N} \quad \text{Equation 3.2}$$

Where:

P_x = the precipitations from the station with the missed record $P_1, P_2, P_3 \dots P_n$ are the corresponding index station.

N = number of index station

The normal ratio method is used when the surrounding gauged have the normal annual precipitation exceeded 10% consider gauged (Equation 3.3).

$$P_x = \frac{N_x}{N} \left(\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \dots \frac{P_n}{N_n} \right) \quad \text{Equation 3.3}$$

Where:

P_x = missing values of precipitation to be computed

$P_1, P_2, P_3 \dots P_n$ = rainfall neighboring station during missing period

$N_1, N_2, N_3 \dots N_n$ = average values of rainfall for the neighboring station

N = Number of station used in the computation

Nx = Average values of rainfall for the station in question for the recording period

3.4.3 Checking Homogeneity of Selection Station by Non-Dimensional Parameterization

Checking homogeneity of group stations is useful to select the representative meteorological station for the rainfall analysis. The causes of variation can naturally by land use change. These include alterations to land use and relocation of the observation station. Therefore, monthly rainfall records of the homogeneity of selected gauging stations were carried out by non-dimensional (Equation 3.4) as follows.

$$Pi = \frac{\bar{P}i}{P} * 100 \tag{Equation 3.4}$$

Where:

Pi is a non – dimensional value of precipitation for the month in the station i

$\bar{P}i$ is over year’s average monthly precipitation for the station i

\bar{P} is over year’s average yearly precipitation for the station i

The selection stations are plotted for compares for each other and the same – mode and pattern of the stations are observed and hence group stations selected are homogenies (figure 3.13).

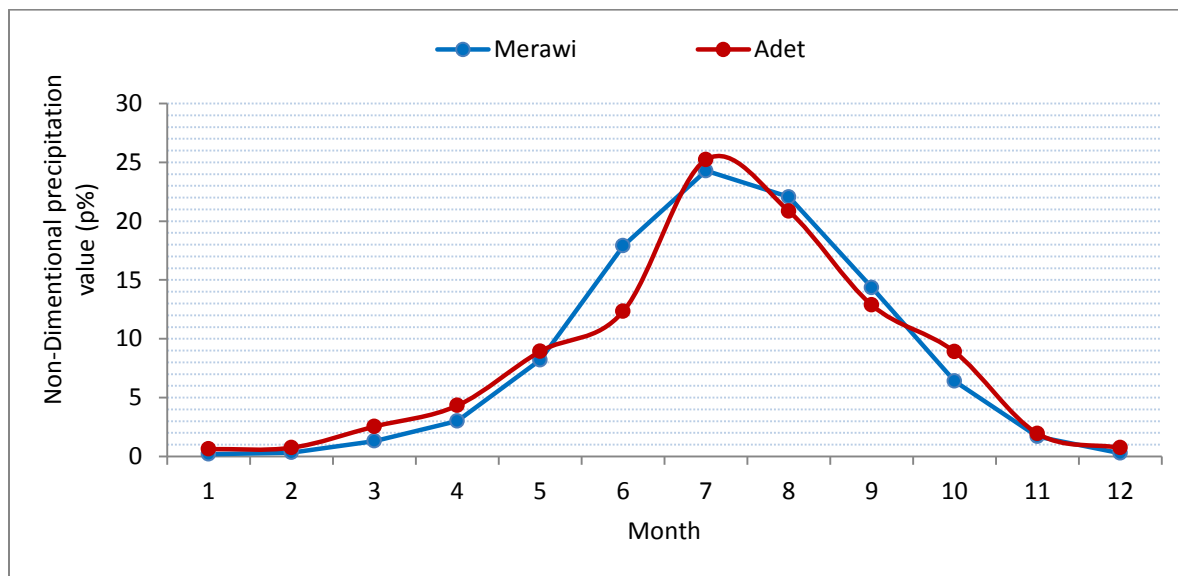


Figure 3.13 Homogeneity test for Merawi and Adet weather station

3.4.4 Hydrological Data Collection and Analysis

3.4.4.1 Stream flow Data Collection and Analysis

The Koga River at the Koga dam drains a watershed of 155.75 km². The average discharge of the catchment in thirty one years of record period (1986 - 2016) is 5.2 m³/s (figure 3.14). Daily flow data is required for SWAT input for calibration and validation purpose. This data was obtained from Ministry of Water, Irrigation and Electricity, Hydrology and Water Quality Directorate and Ethiopian Construction, Design and Supervision Works Cooperation. Flow data was collected and arranged as per the requirement of SWAT CUP. Flow at the Koga Dam site was synthesized for rating curve development.

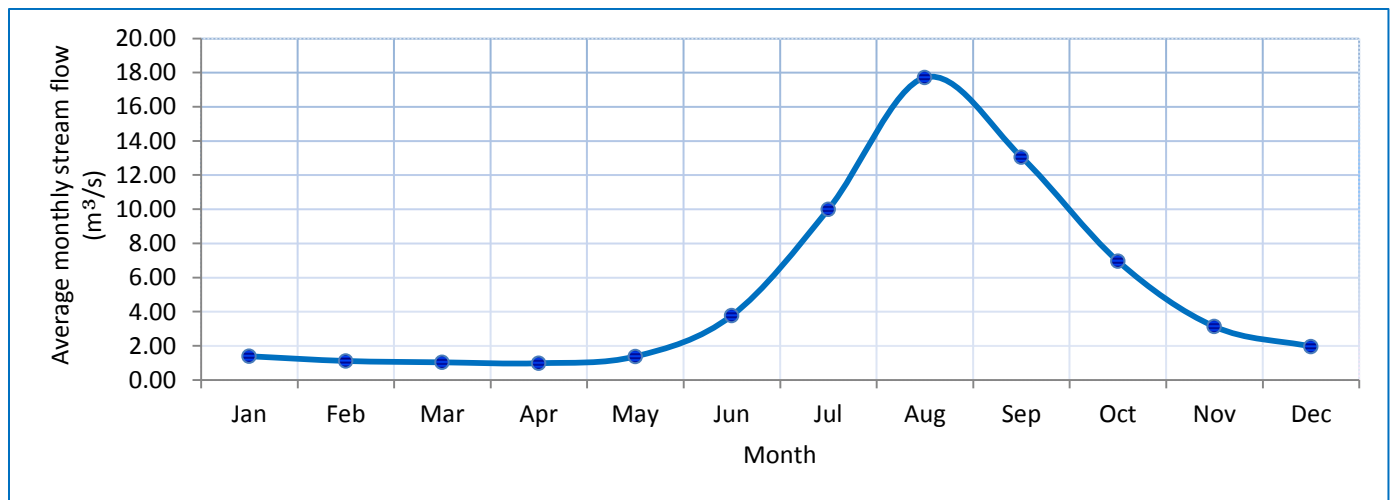


Figure 3.14 Monthly average stream flows at Koga watershed dam site (1986-2016)

According to Mott MacDonald, (2004) the maximum stages for dam Site inflows have been estimated using the rating curve derived from Koga dam site. The peak discharge estimates are shown in table 3.9

Table 3.9 Peak discharge estimation at koga dam site (Mott MacDonald, 2004)

Return Period	Rainfall (mm)	Catchment Rainfall (mm)	Peak Discharge (m ³ /s)	Volume (m ³ 10 ⁶)	Flow depth (m)
10 year	44.1	38.8	48.9	0.74	3.01
20 year	51.6	45.4	78.2	1.18	-
50 year	61.2	53.9	122.7	1.85	-

3.4.4.2. Sediment Data Collection and Analysis

Sediment rating curve

To calibrate and validate the SWAT model, adequate measured flow and sediment data are required. If not sediment rating curve used to estimate suspended sediment when measured data are inadequate (Asselman, 2000). Sediment rating curve expresses the average relation between river discharge and suspended sediment concentration for a certain existing data. Sediment rating curve developed from measured sediment data from that value were generated and arranged as per the requirement of SWAT CUP for sensitivity analysis and calibration of SWAT model. Measured sediment data was taken from MWIE, Hydrology and Water Quality Directorate and ECDSWC at Koga dam site (37⁰ 08' E and 11⁰ 20' N). The sediment rating curve usually express as a power function of discharge.

$$Q_s = aQ^b \tag{Equation 3.5}$$

Where: Q_s is suspended sediment (ton/day), a and b is regration coefficient and exponent and Q is river discharge.

The sample of suspended sediment measured by (mg/l) can be converted to sediment load (ton/day) by using the following formula.

$$Q_s = 0.0864 * C_s * Q \tag{Equation 3.6}$$

Where: Q_s is sediment load (ton/day), C_s is sediment concentration (mg/l), Q river flow (m³/s) and 0.0864 conversion factor.

Suspended fine silt particles from the catchment area rather than from streambed is called the wash load. Most of the time the ratio of bed load to suspended load is from 1:5 to 1:50 (Asselman, 2000). Therefore, in this study, 8% of the suspended load is taken as bed load (figure 3.15).

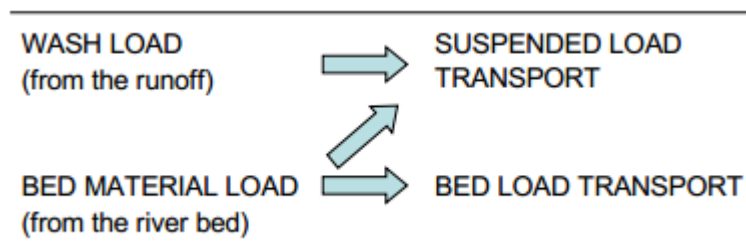


Figure 3.15 Composition of the sediment transport (George L. M. 2008)

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In this study, sediment rating curve was developed for wet and dry season separately because, the major sediment source occur in wet rainy season of the year due to 95% of the annual rainfall occurrence (figure 3.9) and availability of loose sediment from the ploughed agricultural fields (figure 3.16). Dry season relatively did not contribute reservoir sedimentation.



Figure 3.16 June run-off from ploughed fields and land use/cover (source from Eleni Yeshaneh, 2013)

Wet season and dry season sediment data values were obtained from dry season rating curve $SSY = 27.817 Q_{peak}^{1.292}$ and wet season rating curve $SSY = 0.0983 Q_{peak}^{2.2914}$ respectively (figure 3.17).

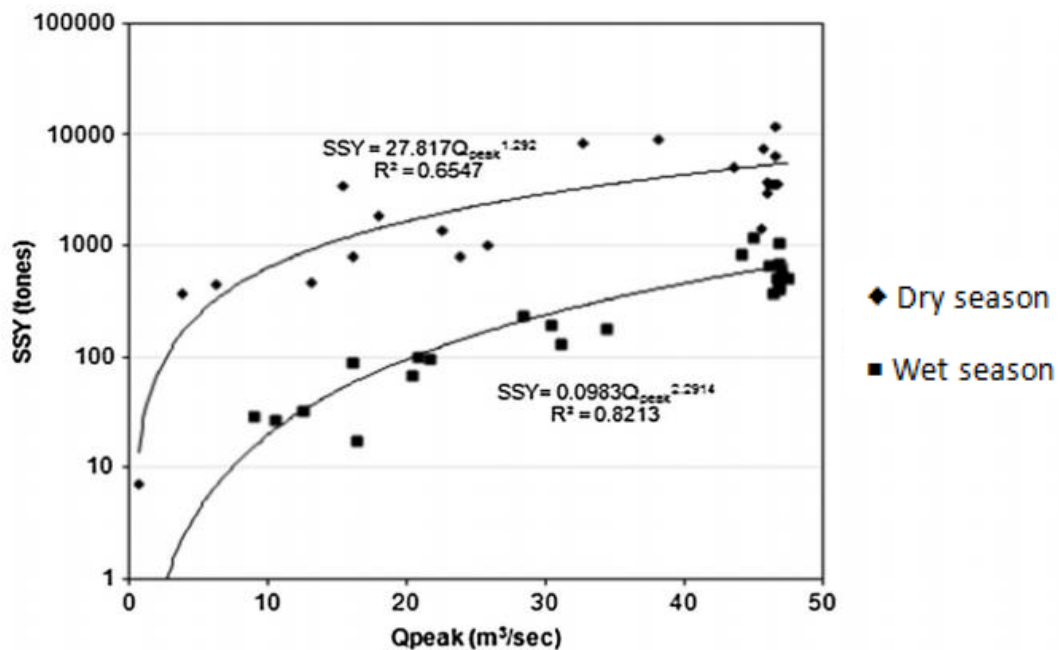


Figure 3.17 Sediment rating curves based on Q_{peak} for wet and dry season

3.4.5 Spatial Data Collection and Analysis

Spatial data are soil data, land use/land cover data, digital elevation model, and it is used as input for SWAT model for HRU definition.

3.4.5.1 Digital Elevation Model (DEM)

Digital Elevation Model data at a spatial resolution of 30m by 30m could be obtained from Ministry of Water, Irrigation & Electricity, GIS Team (figure 3.18). Digital elevation data is one of the basic inputs required by SWAT model to extract the altitude of the meteorological stations, and to derive basic watershed morphometric properties that include catchment boundaries, slope, stream networks, etc.

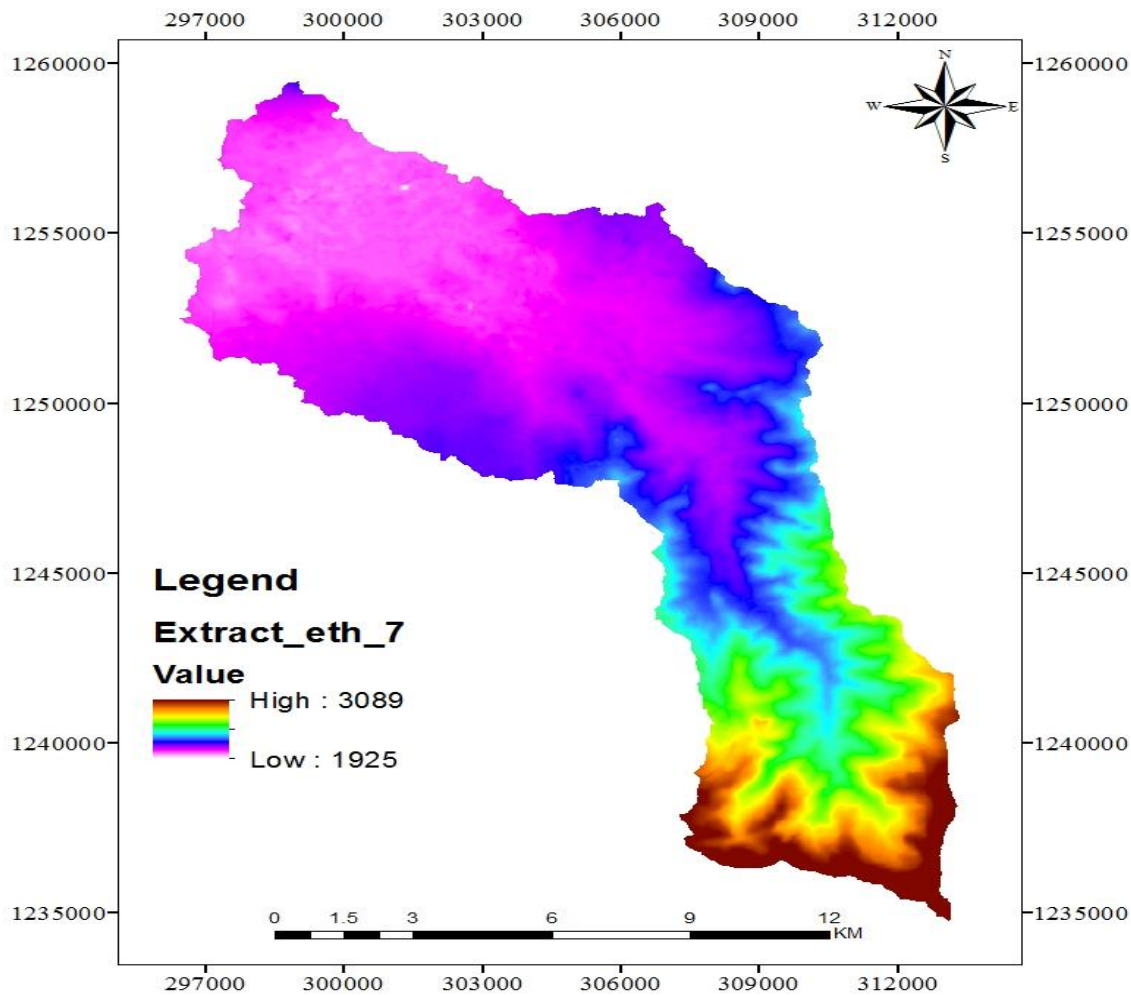


Figure 3.18 Digital elevation model of the Koga catchment

3.4.5.2 Land Use/ Land Cover

The land use/ land cover shape file was collected from MoWIE, GIS Team as an input for SWAT model (figure 3. 19). It shows the percentage of the types land coverage of the study area that indicates how people use the land resource. SWAT has predefined land uses identified by four letter codes and it uses these codes to link land use maps to SWAT land use databases in the GIS interfaces. Hence, while preparing the lookup table, the land use types were made compatible with the input needs of the model. Hence, the classified land use map and its attribute were adjusted to the SWAT model requirement format and database. Seven types of land cover classes could be identified for the Koga basin. The most dominant land use/ land cover are cropland and mosaic natural vegetation which are 74.67% and 16.73% respectively (table 3.10).

Table 3.10 Distribution of land cover types in Koga watershed data taken in 2014 G.C

No.	Land Use Types	SWAT Code	Area (ha)	PERCENT
1	Agricultural Land-Generic	AGRL	11630.1	74.67
2	Forest-Evergreen	FRSE	2604.95	16.73
3	Range-Grasses	RNGE	38.47	0.25
4	Range-brush	RNGB	148.73	0.95
5	Forest-Deciduous	FRSD	1132.53	7.26
6	Forest-Mixed	FRST	20.1	0.13
7	Water body	WATR	0.18	0.01
		Total	15575.06	100

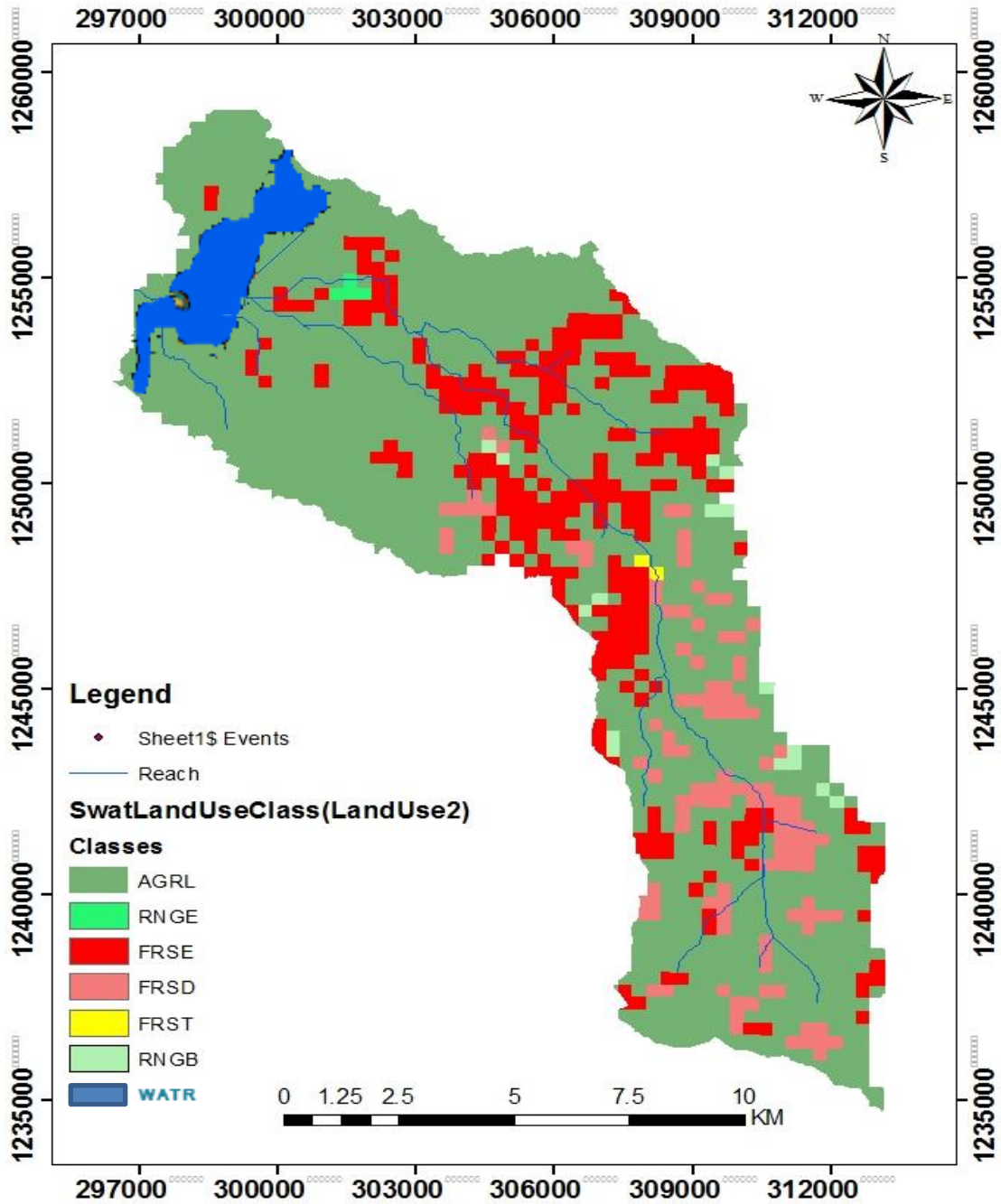


Figure 3.19 Land use/land cover map of Koga catchment data taken in 2014 G.C

3.4.5.3 Soil Data

For SWAT model input, the soil shape file was collected from MoWIE. Soil data provide a geographical representation of both the distribution of soil types and the various soil properties in the watershed that describe the soils hydrological including saturated hydraulic conductivity, field capacity, permanent wilting point, infiltration capacity, bulk density, and soil textural properties (figure 3.20). According to SWAT classification the Koga watershed comprises Chluvisols and Euvvertisols soil types (table 3.11).

Table 3.9 Soil Distribution of the Koga Watershed in 2014 G.C

No	Soil Name	SNAM	Area, (ha)	Percent of watershed area (%)
1	Chluvisols	LVx	12385	79.52%
2	Euvvertisols	VRe	3190	20.48%
Total			15575	100%

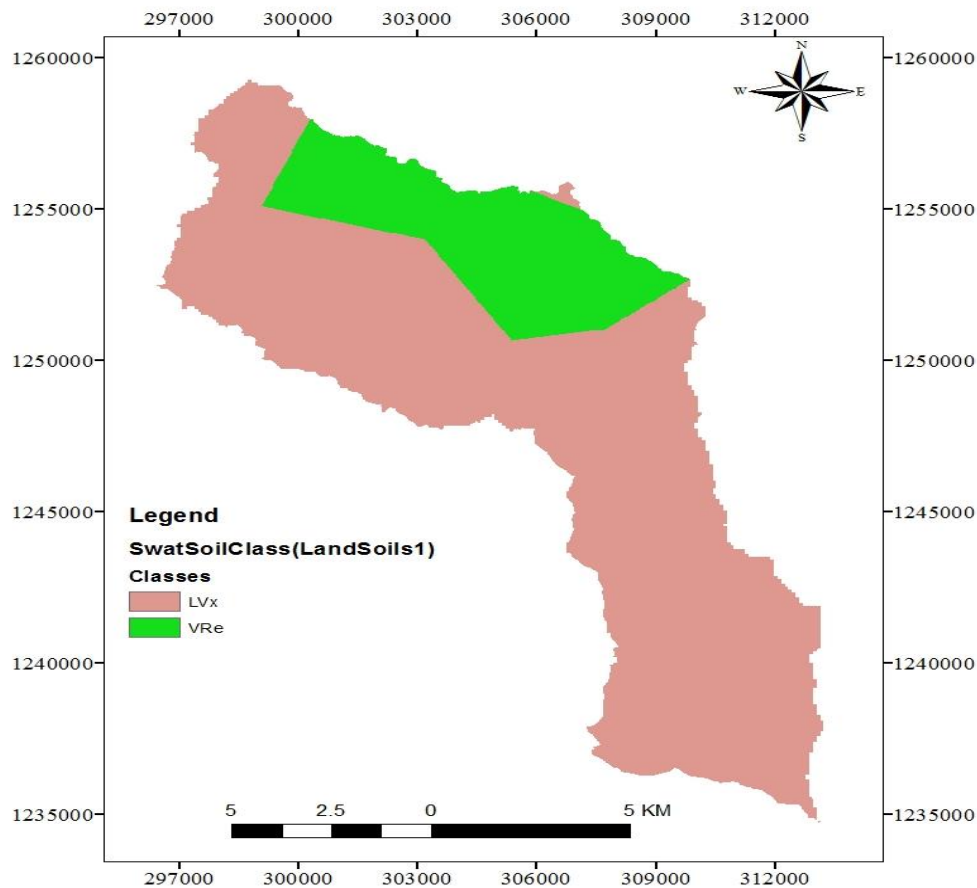


Figure 3.20 Soil map of Koga catchment in 2014 G.C

3.4.5.4 Slope

As per digital elevation model (DEM), the minimum and the maximum elevation in the watershed is 1,925 and 3,089 meter above sea level respectively (figure 3.21). The mean elevation of the watershed is 2197.65 meter above sea level. Table 3.12 shows the slope distribution of the Koga catchment in 2014 G.C.

Table 3.10 Slope Distribution of the Koga catchment

No.	Slope	Area contribution with respect to the outlet	
		Area (ha)	Area (%)
1	0-5	4926.21	31.63
2	5-10	4014.76	25.78
3	10-15	1924.33	12.36
4	15-20	1349.76	8.67
5	>20	3360	21.56
Total		15575.06	100

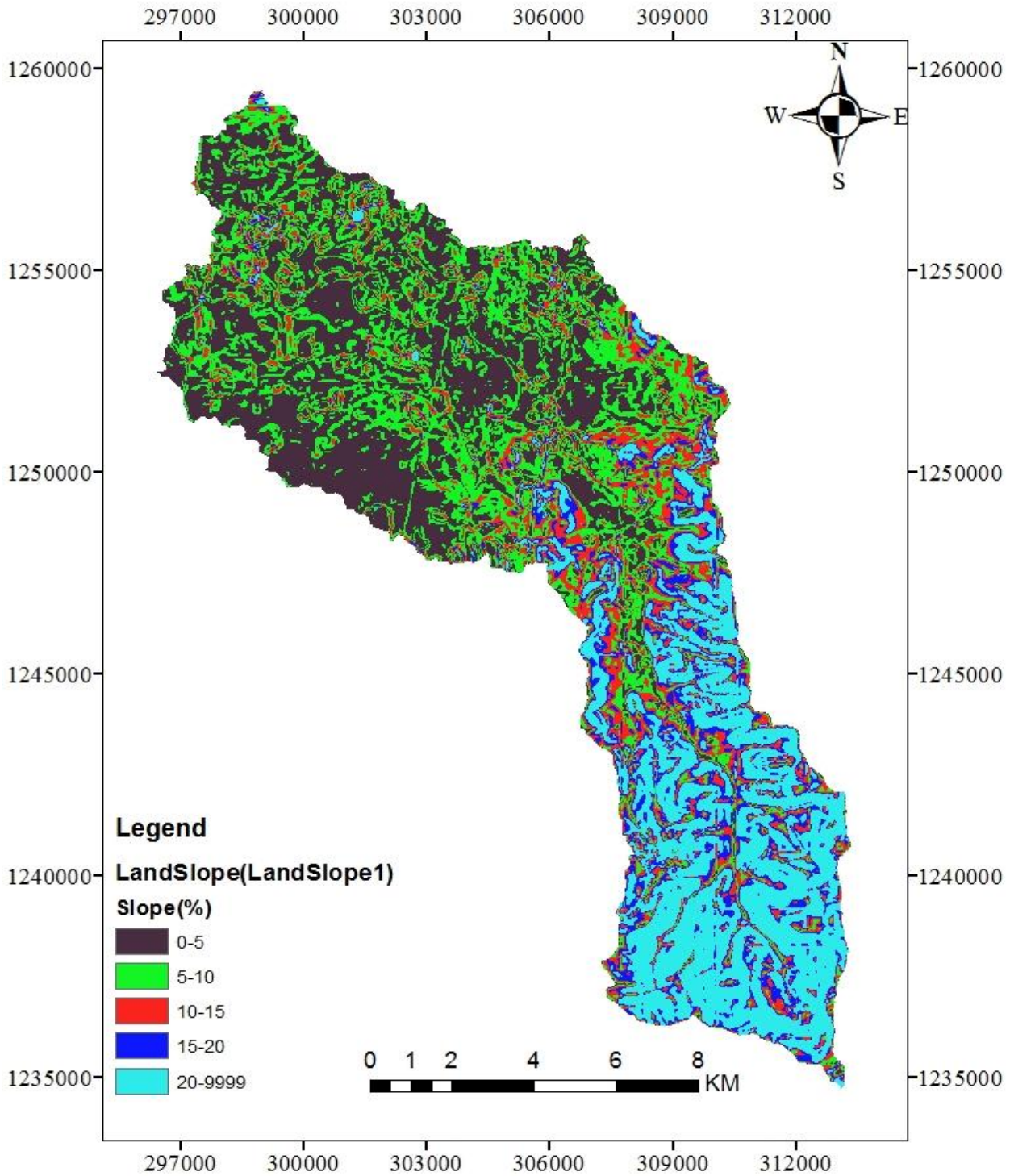


Figure 3.21 Slope classes of Koga catchment in 2014 G.C

Hydrological Component of SWAT

The land phase of the hydrologic cycle is simulated based on the water balance as Eq. (1).

$$SW_t = SW_o + \sum_{i=1}^t (R_{day} - Q_{surf} - Ea - w_{seep} - Q_{gw}) \quad \text{Equation 3.7}$$

Where: SW_t is the final soil water content (mm H_2O), SW_o is the initial soil water content in day i (mm water), t is the time (days), R day is the amount of precipitation in day I (mm H_2O), Q_{surf} is the amount of surface runoff in day i (mm H_2O), Ea is the amount of evapotranspiration in day i (mm water), W_{seep} is the amount of water entering the vadose zone from the soil profile in day i (mm H_2O), and Q_{gw} is the amount of return flow in day i (mm H_2O).

To estimate surface runoff two options are available: The SCS curve number procedure of USDA Soil Conservation Service (USDA SCS, 1972) and the Green & Ampt infiltration method (Green and Ampt, 1911). In this study, the SCS curve number method was used to estimate surface runoff. The SCS curve number is determined as:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \quad \text{Equation 3.8}$$

Where Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), I_a is the initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm H_2O) and S is the retention parameter (mm H_2O). The retention parameter is defined by Eq. (3).

$$S = 254 \left(\frac{100}{CN} - 1 \right) \quad \text{Equation 3.9}$$

Where; CN is the curve number for the day. The initial abstraction, I_a is commonly approximated as $0.2S$ and equation 2 becomes

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} - 0.8S)} \quad \text{Equation 3.10}$$

The SCS curve number is a function of the soil's permeability, land use and antecedent soil moisture conditions.

3.5 SWAT model to Sediment Yield

SWAT estimates the erosion and sediment yield for each HRU with the Modified Universal Soil Loss Equation (MUSLE) (Williams 1975). MUSLE uses the amount of runoff to model erosion and sediment yield. The main strengths of MUSLE are the prediction accuracy and the possibility of estimating the sediment yields of single storm events. (Neitsch et al. 2011). The MUSCLE is:

$$sed = 11.8 (Q_{surf} \cdot q_{peak} \cdot area_{hru})^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG \quad \text{Equation 3.11}$$

Where: *sed* sediment yield on a given day (tons), Q_{surf} is the surface runoff volume (mm water/ha), q_{peak} is the peak runoff rate (m3/s), area HRU is the area of the HRU (ha), K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m2hr/ (m3.metric ton cm)), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor and $CFRG$ is the coarse fragment factor.

Sediment transport in the channel network is a function of two processes, deposition and degradation, operating simultaneously in the reach. SWAT computes the maximum concentration of sediment in the reach at the beginning of the time step. Depending on the concentration of sediment in the reach and transport capacity of the channel deposition or degradation process will occur.

The maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity and is calculated by equation.

$$conc_{sed,ch,mx} = C_{sp} \cdot v_{ch,pk}^{spexp} \quad \text{Equation 3.12}$$

Where $conc_{sed,ch,mx}$ is the maximum concentration of sediment that can be transported by the water (ton/m3or kg/L), C_{sp} is a coefficient defined by the user, $v_{ch,pk}$ is the peak channel velocity (m/s), and $spexp$ an exponent defined by the user. The exponent $spexp$ normally varies between 1.0 and 2.0 and was set at 1.5 in the original Bagnold stream power equation (Arnold, 1995).

The amount of sediment degradation in the channel can be calculated by the model by using equation 4.5 and the net amount of sediment deposited in the reach segment is calculated by equation 4.6.

$$Sed_{deg} = (conc_{sed,ch,mx} - conc_{sed,ch,i}) * V_{ch} * K_{ch} * C_{ch} \quad \text{Equation 3.13}$$

$$Sed_{dep} = (conc_{sed,ch,i} - conc_{sed,ch,mx}) * V_{ch} \quad \text{Equation 3.14}$$

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

$conc_{sed,ch,i}$ is the amount of initial sediment concentration in the reach.

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

K_{ch} is the channel erodibility factor

C_{ch} is the channel cover factor and

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

Sed_{dep} is the amount of sediment deposited in the reach (metric tons).

The final amount of sediment in the reach is determined as:

$$sed_{ch} = sed_{ch,i} - sed_{dep} + sed_{deg} \quad \text{Equation 3.15}$$

where sed_{ch} is the amount of suspended sediment in the reach (metric tons day⁻¹), $sed_{ch,i}$ is the amount of suspended sediment in the reach at the beginning of the time period (metric tons day⁻¹), sed_{dep} is the amount of sediment deposited in the reach segment (metric tons day⁻¹), and sed_{deg} is the amount of sediment re-entrained in the reach segment (metric tons day⁻¹).

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

$$sed_{out} = sed_{ch} \times \frac{V_{out}}{V_{ch}} \quad \text{Equation 3.16}$$

Where sed_{out} the amount of sediment is transported out of the reach (metric tons day⁻¹), sed_{ch} is the amount of suspended sediment in the reach (metric tons day⁻¹), V_{out} is the volume of outflow during the time step (m³/s), and V_{ch} is the volume of water in the reach segment (m³). A detailed description of the model components can be found in (Neitsch et al., 2011).

3.5 SWAT Model Analysis

3.5.1 SWAT Project Setup

SWAT model needs the digital elevation model (DEM) that used to analyze the drainage patterns of the land-surface by determining slope, slope length, channel slope and length of the Koga watershed. The first step is SWAT project setup creating new swat project then selecting project directory where to save the project. Then the project setup is done.

3.5.2 Automatic Watershed Delineator

Watershed delineation has four parts DEM Setup, stream definition, outlet and inlet definition, watershed outlet(s) selection and definition and calculations of sub basin parameters. Open DEM raster and select load from disk using a 30m x 30 m digital elevation model (DEM) and then select the DEM projection set up is adjusted in meter. Stream network was defined for the whole DEM by SWAT using the concept of flow direction and flow accumulation. The size and number of sub basins and details of stream network depends on this threshold area (Winchell et al., 2007). The watershed outlet is manually added and selected for finalizing the watershed delineation. Then calculation of sub basin parameter is selected. The impact hydrology on the watershed with similar and different land uses and soil types can be seen clearly by subdividing the watershed area into sub basins which helps to differentiate one another, and also to select and implement the appropriate mitigation measure can be selected and implemented. Finally, 27 sub watershed and 155.75 km² area of watershed is delineated (Table 3.13).

Table 3.11 SWAT topographic report

```

-----
Statistics:: All elevations reported in meters
-----
Min.      Elevation: 1925
Max.      Elevation: 3089
Mean.     Elevation: 2197.65453810735
Std.      Deviation: 212.252430404464
    
```

3.5.3 HRU

The land area in a sub basin divided into hydrologic response units (HRUs). Hydrologic response units are portions of a sub basin that possess unique land use/management/soil attributes. The benefit of HRUs is the increase in accuracy it adds to the prediction of loadings from the sub basin (S.L. NEITSCH, et, al 2002)

Before loading the soil and land use the shape file, it should be projected. After loading the land use, the soil shape file successfully loaded and clipped of the watershed boundary. It will be reclassified and HRU feature class created. Slope discretization is done with single slope or multiple slopes. In this study, the land slope was also classified in to five slope classes and made to overlay with land use and soil maps to subdivide the study watershed into hydrologic response units (HRUs) (Table 3. 14).

The last step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. Land uses, or soils which cover less than the threshold level are Eliminated. After the elimination process, the area of the remaining land use, or soil was reapportioned so that 100% of the land area in the sub-basin is modeled. The threshold levels set is a function of the project goal and amount of detail required. In this study 365 HRU is created.

Table 3.12 SWAT HRU analysis report

		Area [ha]	Area[acres]	
Watershed		15575.1236	38486.9093	
LANDUSE:		Area [ha]	Area[acres]	%Wat.Area
	Agricultural Land-Generic --> AGRL	11630.1332	28738.6407	74.67
	Forest-Evergreen --> FRSE	2604.9589	6436.9836	16.73
	Range-Grasses --> RNGE	38.4702	95.0619	0.25
	Range-Brush --> RNGB	148.7394	367.5424	0.95
	Forest-Deciduous --> FRSD	1132.7146	2798.9943	7.27
	Forest-Mixed --> FRST	20.1074	49.6863	0.13
SOILS:				
	LVx	12385.0314	30604.0319	79.52
	VRe	3190.0922	7882.8773	20.48
SLOPE:				
	5-10	4014.7694	9920.6958	25.78
	10-15	1924.3385	4755.1367	12.36
	15-20	1349.7639	3335.3340	8.67
	20-9999	3360.0407	8302.8286	21.57
	0-5	4926.2112	12172.9141	31.63

3.5.4 Write Input Table

It has three steps to do, these are weather data definition, write SWAT input tables and data base update.

3.5.5 Weather data definition

Weather data definition filled with as per swat intake form prepared data of rainfall, temperature, winds speed, solar radiation, relative humidity data.

Weather generator

The weather generator used to fill the missing values in measured records and also to simulate the data if simulation option is selected. The WXGEN was provided with all the necessary statistical information from the meteorological records of the watershed to fill the missing portion properly. These statistical values were calculated from the relatively having full meteorological data using pcp STAT and Due point. After loading this WXGEN parameter and location table, the daily meteorological data with the missing data filled with a missing data identifier of -99.0 and including the corresponding location table prepared according to the SWAT format were loaded to the model. Daily values for weather are generated from average monthly values. The model generates a set of weather data for each sub basin. The parameters needed for the weather generator are listed in Appendix 1 (for definition of each parameters listed, look at Neitsch et al., 2005) and statistical values of each station was presented in Appendix 2.

In this study, Adet, Bahir Dar and Dangila meteorological stations were added to the WXGEN with their statistical values to use as weather generator to fill the missing data of Merawi metrological station. SWAT model takes data of each climatic variable for each sub-basin from the nearest weather station in the weather generation process.

Write SWAT input tables

Write SWAT input tables were done by the model itself. The Arc SWAT program built database file that contained information needed to generate default input for running of SWAT model (Arnold et al, 1998).

3.5.6 Edit SWAT input

Edit swat input is an optional step. It allows the SWAT model input database and the watershed database to be edited. In this study, it was not needed to edit the swat input.

3.5.7 SWAT Simulation

It has an option to run swat model where the simulation is done and the simulated files imported to database to be save with unique remembered name.

3.6 SWAT-CUP

SWAT-CUP is Soil and Water Assessment Tools, Calibration and Uncertainty Procedures. It incorporates sensitivity and uncertainty. The model output files compared with the measured data using five types of uncertainty algorithms (SUFI-2, PSO, MCMC, ParaSol and GLUE) which are applied in SWAT-CUP (Abbaspour 2015). SWAT-CUP provides a link between the input and output of the SWAT model for optimizing the output of SWAT model. It provides iteration statistics between auto calibration runs for goodness-of-fit. Figure 3. 22 show SWAT CUP version 5.1.6 starting page.

SWAT-CUP is suitable for calibration and validation of SWAT model because it represents uncertainties of all sources determines best-fit parameters (Yang et al., 2008). In this work SWAT_CUP 5.1.6 version, and SUFI-2 algorithm, has been used for calibration and validation.



Figure 3.22 SWAT CUP version 5.1.6 starting page

3.6.1 Sensitive Analysis Calibration and Validation

3.6.1.1 Sensitivity Analysis

Parameter sensitivity analysis, calibration and validation are done using SWAT CUP. The model sensitivity is the ratio of the change in model output to a change in parameter input. Identifying Sensitive parameters used to reduce the number of input parameters which saves time during calibration. Sensitivity parameter analysis is a method of identifying the most sensitive parameters for the study area and these parameters need to be adjusting during model calibration. The sensitivity analysis method implemented in SWAT is using the Latin hypercube One-At-a-Time (LH-OAT) which is design as proposed by Morris (1991). The LH sensitivity analysis combines the strength of global and local sensitivity analysis methods (Van Griensven and Srinivasan, 2005). A local sensitivity analysis method involves changing values one at a time. Global sensitivity analysis method has the ability to change all the parameter values simultaneously.

3.6.1.2 Model calibration

Model calibration is the process of adjusting the model parameters to match the model output with the observed data with limited range of deviation for better prediction of SWAT model. Calibration is designed to reduce the uncertainty in the estimation process. Model calibration is started with the default parameters, and then the parameter values are adjusted more closely to match the model behavior for the watershed. For each calibration run and parameter change, the corresponding model performance statistics (r^2 and E_{NS}) were calculated. For this study, this procedure continued until the acceptable recommended calibration values are achieved. The acceptable calibration values are $R^2 > 0.6$ and $E_{NS} > 0.5$. In this study, two-third of stream flow data from the year 1989 up to 2008 (twenty years) and two-third of sediment data from the year 2004 up to 2010 (seven years) were used for calibration respectively.

3.6.1.3 Validation

Model validation is testing of calibrated model results with independent data set without any further adjustment (Neitsch, 2002). Validation involves running SWAT CUP using parameters that were used during the calibration process, to see if the model is applicable outside the calibration period. In this study the model performance measures used in calibration procedure were used in validating too. In this study, one-third of stream flow data from the year 2009 up to 2016 (eight years) and one-third of sediment data from the year 2011 up to 2014 (four years) were used for validation respectively.

3.6.2 Model Performance Evaluation

SWAT model performance is evaluated using SWAT-CUP during calibration and validation periods. SWAT model performance was done to check the quality and reliability of simulated output with observed data using the statistical measures. In order to evaluate the model's performance relative to the observed data, the following two performance measures were used: Coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE).

According to Moriasi (2007) the coefficient of determination (R^2) is coefficient of determination describes the proportion of the total variance in the observed data that can be explained by the model. The value of R^2 is 0.0 indicated that none of the variance in measured data that is replicated in the simulated model value. On the other hand the value of R^2 is 1.0 indicated that all the variance in the measured data replicated by model simulation. The closer the value of R^2 to 1, the higher is the agreement between the simulated and the measured values and calculated as:

$$R^2 = \frac{[\sum_{i=1}^n (Q_i^{sim} - Q_{mean}^{sim})(Q_i^{obs} - Q_{mean}^{obs})]^2}{\sum_{i=1}^n (Q_i^{sim} - Q_{mean}^{sim})^2 \sum_{i=1}^n (Q_i^{obs} - Q_{mean}^{obs})^2} \quad \text{Equation 3.17}$$

Where: Q_{mean}^{sim} is mean of simulated values, Q_{mean}^{obs} mean of observed values, Q_i^{sim} is simulated stream flow in m^3/s , Q_i^{obs} is observed stream flow in m^3/s , and n number of observations.

$$NSE = 1 - \frac{\sum_{i=1}^n (Q_i^{obs} - Q_i^{sim})^2}{\sum_{i=1}^n (Q_i^{obs} - Q_i^{mean})^2} \quad \text{Equation 3.18}$$

Where: Q_i^{obs} is observed stream flow in m^3/s , Q_i^{sim} is simulated stream flow in m^3/s , and Q_i^{mean} mean of n values, and n number of observations.

According to (Moriasi, et al. 2007) NSE indicates how well the plot of observed versus simulated data fits the one ratio to one line. NSE ranges from negative infinity to 1.0, where NSE is 1.0 Shows that a perfect model. Generally the value between 0.0 and 1.0 acceptable model performance where below 0.0 is not acceptable performance. When NSE approaches to 1.0 implies the observed mean is as good a predictor as the model.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Sensitive Parameters

Sensitive parameter is done to identify the most influential parameters to focus on for calibration and validation process as inputs for SWAT CUP to save time during calibration. Because of their physical characteristics, both sediment and flow sensitive parameters are selected, separately and independently.

4.1.1 Flow Sensitivity Analysis

Sensitive parameters are selected by using the Latin hypercube one-factor-at-a-time (LH-OAT) method of SWAT for calibration purpose (Van Griensven et al., 2006). Monthly flow data from 1989 to 2016 used for flow sensitivity parameter identification, including three year of warm-up period. From 500 iteration output, eight parameters were selected as sensitive parameters for further calibration process. Table 4.1 shows the most flow sensitive parameters. The highest flow sensitive parameter is base flow alpha factor for bank of storage (ALPHA- BNK), the next significant sensitive parameters are the curve number (CN2), Ground water revap coefficient (GW-REVP), effective hydraulic conductivity in main channel alluvium (Ch_K2), threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN), (CANMX), maximum canopy storage, (SLSUBBSN), average slop length, (SPEXP), exponent parameter for calculating sediment retrained in channel sediment routing. Figure 4.1 shows the identification of significant sensitive parameters using p-value and t-stat. A p-value close to zero is more sensitive and the largest absolute value of t-stat is more sensitive (EAWAG, 2013).

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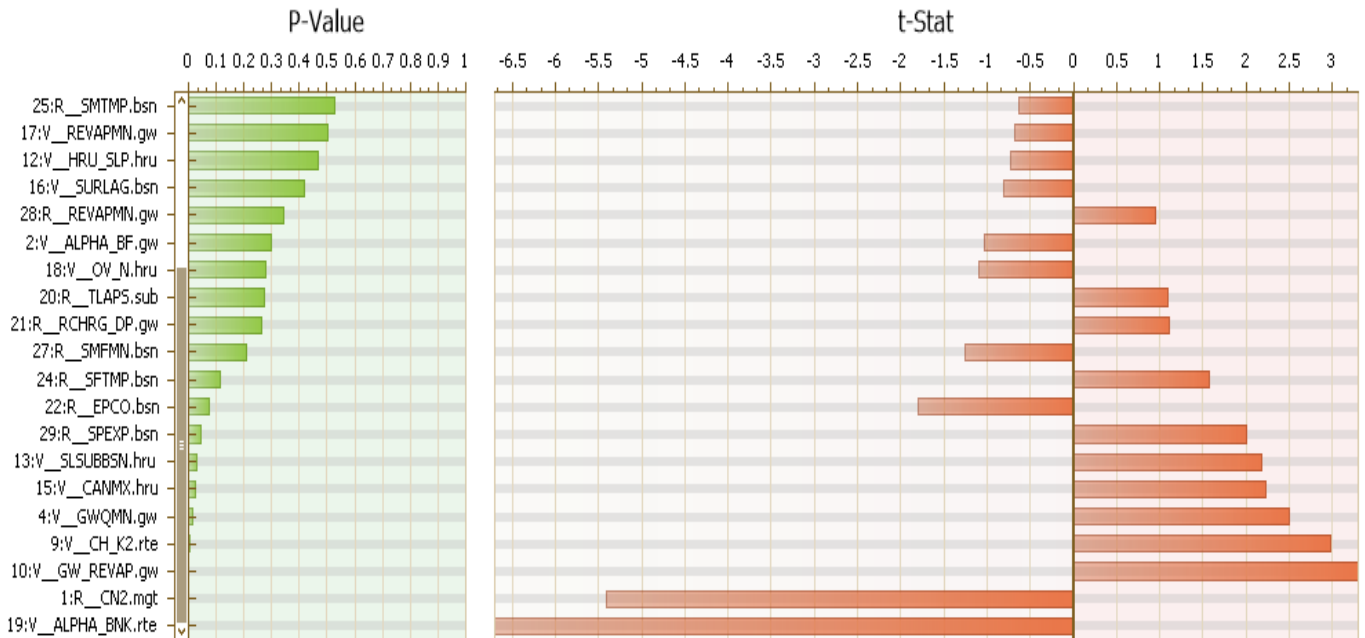


Figure 4.1 Graph views of P-Value and t-Stat for stream flow sensitive parameters

Table 4.1 Grid view of stream flow sensitive parameter

No	Parameter	Description of parameter	P-Value	t-Stat	Rang		Fitted value	Rank
					Min	Max		
1	ALPHA_BNK	Base flow alpha factor for bank of storage	0	-6.70	0	1	0.07	1
2	CN2	SCS runoff curve number f	0	-5.41	-0.25	0.25	-0.06	2
3	GW_REVAP	Ground water revap coefficient	0.001	3.29	0.02	0.2	0.14	3
4	CH_K2	Effective hydraulic conductivity in main channel alluvium	0.003	2.97	0	150	104.8	4
5	GWQMN	Threshold depth of water in the shallow aquifer	0.012	2.50	0	5000	735	5
6	CANMX	Maximum canopy storage	0.026	2.22	0	100	72.5	6
7	SLSUBBSN	Average slop length	0.02	2.18	10	150	66.41	7
8	SPEXP	Exponent parameter for calculating sediment retained in channel sediment routing	0.04	2.00	1	1.5	1.27	8

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Table 4.2 Selected parameters to select flow sensitive parameters

No	Parameters	Description of Parameters	P-Value	t-Stat	Range		Rank
					Min	Max	
1	ALPHA_BNK.	Base flow alpha factor for bank of storage	0.00	-6.7	0	1	1
2	CN2	SCS runoff curve number f	0.00	-5.4	-0.25	0.25	2
3	GW_REVAP	Ground water revap coefficient	0.00	3.29	0.02	0.2	3
4	CH_K2	Effective hydraulic conductivity in main channel alluvium	0.00	2.9	0	150	4
5	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	0.012	2.5	0	5000	5
6	CANMX	Maximum canopy storage	0.02	2.22	0	100	6
7	SLSUBBSN	Average slop length	0.029	2.18	10	150	7
8	SPEXP	Exponent parameter for calculating sediment retained in channel sediment routing	0.046	2.0	1	1.5	8
9	EPCO	Plant uptake compensation factor	0.073	-1.79	0	1	9
10	SFTMP	[OPTINAL] Snowfall temperature.	0.115	1.57	-20	-20	10
11	SMFMN	Maximum melt rate for snow during year (occurs on summer solstice)	0.20	-1.26	0	20	11
12	RCHRG_DP	Deep aquifer percolation fraction	0.26	1.11	0	1	12
13	TLAPS	Temperature lapse rate	0.27	1.09	-10	10	13
14	OV_N	Meaning n value for over land flow	0.27	-1.08	0.01	30	14

SEDIMENTATION PROBLEM AND MITIGATION MEASURE OF KOGA RESERVOIR

No	Parameters	Description of Parameters	P-Value	t-Stat	Range		Rank
					Min	Max	
15	ALPHA_BF	Base flow alpha factor	0.29	-1.03	0	1	15
16	REVAPMN	Threshold depth of water in the shallow	0.34	0.95	0	500	16
17	SURLAG	Surface runoff lag time	0.42	-0.80	0.05	24	17
18	HRU_SLP	Average slop steepness	0.46	-0.72	0	1	18
19	SMTMP	Snow melt base temperature	0.52	-0.62	-20	-20	19
20	SMFMX	Maximum melt rate for snow during year (occurs on summer solstice)	0.60	0.51	0	20	20
21	TIMP	Snow pack temperature lag factor	0.61	-0.50	0	1	21
22	SOL_ALB	Moist soil albedo	0.63	-0.47	0	0.25	22
23	ESCO	Soil evaporation compensation factor	0.68	-0.40	0	1	23
24	CH_N2	Manning's "n" value for the main channel	0.80	0.24	-0.01	0.3	24
25	SOL_Z	Depth from soil surface to bottom of layer	0.81	0.23	0	3500	25
26	SOL_AWC	Available water capacity of the soil layer	0.82	-0.21	0	1	26
27	SOL_K	Saturated hydraulic conductivity	0.91	-0.11	0	2000	27
28	GW_DEL	Groundwater delay (days).	0.98	0.02	0	500	28

4.1.2 Sediment Sensitive Parameters

Table 4.3 shows the considered eighteen sediment parameters to select the most sensitive sediment parameters for monthly sediment simulation analysis. Figure 4.1 shows the identification of significant sensitive parameters using p-value and t-stat. Table 4.4 shows out the five the most sensitive parameters.

Table 4.3 Considered Sediment sensitive parameters

No	Parameters	Description of Parameters	P-Value	t-Stat	Range		Rank
					Min	Max	
1	SPEXP	Exponent parameter for calculating sediment restrained in channel sediment routing.	0.038	2.63	1	1.8	1
2	SOL_BD	Moist bulk density	0.051	2.42	0.9	2.5	2
3	USLE_P	USLE equation support pra	0.1	1.93	0	1	3
4	SOL_Z	Depth from soil surface to bottom of layer	0.2	-1.43	0	3500	4
5	SPCON	Linear parameter for calculating the maximum amount of sediment that can be retrained during channel sediment routing.	0.21	-1.37	0.0001	0.01	5
6	CH_S2	Average slope of main channel	0.21	1.39	-0.001	10	6
7	RSDIN	Initial residue cover	0.22	-1.35	0	10000	7
8	CH_EQN	Sediment routing method	0.22	1.35	0	4	8
9	CH_ERODMO	Jan. channel erodibility factor	0.30	-1.12	0	1	9
10	SOL_CRK	Crack volume potential of soil	0.32	1.06	0	1	10
11	CH_N2	Manning's "n" value for the main channel	0.37	0.96	-0.01	0.3	11

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12	LAT_SED	Sediment concentration in lateral flow and groundwater flow	0.68	-0.43	0	5000	12
13	IGRO	Land cover status code	0.70	-0.40	0	1	13
14	CN2	SCS runoff curve number f	0.87	-0.16	-0.25	0.25	14
15	CH_L2	Length of main channel	0.88	-0.15	-0.05	500	15
16	SLSUBBSN	Average slope length.	0.90	-0.11	10	100	16
17	HRU_SLP	Average slope steepness	0.92	-0.09	0	1	17
18	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	0.93	0.09	0	5000	18

Table 4.4 Selected sediment sensitive parameters

No	Parameters	Description of Parameters	P-Value	t-Stat	Range		Fitted value	Rank
					Min	Max		
1	SPEXP	Exponent parameter for calculating sediment restrained in channel sediment routing.	0.038	2.63	1	1.8	1.43	1
2	SOL_BD	Moist bulk density	0.051	2.42	0.9	2.5	2.4	2
3	USLE_P	USLE equation support pra	0.1	1.93	0	1	0.22	3
4	SOL_Z	Depth from soil surface to bottom of layer	0.2	-1.43	0	3500	3010	4
5	SPCON	Linear parameter for calculating the maximum amount of sediment that can be retrained during channel sediment routing.	0.21	-1.37	0.0001	0.01	0.007	5

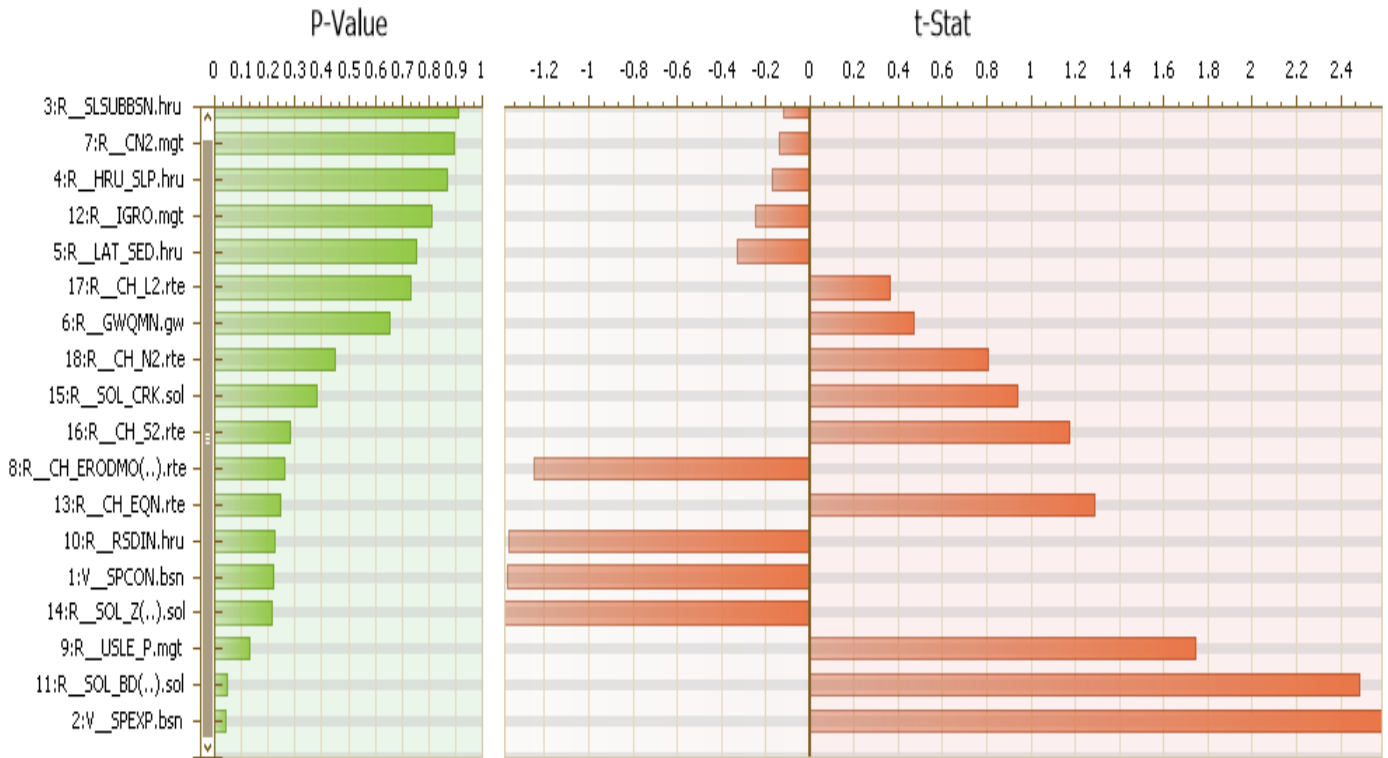


Figure 4.2 Graph views of P-Value and t-Stat for sediment sensitive parameters

4.2 Calibration and Validation

4.2.1 Flow Calibration

The model results were compared with the observed monthly stream flow data at Koga dam site gauging station for calibration process. Two-third of available stream flow data from the period January 1989 to December 2008 used for calibration (twenty years) and the remaining one-third stream flow from the period January 2009 to December 2016 used for validation purpose (eight years). As shown on Figure 4.3, the calibration results are 0.81 and 0.76 for the coefficient of determination (R^2) is and Nash Sutcliff Efficiency (NS) respectively. Figure 4.3 and 4.4 shows graphical comparison between observed and simulated monthly stream flow. Table 4.5 shows observed and simulated average stream flows and model efficiency results of the calibration.

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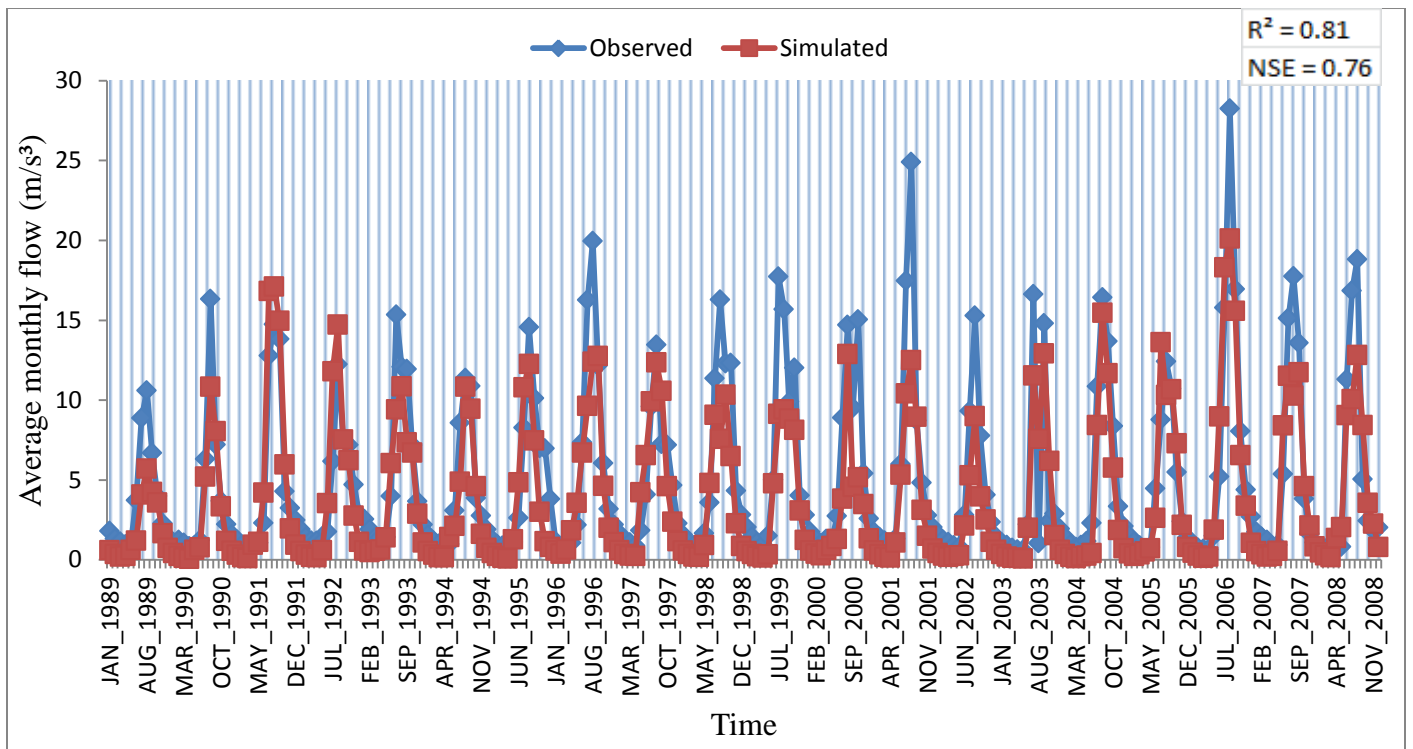


Figure 4.3 Measured and simulated monthly stream flow calibration

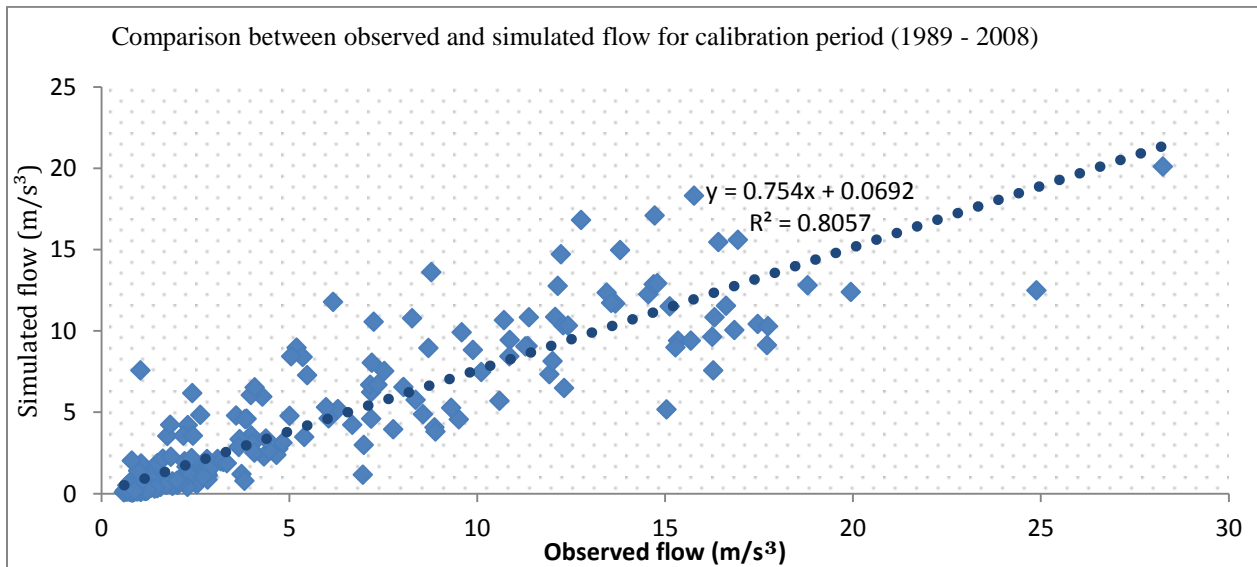


Figure 4.4 Fit line of measured and simulated flow for calibration

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Table 4.5 Observed and simulated flow at the calibration period

Time (year)	Average Flow (m ³ /s)		Model Efficiency (Monthly)	
	Observed	Simulated	R ²	NSE
1989-2008	14.42	10.08	0.81	0.76

Figure 4.5 shows flow calibration dot plots these are plots of parameter values vs objective function (NSE). The main purposes of these graphs are to show the distribution of the sampling points as well as to give an idea of parameter sensitivity. ALPHA_BNK, CN2, CH_K2 and CANMX are most sensitive parameters after calibration. Almost all the 31 years the NSE values are above 50.

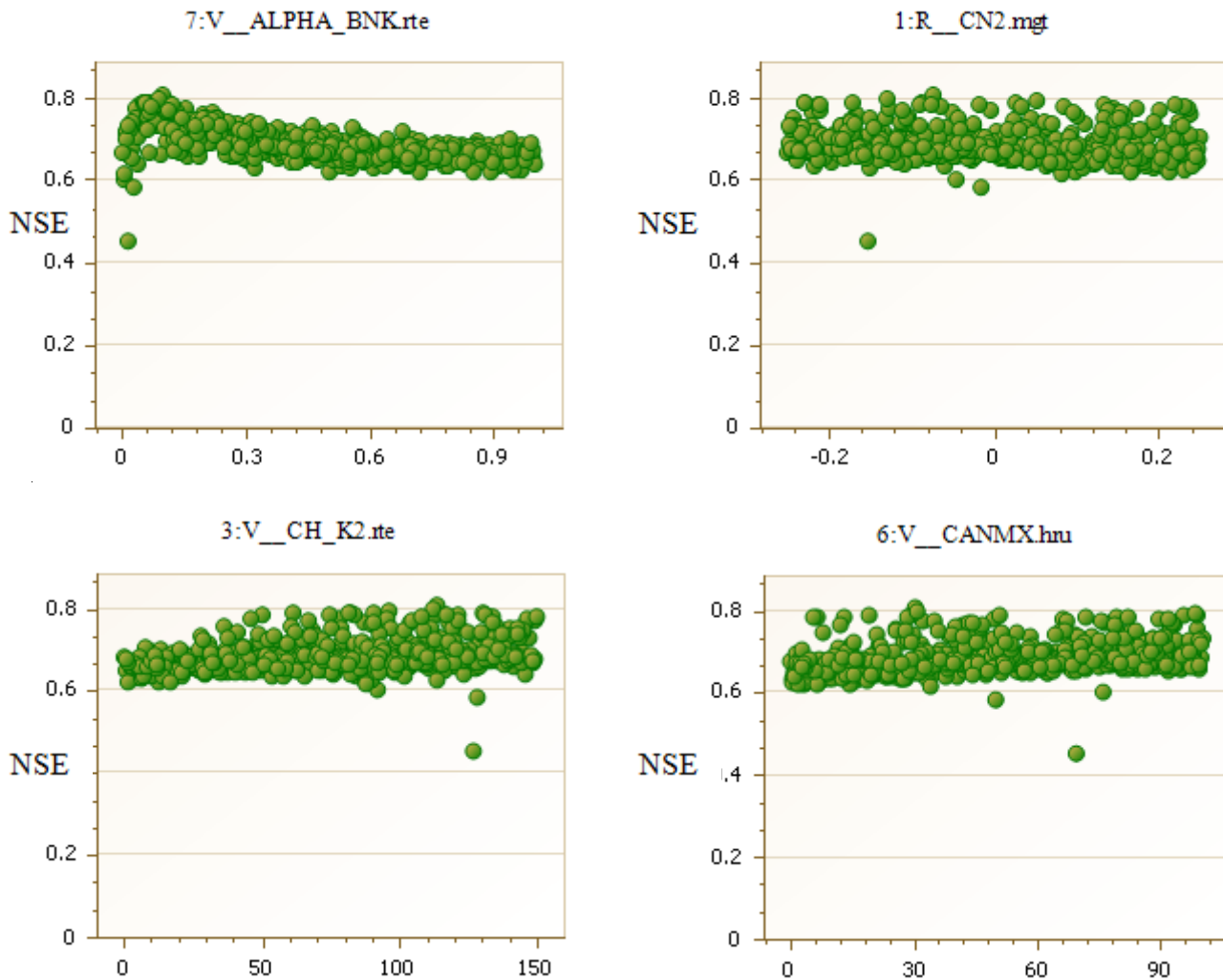


Figure 4.5 Distribution of sampling points; parameter values vs Nash-Sutcliffe Efficiency (NSE)

4.2.2 Flow Validation

The model is re-run without any adjustment of calibration parameters using different time and monthly stream flow input data from the calibrated period which increase the model reliability on the calibrated result. The model validation carried out from January 2009 to May 2016, and the obtained results are 0.77 and 0.74 for the coefficient of determination (R^2) is and Nash Sutcliffe Efficiency (NSE) respectively. Figure 4.6 and 4.7 shows graphical comparison between observed and simulated monthly stream flow. Table 4.6 shows observed and simulated average stream flows and model efficiency results of the validation.

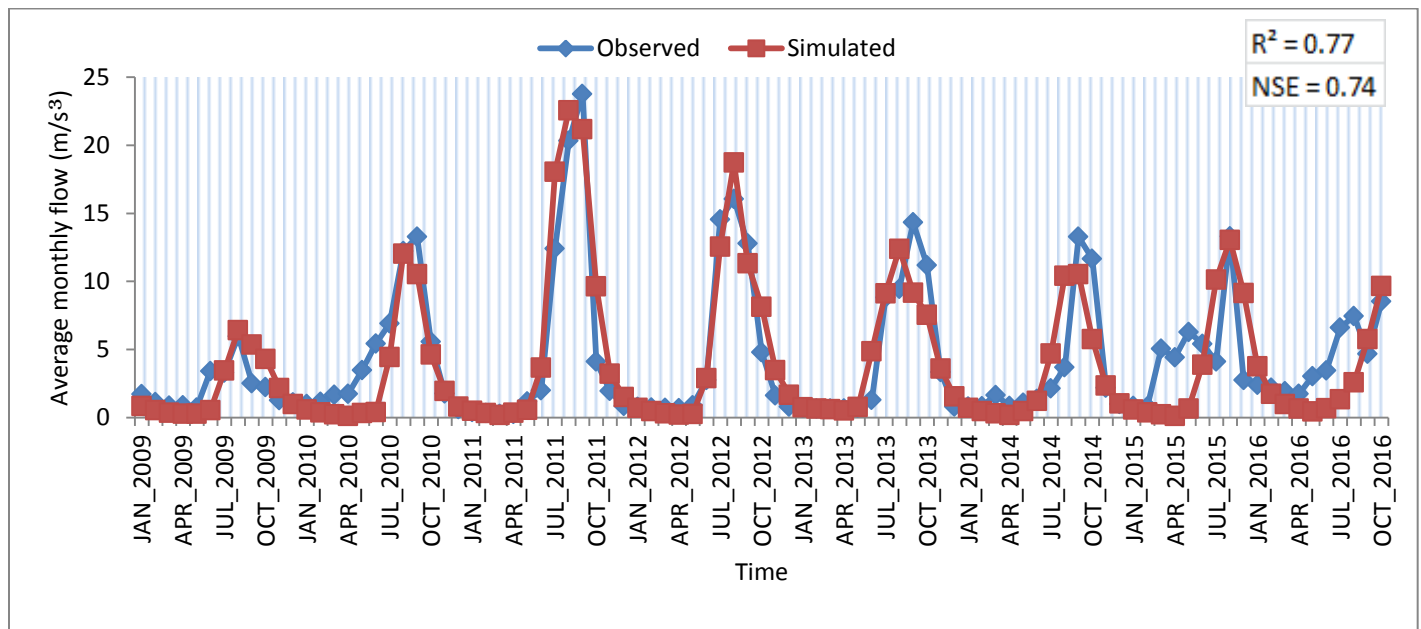


Figure 4.6 Measured and simulated monthly stream flow validation

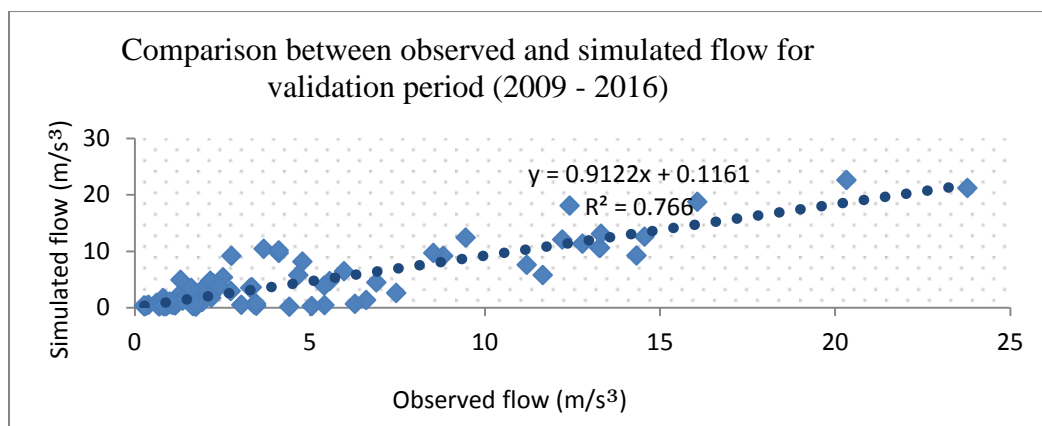


Figure 4.7 Fit line of measured and simulated flow for validation

Table 4.6 Observed and simulated flow at the validation period

Time (year)	Average Flow (m ³ /s)		Model Efficiency (Monthly)	
	Observed	Simulated	R ²	NSE
2009-2016	12.16	11.41	0.77	0.74

Figure 4.8 shows flow calibration dot plots these are plots of parameter values vs objective function (NSE). The main purposes of these graphs are to show the distribution of the sampling points as well as to give an idea of parameter sensitivity. CH_K2, ALPHA_BNK, SPEXP, and CANMX are most sensitive parameters after calibration. Almost all the 31 years the NSE values are above 50.

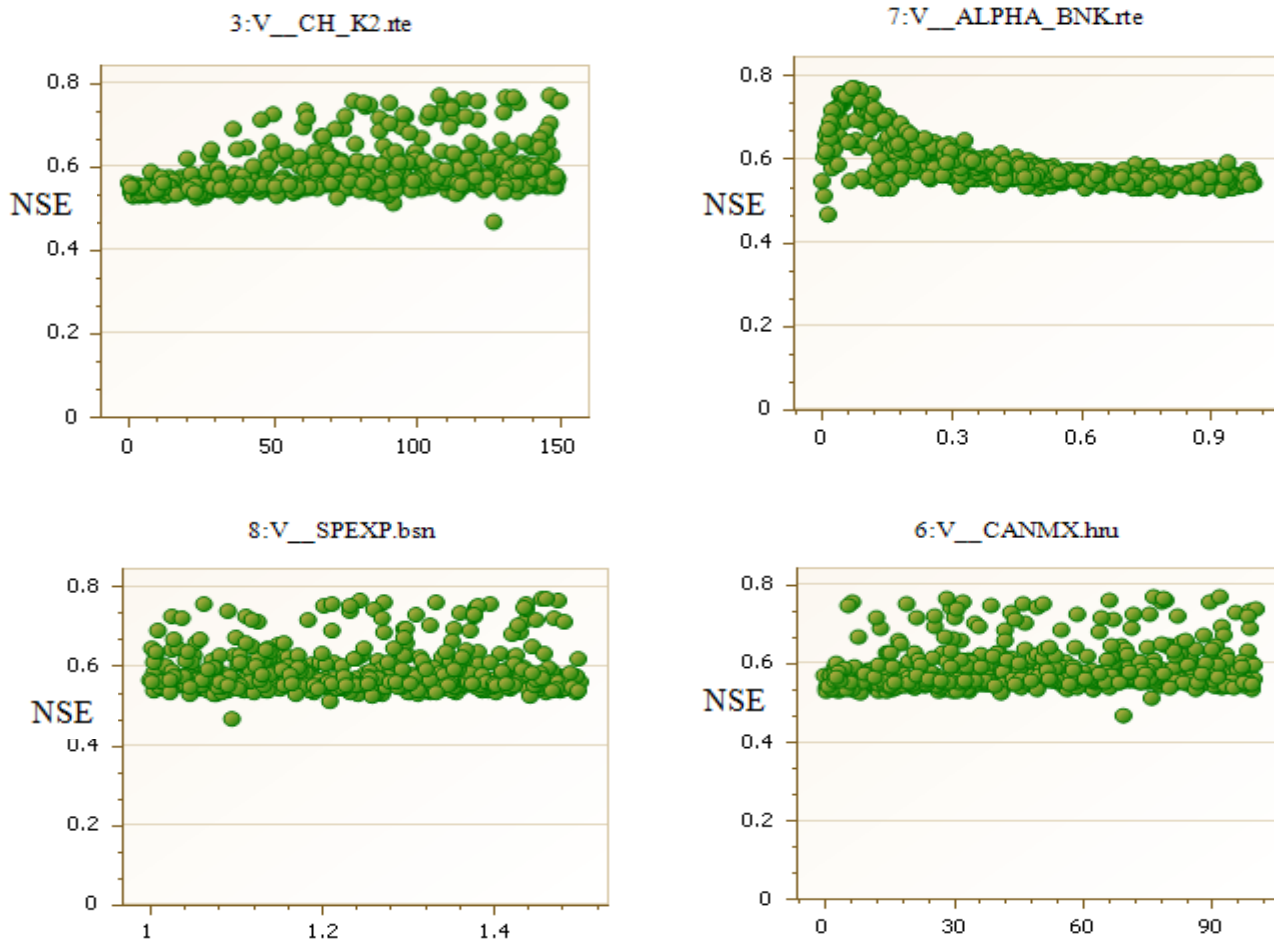


Figure 4.8 Distribution of sampling points; parameter values vs Nash-Sutcliffe Efficiency (NSE)

4.2.3 Sediment Calibration

After calibrating and validating the simulated stream flow data the next step is calibrate and validate the simulated sediment yield of model result by developing rating curve based on the observed sediment data at the Koga dam site. During calibration, the model compered the observed sediment data with simulated sediment yield for the calibration period from January 2004 up to December 2010. During sediment calibration the model simulation result overestimated the sediment load. Five selected sediment calibration parameters were used to increase the quality of the simulated result. The overall performance of the model during calibration has been measured using the coefficient of determination (R^2) and Nash- Sutcliff model efficiency (NSE). The coefficient of determination (R^2) value is 0.66 and Nash- Sutcliff model efficiency (NSE) value is 0.61. Table 4.7 shows observed and simulated average monthly sediment yield (ton/month) and model Efficiency for calibration period. Figure 4.9 and 4.10 show graphical comparisons between measured and simulated sediment yield of Koga reservoir from January 2004 up to December 2010.

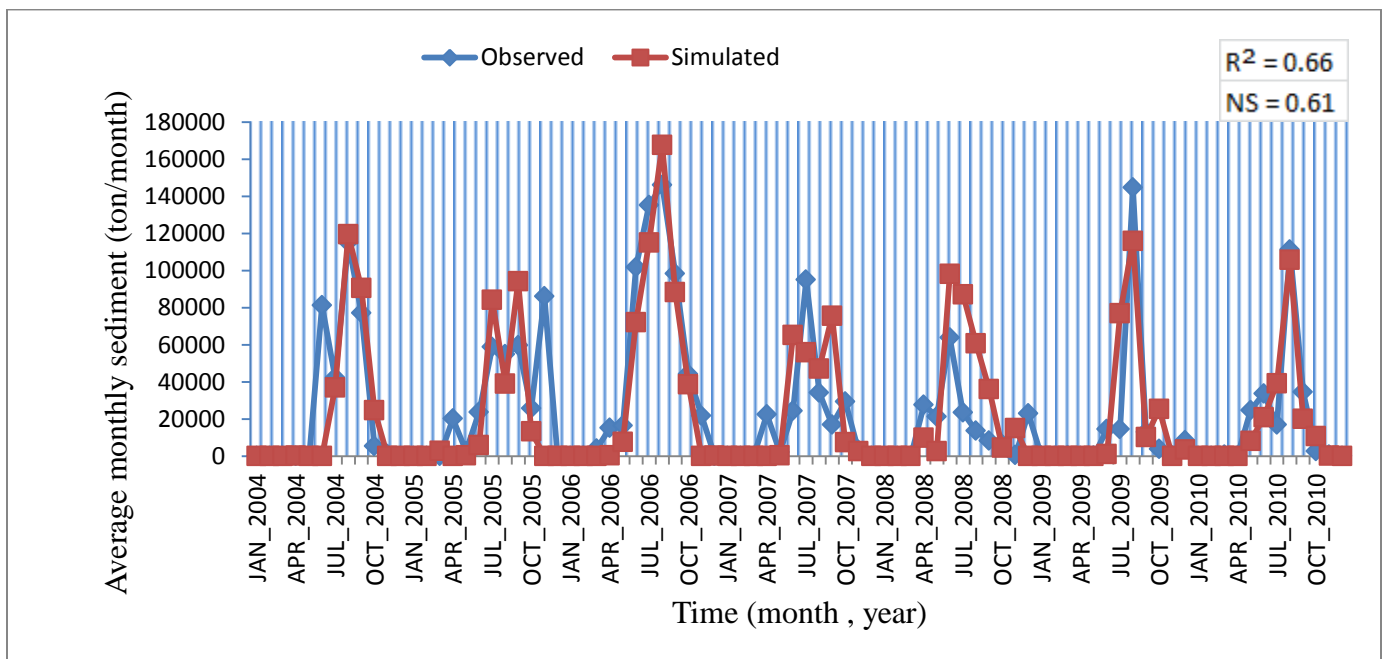


Figure 4.9 Observed and simulated sediment Calibration

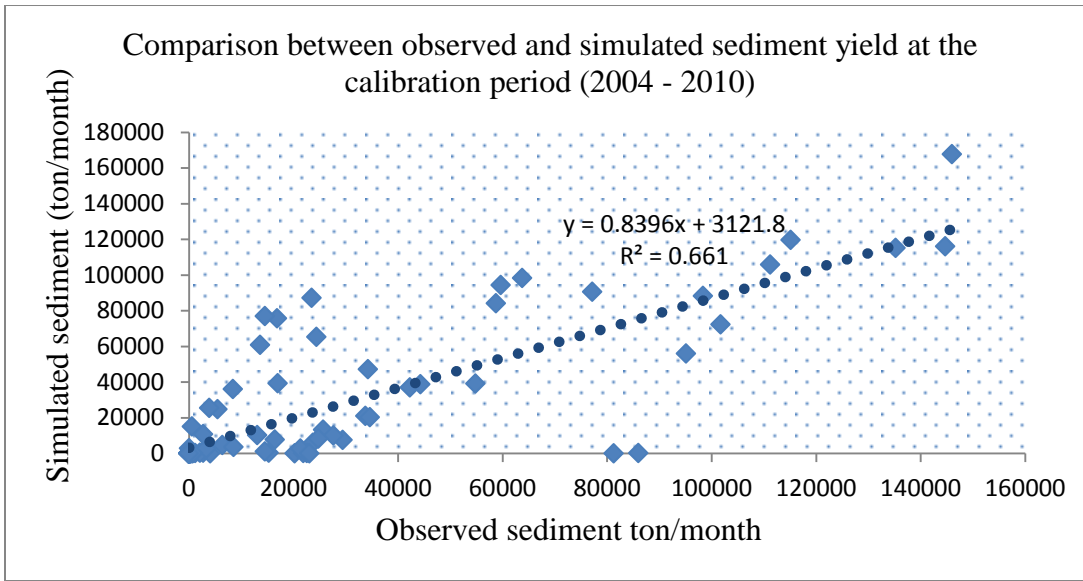


Figure 4.10 Fit line observed and simulated sediment for calibration period

Table 4.7 Observed and simulated at the sediment calibration period

Time (year)	Average monthly sediment (ton/month)		Model Efficiency (Monthly)	
	Observed	Simulated	R ²	NSE
2004 - 2010	173377	167420	0.66	0.61

Figure 4.11 shows flow calibration dot plots these are plots of parameter values vs objective function (NSE). The main purposes of these graphs are to show the distribution of the sampling points as well as to give an idea of parameter sensitivity. Sol_Z and USLE_P are most sensitive parameters after calibration. Most of the values of the 31 years the NSE values are above 50.

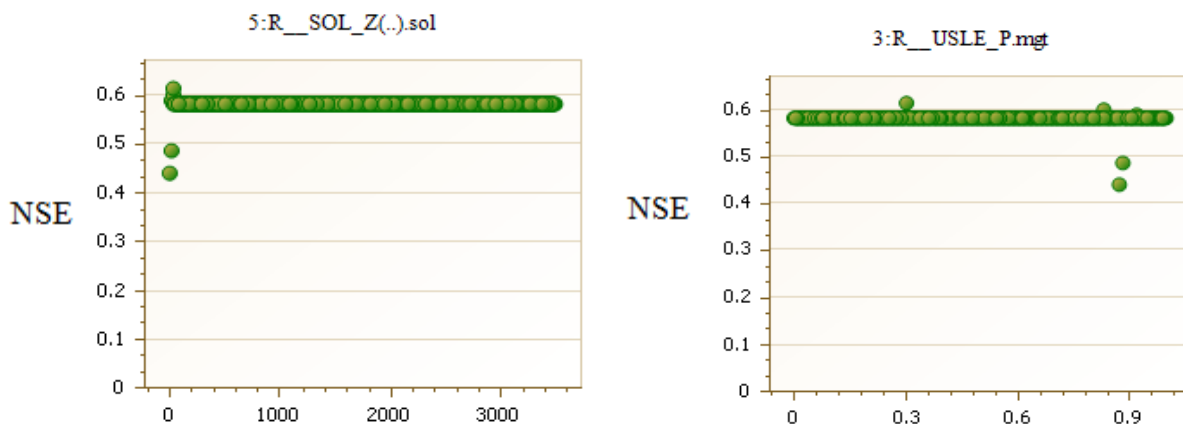


Figure 4.11 Distribution of sampling points; parameter values vs Nash-Sutcliffe Efficiency (NSE)

4.2.4 Sediment Validation

Without further parameter adjustment, the calibrated sensitive parameters are used for monthly sediment validation. Monthly sediment validation was performed by using SWAT CUP SUFI algorithm different from the calibration period which is from January 2011 to December 2014. The model shows a good agreement between observed and simulated sediment with values of correlation coefficient (R^2) is 0.76 and Nash-Sutcliffe Efficiency (NS) is 0.70. Table 4.8 shows observed and simulated average monthly sediment yield (ton/month) and model Efficiency for validation period. Figure 4.12 and 4.13 shows the relationship between the observed and the simulated sediment yield of validation period and the fitted line of observed and simulated sediment yield of validation period respectively.

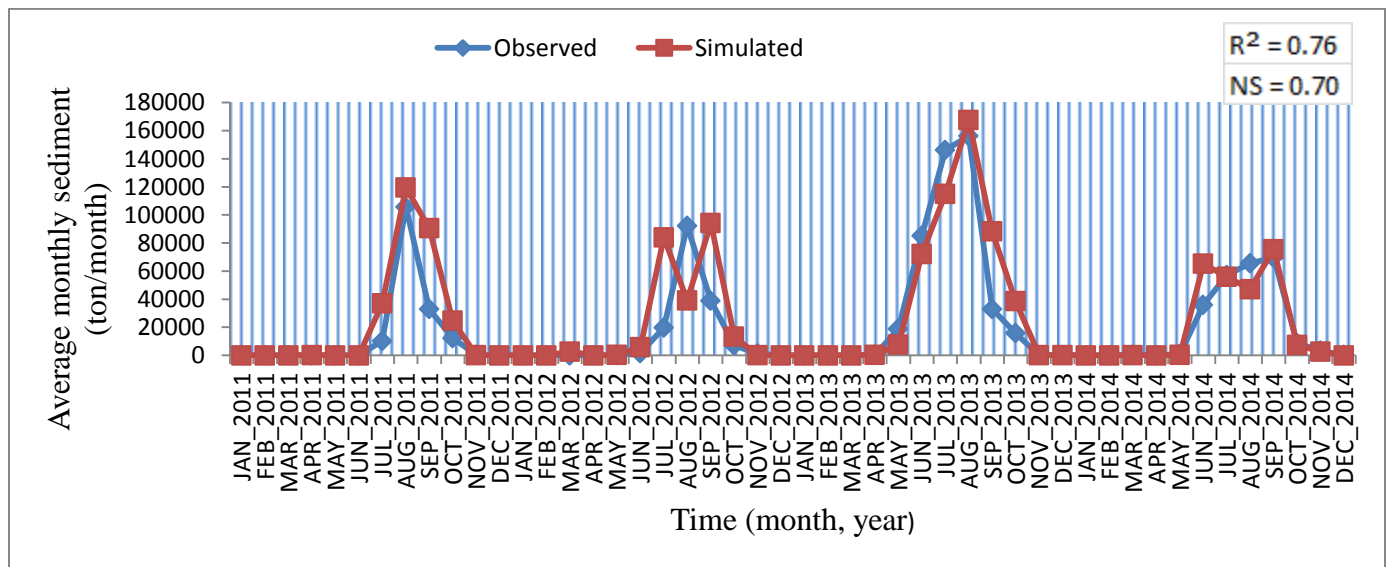


Figure 4.112 Observed and simulated sediment for validation period

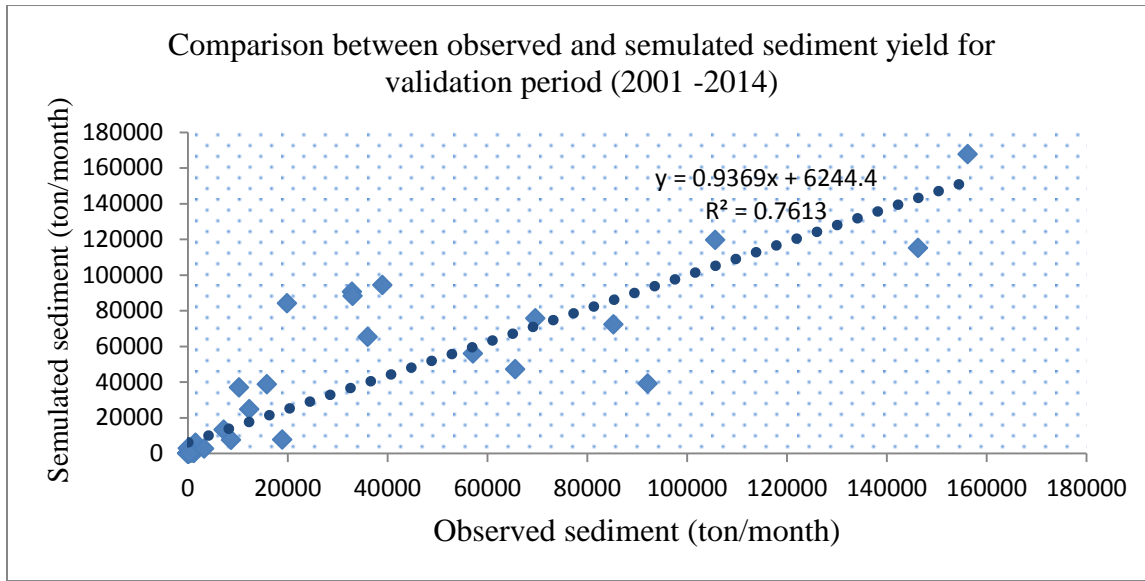


Figure 4.12 Fit line observed and simulated sediment for validation period

Table 4.8 Observed and simulated at the sediment validation period

Time (year)	Average monthly sediment (ton/month)		Model Efficiency (Monthly)	
	Observed	Simulated	R ²	NSE
2011- 2014	85096	104708	0.76	0.70

Figure 4.14 shows flow calibration dot plots these are plots of parameter values vs objective function (NSE). The main purposes of these graphs are to show the distribution of the sampling points as well as to give an idea of parameter sensitivity. Sol_Z and USLE_P are most sensitive parameters after calibration. Most of the values of the 31 years the NSE values are above 50.

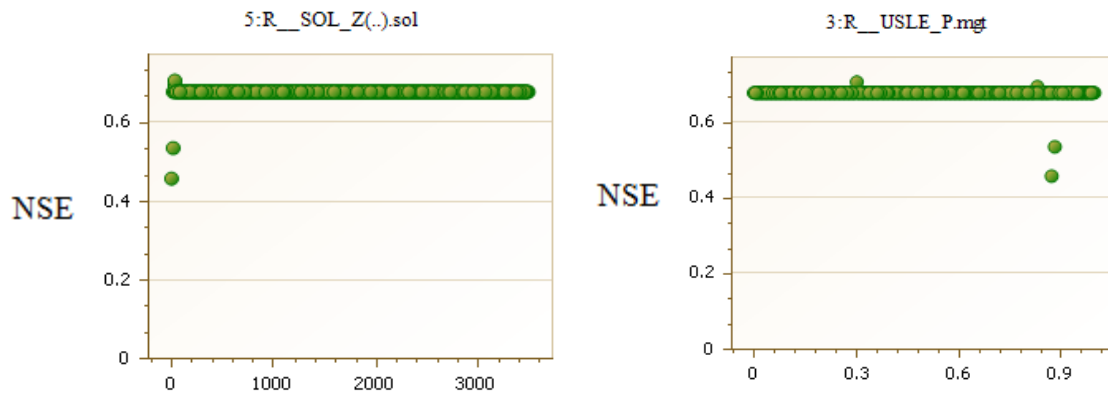


Figure 4.14 shows sediment validation dot plots these are plots of parameter values vs objective function (NSE).

After calibration and validation of the model the total observed and simulated of sediment yield in the Koga catchment at the dam site during calibration period are 3101686 ton and 3265555 ton respectively. Therefore, SWAT model is good result for the estimation of catchment sediment yield in the study area. The result indicated that the model simulation almost similar to the observed sediment yield.

The total annual sediment yield from catchment in to the reservoir during calibration and validation period was estimated using SWAT model is 24739 ton. Based on this result 24739 ton/year sediment enters into the reservoir. The total catchment area of this study is 155.75 km². Therefore, the annual specific sediment yield from the catchment can be calculated as the total sediment yield divided by the area of the catchment which is equal to 158 ton/km²/year which are very high when it is compared to the other studies.

Comparing the result with previous works

Table 4.9 shows, Both this study result and a thesis done by Nigussie & Yared by bathymetry survey sediment yield result are similar but when compared with feasibility report, this study’s decrease because it is done after twelve years and shows there is some measures were taken even if it doesn’t vanish the problem. But when it is compared with different physiographic catchment the results vary due to the combined effect of factors such as climatic condition, land use, soil type and slope, etc...

Table 4.9 Sediment yield in some reservoir in Ethiopia

Name of reservoir	Sediment yield (ton/km ² /year)	Catchment area (Ha)
Angereb	2210	7653
Legedadi	760	23400
Koga (SWAT)	158	15575
Koga (bathymetry)	140	20232
Koga (feasibility report)	500	25000
Gibe I	106	36000
Gelana	89.14	64428
Ribb dam	72.79	84400

4.3 Identifying erosion prone areas in Koga catchment

Soil erosion is the soil moved off a particular slope or field. Sediment yield is the soil loss delivered to a point or place. For reservoir sedimentation the sediment source can be from land erosion and/or river bed and bank erosion.

4.3.1 Koga land erosion

As shown in figure 3.19, in Koga catchment more than 74% of the land is occupied by agricultural field. Figure 4.15 shows Mecha Woreda Abiyot Fana Kebele Filkelekit Gote right and left side agricultural land degradation. This kind of land is the main source of reservoir sedimentation during the starting month of rainy season.



Figure 4.15 Erosion at Koga watershed at left and right side of agricultural land

4.3.2 Spatial variations of sediment yield in Koga sub basins

Critically erosion prone areas of Koga catchment are ranked according to feasibility report. Identifying erosion prone areas is an important input for policy makers and researcher's to implement short and long term management strategies. After model calibration and validation, the spatial sediment distribution on the Koga catchment was identified. Table 4.10 and figure 4.16 show the spatial distribution of sediment yield in the Koga catchment whereas table 4.11 shows rank category of erosion prone areas. The maximum annual sediment yield is generated in the sub-catchment 25, sub-catchment 26 and the minimum annual sediment yield is generated in the sub-catchment 4 and sub-catchment 8. This result shows that there are some sub catchments which are vegetated enough. On the other hand, sub-catchment 25 and 26 are the most erodible area and needs rehabilitation. The average annual sediment yield distribution ranges from 1.79 ton/ha to

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62.53 ton/ha. Out of the total catchment area 155.75km², 81.7 km² areas is eroded area that means 52.5% of the total Koga catchment area is eroded.

Table 4.10 Spatial variation of sediment at Koga catchment

No	Sub catchment	Sediment distribution (ton/hectare/year)	Area (km ²)	No.	Sub catchment	Sediment distribution (ton/hectare/year)	Area (km ²)
1	1	7.07	7.94	15	15	12.90	12.08
2	2	19.35	8.53	16	16	6.29	16.69
3	3	7.943	0.044	17	17	6.99	9.23
4	4	1.79	0.31	18	18	9.22	3.03
5	5	5.43	0.36	19	19	16.96	14.68
6	6	5.55	0.92	20	20	22.37	7.04
7	7	5.87	0.29	21	21	25.68	12.01
8	8	3.54	2.04	22	22	7.42	4.33
9	9	5.34	3.22	23	23	20.75	2.28
10	10	14.66	5.44	24	24	11.66	4.07
11	11	20.91	5.43	25	25	48.22	3.71
12	12	15.13	3.44	26	26	62.53	7.08
13	13	5.18	5.23	27	27	16.05	7.05
14	14	4.98	9.19				

Table 4.11 According to Koga feasibility report erosion prone areas rank category

No.	Range	Description	Remark
1	0 - 5	Relatively not eroded area	Vegetated enough
2	6 - 10	Slightly eroded	
3	11 - 20	Eroded	Vegetative recovery needed
4	> 21	Highly eroded areas	Immediate integrated watershed management implementation needed

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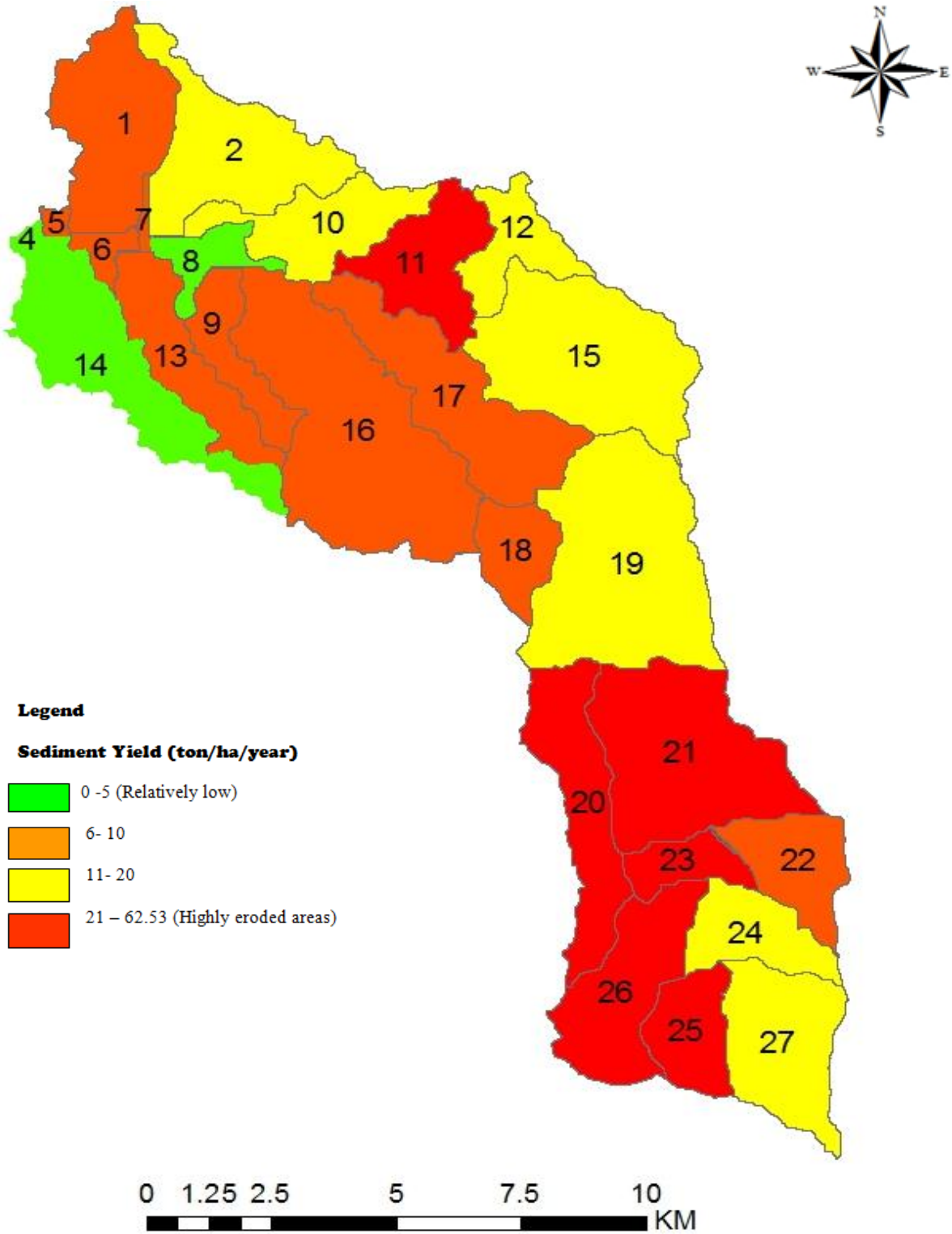


Figure 4.16 Identified erosion- prone areas (Spatial variations of sediment yield) in Koga sub basins

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Table 4.12 shows the comparison between the LULC, slope and soil with sediment yield of sub basin 25 and 26. Sub basin 25 produced 48.22 ton/hectare/year. From the total area 78.7% of the land use land cover type is agricultural land with chluvisols soil type and the topography is 100% hilly. Sub basin 26 produced 62.53 ton/hectare/year from the total area 90.9% of the land use land cover type is agricultural land with chluvisols soil type and 99.79% of the total area hilly.

Table 4.12 Sub basin 25 and 26 sediment yield, LULC, slope and soil

No	Sub catchment	Sediment distribution (ton/hectare/year)	Area (km ²)	Watershed data	SWAT Code	Area (km ²)	% from the total area
1	25	48.22	3.71	LULC	Agricultural Land	2.92	78.7
					Forest- Deciduous	0.79	21.3
				Slope	> 20	3.71	100
				Soil	LVx	3.71	100
2	26	62.53	7.08	LULC	Agricultural Land	6.44	90.9
					Forest- Deciduous	0.64	9.1
				Slope	> 15	0.02	0.21
					> 20	7.06	99.79
				Soil	LVx	7.08	100

Comparing the spatial variations result with previous works

Mengist (2016) showed the spatial distribution of sediment in the Gelana catchment with an average annual sediment distribution ranges from 7.58 ton/ha to 53.17 ton/ha whereas Zelalem (2016) the runoff sediment yield modeling using Soil and Water Assessment Tool for management planning of Mojo watershed Ethiopia, showed that the estimated soil loss rate from different sub-watershed ranges from 2 t/ha/year to 204 t/ha/year. This study identified the average annual sediment distribution ranges from 1.79 ton/ha to 62.53 ton/ha in the Koga catchment. The sub-catchments sediment yield of this study is different from others listed above due to the combined effect of erodibility physiographical factors such as land use, soil type and slope, etc.

4.3.3 Koga river bank erosion

Upstream erosion critical in producing reservoir sedimentation, but we must consider all sediment sources. Channel erosion is known to be a significant contributor to total sediment and nutrient loading. According to Garey A. et, al (2002) sediment in streams originated more from channel and bank erosion than from soil erosion and sediment from stream banks can account for up to 85% of watershed sediment yields. The cause of stream bank failure can be sub aerial processes (weathering) fluvial erosion (direct removal by flow) bank failure (slope instability). Figure 4.17 shows that Koga River has unstable river bank that contribute high sediment load transported to the Koga reservoir. River bank erosion is serious than other and more sediment.



Figure 4.17 Erosion at Koga river bank and stream bank erosion (source site visit)

4.3.4 Koga catchment and reservoir sediment sample identification

Figures 4.18 and 4.19 and table 4.13 show that more sand particles are available at the upper catchment of Koga reservoir but some of them were trapped by the nature of physical structure. But most of the clay particles entered in to the reservoir area intensively. More silt particles were also entered in to the reservoir to go deeper and deeper.

The sedimentation pattern has been investigated and found that sediment nature around the reservoir is dominated by clay sediment particles. According to Murray (1977) the sediment rate in mixtures with more than 50% clay content are determined by porosity. For clay contents smaller than 50% the increase of transport is related to a decrease in clay percentage. Low velocity turbidity currents are capable of carrying large amount of fine sediments into the deeper parts of the reservoir. Sand size or larger deposit first then silt and clay sizes are transported further into the pool. Factors governing location of deposits are longitudinal slope of original stream bed, shape of reservoir, mineral characteristic of the clay size elements, chemistry of water. Deposit consists of backwater deposit in the backwater reach of the stream above the reservoir level delta deposit (sand and gravel delta): soon after the flow enters the reservoir bottom deposit (silt and clay): into the pool beyond the delta.

Generally, the laboratory result indicated that relatively more clay soils are eroded from the upper catchment and enter in to the reservoir. These clay soils can be retained by suitable sediment detention mechanism to be used as nutrient input for agricultural land.

Table 4.13 Laboratory result of sediment sample identification

Profile code	Inside Koga reservoir percentage	Upper stream of Koga catchment percentage	Average percentage
Sand	11.33	72.68	42.005
Silt	35.88	11.55	23.715
Clay	52.77	15.75	34.26
Texture class	Clay	Sandy loam	♣

Sediment grain size distribution of upper stream of Koga catchment

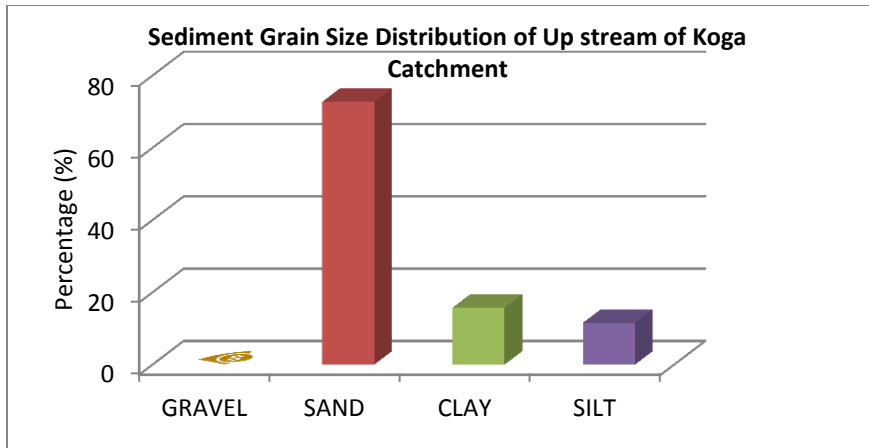


Figure 4.18 Sediment grain size distributions upstream of Koga reservoir

Sediment grain size distribution inside the Koga reservoir

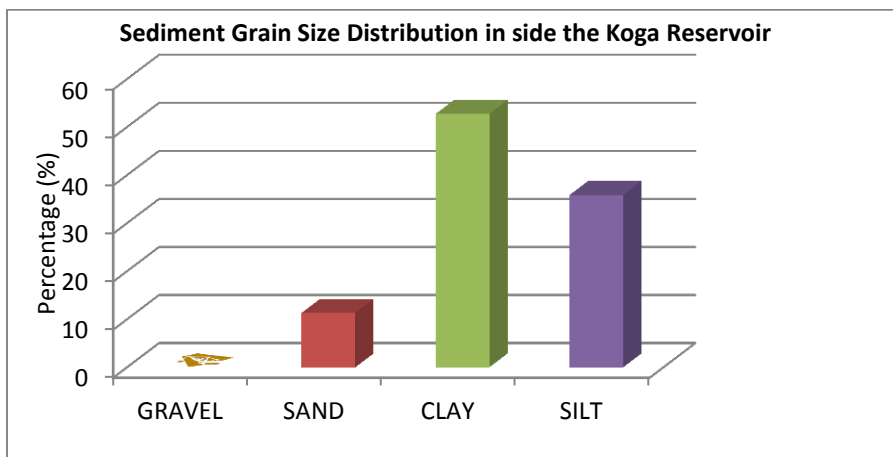


Figure 4.19 Sediment grain size distributions inside the Koga reservoir

4.4 Upper catchment rehabilitation strategies

Reducing sediment inflow from the upstream catchment can be done from two places.

- (1) At upland and;
- (2) At stream banks

(1) Reducing sediment inflow at upland of the catchment

Additional to integrated watershed management applied before in the catchment, the following biological and physical supplementary structures are recommended to reduce the sediment inflow to Koga reservoir.

4.4.1 Afforestation

Stabilization especially the above listed critical sub watersheds by forests result in a significant reduction in sediment input to the reservoir. Scenario development used to know how much percent of land use cover should be changed forest land to reduce the sediment highly that caused high erosion

The important of SWAT model is the ability to build different scenarios. Scenarios are reasonable and often simplified description of future plan. Scenario analysis is a process of evaluating possible future events through the consideration of alternative possible outcomes. From model output HRU report 74.67 % of Koga catchment is agricultural land. Therefore, to minimize soil erosion and sediment deposing in the Koga reservoir, different scenario development was required to be applied. The developed scenario was based on site observation, farmers' suggestion, laboratory and the model result indication.

One of the qualities of a research is being applicable on the specific place, whether the proposed solution will work or not is determined by asking the local farmers (figure 4.20). The farmers told me that the command area and the beneficiaries from Koga dam is found downstream behind the main road to Bahir Dar-Addis Ababa and they are affected by the sediment coming from the upper catchment besides that there are some conflicts because of the water becoming scarce, almost all the farmers are aware of the value of irrigation and are in need. At upstream Koga catchment they are implementing recession farming and contour ploughing type of agricultural works intensively, but this practice are causing reservoir sedimentation. The farmer added that the irrigation at the downstream gives two and three time's production per year. When there is no rain on that year drought will occur or food production will decrease. Not to get back to rain fed or rain dependent agriculture suitable sediment reduction should be there not to harm the dam and the irrigation structures downstream. So if they get established nearby seedling nursery station and encouraged by somebody they will change some of their agricultural land to forest production to earn money.



Figure 4.20 Discussion on the options on reduction measure with one of the farmers (source from site visit)

For laboratory analysis one of the sediment samples was taken from upstream of Koga catchment near the river that is also adjacent the agricultural land. This laboratory result indicated that more sediment came from around agricultural land area. The model also indicated that at high sediment yield is at the month June and July of low peak flows has high sediment yield it is due to the availability of loose sediment from the ploughed fields in this period of the year, on these months' agricultural fields like crop fields and hill slopes are the most important sediment sources than the channels for most of the yearly rainy season.

The last reason for developing this kind of scenario is measured data and site observation. From site observation as it is seen on figure 4.1 the sides of agricultural land area are the most eroded vulnerable area that affected by soil erosion and source of sedimentation. To be more effective on the upper catchment rehabilitation both the agricultural land and the agricultural land side must be vegetated. So from the above listed reasons there are three alternative of agricultural change to forest-evergreen, forest-deciduous and forest mixed to minimize sediment loading in to the reservoir. From those alternative agricultural land changed to forest mixed land is high amount of sediment reduction when compare to others. Therefore, scenario development was made by agricultural land changed to forest mixed cover by 10%, 20%, 30%, 40% and 50%. The scenarios are:

So = Original land

Scenario1 (S1) = 10% Agricultural land change to forest mixed land

Scenario2 (S2) = 20% Agricultural land change to forest mixed land

Scenario3 (S3) = 30% Agricultural land change to forest mixed land

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Scenario4 (S4) = 40% Agricultural land change to forest mixed land

Scenario5 (S5) = 50% Agricultural land change to forest mixed land

Scenario5 is 48% reduction of sediment depositing in to the reservoir. The result of scenario development summarized in table 4.14

Table 4.14 The result of scenario development in Koga catchment

Scenarios	Average annual sediment yield (ton/hectare/year)	Sediment change (%)
S ₀	389.87	0
S ₁	333.25	-14.53
S ₂	300.62	-22.9
S ₃	268.14	-31.23
S ₄	236.05	-39.46
S ₅	204.08	-47.66

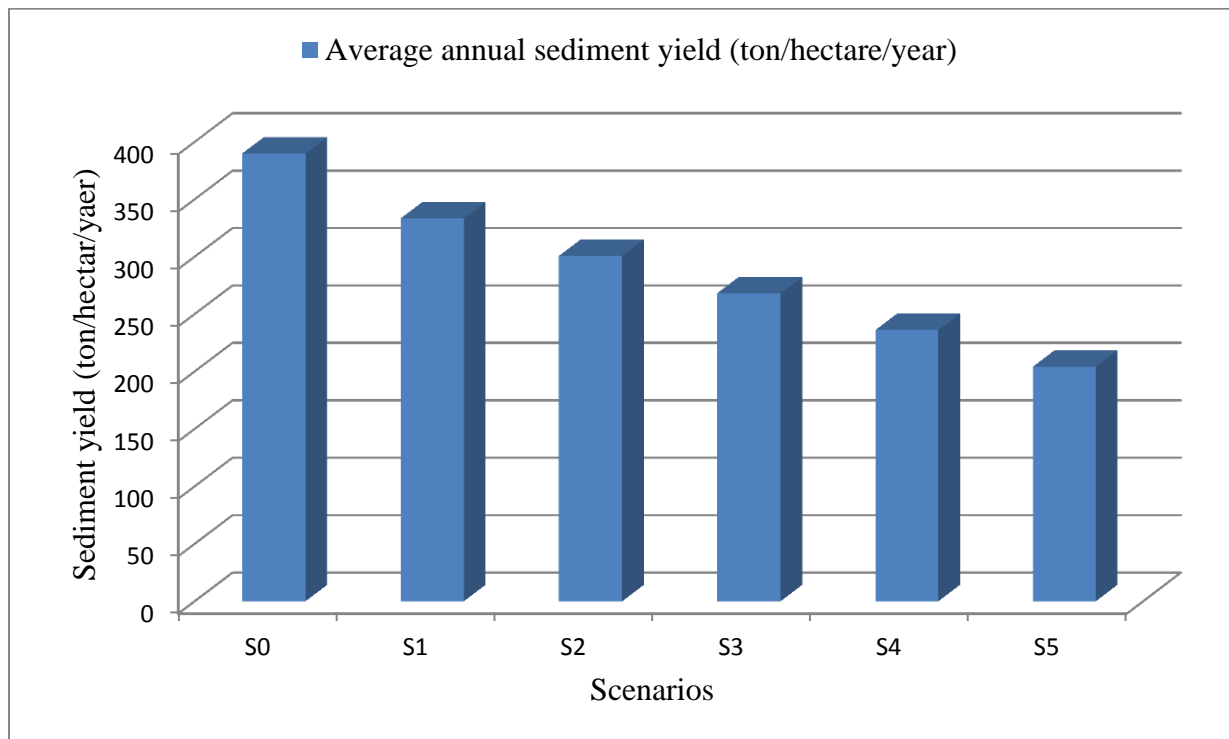


Figure 4.21 Graphical comparisons for sediment yield in the five scenarios

From the above figure 4.21, we can conclude that changing 50% agricultural land to forest mixed land can reduce 47.66% of sediment entering the Koga reservoir. To reduce the side effect of this scenario solution the following remedial alternative is suggested to be implemented.

- On agricultural land SWC must be done, to minimize farmer's displacement.
- Modified farming system should be applied on the remaining agricultural land to optimize producing more crop yield increase the agricultural yield. The farmers need to make changes in their usual style of farming system and practice such as contour farming and strip cropping, crop rotation, no-till farming.
- The people should be advised and facilitated to encourage forest production by their willing.

4.4.2.2 Additional sediment trapping structures

Additional to other integrated watershed management interventions, sediment trapping structure, like reconstructing check dams with gabions, to give stabilized strength to the check dam. Check dam used to trap the sediments and the water comes from the agricultural; the sediment the topsoil (clay soil) used as nutrient. Vegetating the physically soil and water conservation structures has two benefits first it could serve to reduce the velocity of incoming flow and trap sediment. Second, the local people can use the planted wisely, to feed their cattle. In figure 4.22 the red pen shows unstable check dam that was unable handle upcoming sediment load. Generally, to reduce the sediment generated from the catchment this kind of distorted check dams should be reconstructed using gabions.



Figure 4.22 Distorted check dam

Sediment detention basins like sediment bypass can also reduce sediment inflow to Koga reservoir. Sediment bypass is performed to divert water of low sediment concentration from the main channel to a reservoir located off it (off-channel storage). In off-stream reservoirs, intake structure is used to appropriately select water inflow from the main stream, excluding either partially or completely sediment-laden flow from large floods (Morris and Fan, 1997), as presented in Figure 4.23.

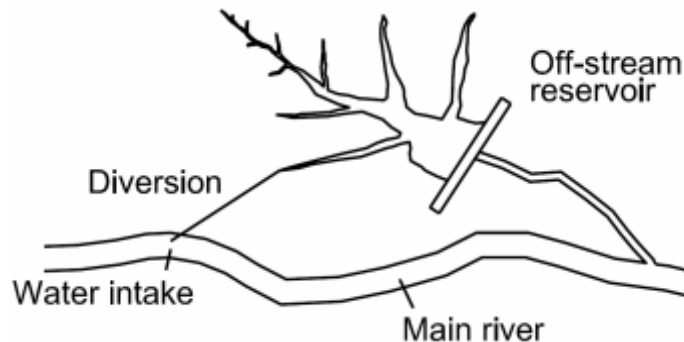


Figure 4.23 Sediment detention basin (Sediment bypass) around an off stream impoundment (adapted from Morris and Fan, 1997)

By participating local people, implementing sediment detention basin while at the same time promoting the use of sediment for land recovery nutrient source of agricultural lands is another advantage. In recent study, Girmay et al. (2012) demonstrated that the use of relatively small quantities of clay-rich reservoir sediments in northern Ethiopia is an economical viable strategy for land reclamation. Such sediment applications result in improved soil nutrients that increase crop yield and increased life expectancy of the reservoir.

(2) Reducing erosion at stream banks

By selecting the most critical river banks failure and stabilizing of channel banks by land slope structures such as riparian protection and vegetation can reduce sediment originated at stream banks.

Comparing the sediment reduction measure result with previous works

Simulation of sediment yield using SWAT model, five scenarios (S1-S2) developed which is 40% of sediment reduces by agricultural land change to forest land (Lemma, 2015). Fasil (2012), prediction of sediment inflow to Gefersa reservoir using SWAT model and assessing sediment reduction measure indicated that: changing 53 % of forest land to agricultural land, result in 74.5 % of sediment reduced where as in Koga catchment changing 50% agricultural land to forest mixed land can reduce 47.66% of sediment

entering the reservoir. The result varies due to the percentage of erodible area availability varies from one catchment to another catchment.

According to Haregeweyn (2012), analyzed Options to prolong the life of Angereb reservoir using multi-criteria analysis approach and removing the sediment using machinery and undertaking watershed management interventions of sediment management options were proposed. Also this study for Koga catchment similar in proposing upper catchment rehabilitation sediment management options but different the second method sediment flushing from the reservoir.

CHAPTER FIVE

CONCLUSION AND RECOMANDETION

5.1 Conclusion

To meet the objective of this study, SWAT model was used in estimating stream flow and sediment load in Koga watershed, Upper Blue Nile basin, Ethiopia. The model was applied on a monthly basis for thirty one years from 1986 to 2016. For stream flow, the model output was calibrated for eleven years from 1989 to 2010 and validated for four years from 2011 to 2016. For sediment yield estimation, the model output was calibrated for eleven years from 2004 to 2010 and validated for four years from 2011 to 2014.

The result of sensitivity analysis indicated that Base flow alpha factor for bank of storage (ALPHA_BNK.rte) was the most sensitive parameter and produces the largest variations in the output of runoff and peak runoff rate whereas, SPEXP (Exponent parameter for calculating sediment restrained in channel sediment routing) were the most sensitive parameters for sediment yield. After the most influential sensitive parameters are identified, the model was calibrated and validated using SWAT CUP optimization algorithm SUFI-2 and the performance was evaluated by coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE).

Both the calibration and validation result indicated that good agreement between observed and simulated stream flow and sediment yield. Model calibration was performed for stream flow and sediment yield at Koga dam site performance evolution during monthly stream flow calibration and validation period indicated that $R^2=0.81$, $NS=0.76$ and $R^2=0.77$, $NS=0.74$ respectively. From the developed rating curve values generated and arranged for sensitivity analysis, calibration and validation as per the requirement of SWAT CUP for the period 2001-2014 excluding 3 years warm up period, the model calibration period was from 2004 up to 2010 and the validation period was from 2011 up to 2014, The model performance evaluation during monthly sediment yield calibration and validation period indicated that $R^2=0.66$, $NS=0.61$ and $R^2=0.76$, $NS=0.70$ respectively. The total annual sediment yield into the reservoir is 24739 ton/year. The annual specific sediment yield into the reservoir is 158 ton/km²/year. After the sediment inflow to the koga reservoir is estimated, erosion prone areas are identified and spatial variation of each sub basin's sediment yield is performed. The sediment inflow into the reservoir varies from time to time. Sub-catchment 25 and 26 generated the maximum annual sediment representing the most erodible area and sub-catchment 4 and 8 are low sediment generated area. The average annual sediment distribution ranges from 1.79 ton/ha to

62.53 ton/ha. Out of the total catchment area 155.75km² 81.7 km² areas is eroded area that means 52.5% of the total Koga catchment area is eroded. For the identified erosion prone areas, evaluation of suitable sediment reduction measure analysis were undertaken by SWAT scenario among all alternatives, changing agricultural land to mixed forest lands gave high amount of sediment reduction. Scenario 5 the best alternative among all scenarios that reduces 47.66% of sediment entering the Koga reservoir by changing agricultural land to forest mixed land.

Additionally, sediment detention basins like sediment bypass can also recommended reducing sediment inflow from upper catchment to Koga reservoir. Implementing sediment detention basin at the same time promoting the use of sediment for land recovery nutrient source of agricultural lands is another advantage. And also modified type of check dam construction is recommended. Continuous Follow up of physical and biological upstream catchment rehabilitation conservation structures by stakeholders is a must. Stabilizing of channel banks by vegetation, and land slope stabilization also proposed especially at critical part of river bank. Recession farming near the reservoir area has to be avoided and contour ploughing should be implemented, not to avoid the cohesive nature of the top soil.

5.2 Recommendation

- ➔ Further experimental analyses need to be performed on different types of catchment rehabilitation measures on the identified erosion-prone areas of Koga catchment to get that are more suitable, better management practice for the real agriculture to apply.
- ➔ For the sustainability of the reservoir, continuous reservoir sedimentation assessment should be done.
- ➔ For uni-modal climatic areas sediment–discharge rating curve should be developed for the dry and wet season separately.
- ➔ To get better model simulation, well-distributed meteorological station needed within the catchment.
- ➔ The available spatial data like DEM, land use and soil data are poor quality, not consistent so; it should be recent, updated and continuously available to get better simulation result.
- ➔ National level, one concerned body should be established to gauge sediment and steam flow data, regularly, at the dams bottom outlet and all rivers.
- ➔ The concerned body must gauge continuously sediment and steam flow data at the dam bottom outlets and avail the data for research input.
- ➔ To the upcoming dam construction projects, the implementation of integrated watershed management practice must be completely applied some years before designing and constructing dams. Lack of appropriate soil-conservation measures and late application associated with intense rainfall and steep terrain topography had great contribute reservoir sedimentation. By now, for Koga reservoir, it is too late to use prevention method. There is only one chance, and it is finding the appropriate mitigation measure and curing, to reduce the effect. But first, it is better to prevent than to cure the reservoir from sediment. Prevention is better than curing.
- ➔ The administrative structure has fragmented stake holder that results scattered management. For instance, MoWIE has watershed management directorate but also MoNRA has watershed management administration. At federal level, the two governmental institution works parallel and separately.
- ➔ For integrated watershed management implementation vertical and horizontal data exchange communication should be encouraged.
- ➔ When applying the recommended sediment reduction scenario, it is clear that agricultural land should change to forest lands, to reduce the side effect, the following should be done.
 - On agricultural land SWC must be done, to minimize farmer's displacement.

- Modified farming system should be applied on the remaining agricultural land to optimize producing more crop yield increase the agricultural yield.
- The people should be advised and facilitated to encourage forest production.
- ➔ Further analysis should be done on the effect of climate change, land use and specific soil erosion study with related to different management scenarios on Koga dam.
- ➔ Further research has to be done by coupling the SWAT model with hydrodynamic models.
- ➔ More detailed study has to be done at the time scale of individual flood events to improve the knowledge of sediment dynamics in constructing the sediment rating curve.
- ➔ Future studies should quantify and incorporate sediment outflow during flushing of Koga reservoir.
- ➔ By taking more sediment sample from each sub basin more accurate researches can be done.
- ➔ For the sustainability of Koga the reservoir further study must be undertaken like ‘Enboch’ availability must be checked on the whole reservoir, before it makes hard things like Tana Lake.

5.3 Limitation of the Study

- In some extent, absence of recently updated land use/land cover and soil map might affect the sediment yield simulation. Recent and high resolution geospatial data is recommended to improve the result.
- Even if sediment–discharge rating curve was developed for the dry and wet season separately, it doesn't represent the observed sediment yield and reduce the uncertainty of the model 100%. This is because, during August, September and October months have lower sediment yields than the other rainy seasons which indicate that there was a depletion of sediment from the sediment sources because of the emerging of agricultural vegetation cover. The month June and July of low peak flows has high sediment yield it is due to the availability of loose sediment from the ploughed fields in this period of the year, on these months' agricultural fields like crop fields and hill slopes are the most important sediment sources than the channels for most of the yearly rainy season. So, more detailed study has to be done to improve sediment rating curve formula.
- Koga uses meteorological station data which is out of the watershed. Using spatially distributed meteorological station within the catchment could increase the accuracy of the simulation result.
- SWAT model doesn't account sediment leaving the reservoir, so does this study.
- The reality of land use implementation is policy driven which may not necessarily follow a scientific approach. So, the developed land-use scenario in this study may not be applied even if there are suggested side effect minimization strategies.
- Researches are done to solve the community problem but the responsible body may not use it, efficiently.

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SEDIMENTATION PROBLEM AND MITIGATION MEASURE OF KOGA RESERVOIR

Appendix

		Area [ha]	Area[acres]	
Watershed		15575.1236	38486.9093	
		Area [ha]	Area[acres]	%Wat.Area
LANDUSE:				
	Agricultural Land-Generic --> AGRL	11630.1332	28738.6407	74.67
	Forest-Evergreen --> FRSE	2604.9589	6436.9836	16.73
	Range-Grasses --> RNGE	38.4702	95.0619	0.25
	Range-Brush --> RRGB	148.7394	367.5424	0.95
	Forest-Deciduous --> FRSD	1132.7146	2798.9943	7.27
	Forest-Mixed --> FRST	20.1074	49.6863	0.13
SOILS:				
	LVx	12385.0314	30604.0319	79.52
	VRe	3190.0922	7882.8773	20.48
SLOPE:				
	5-10	4014.7694	9920.6958	25.78
	10-15	1924.3385	4755.1367	12.36
	15-20	1349.7639	3335.3340	8.67
	20-9999	3360.0407	8302.8286	21.57
	0-5	4926.2112	12172.9141	31.63

Appendix 1 HRU Land Use/Soil/Slope Report

Statistics:: All elevations reported in meters

Min. Elevation: 1925
 Max. Elevation: 3089
 Mean. Elevation: 2197.65453810735
 Std. Deviation: 212.252430404464

Appendix 2 Topographic report

SEDIMENTATION PROBLEM AND MITIGATION MEASURE OF KOGA RESERVOIR

No.	YEAR	ADET	MERAWI
1	1986	1125.8	1301.7
2	1987	1294.3	1583.3
3	1988	1321.3	1282.3
4	1989	1232.3	1007.8
5	1990	949.7	1153.5
6	1991	1893.7	2076.9
7	1992	1434.9	1654.6
8	1993	1193.7	1605.3
9	1994	1271.9	1238.5
10	1995	1347.6	1401.5
11	1996	1675.1	1731.8
12	1997	1381.2	1650.3
13	1998	1347.6	1385.4
14	1999	1156.6	1516.8
15	2000	1116.9	1300.7
16	2001	1358.8	1425.2
17	2002	955.7	999.3
18	2003	1118.2	1285.1
19	2004	1132.3	1385.8
20	2005	1128.4	1564.9
21	2006	1613.1	2134.4
22	2007	1128.5	1583.3
23	2008	1399.3	1648.1
24	2009	1031.5	1513.3
25	2010	1174.5	1441
26	2011	1140.3	1607.3
27	2012	1183.9	1622.4
28	2013	1180.9	1464.3
29	2014	1246.2	1464.4
30	2015	1140.3	1232.4
31	2016	1074.2	1412

Appendix 3 Annual rainfall for selection station

SEDIMENTATION PROBLEM AND MITIGATION MEASURE OF KOGA RESERVOIR

Years	Minimum Temperature	Maximum Temperature
1986	11.2939726	25.74712329
1987	11.4169863	27.18054795
1988	9.374863388	25.66038251
1989	7.142191781	25.27287671
1990	6.442465753	26.04931507
1991	9.864383562	25.68465753
1992	8.88715847	25.52459016
1993	9.178082192	25.29917808
1994	9.707945205	26.04712329
1995	7.998630137	26.32712329
1996	9.13442623	25.60300546
1997	9.184109589	25.89945205
1998	9.061369863	25.77808219
1999	8.457260274	25.62876712
2000	9.06010929	25.48469945
2001	9.798356164	26.09287671
2002	10.01123288	26.58575342
2003	10.64	26.54657534
2004	10.30655738	26.24972678
2005	10.13589041	26.45589041
2006	10.52876712	26.29205479
2007	10.25753425	26.54246575
2008	10.7942623	26.26393443
2009	10.88575342	27.38821918
2010	11.77890411	26.70794521
2011	13.3109589	26.89643836
2012	11.16939891	27.19262295
2013	10.90027397	26.88027397
2014	10.91863014	26.42986301
2015	11.26575342	27.06821918
2016	10.85382514	27.21297814
Average	9.992228208	26.25775413

Appendix 4 Adet minimum and maximum temperature

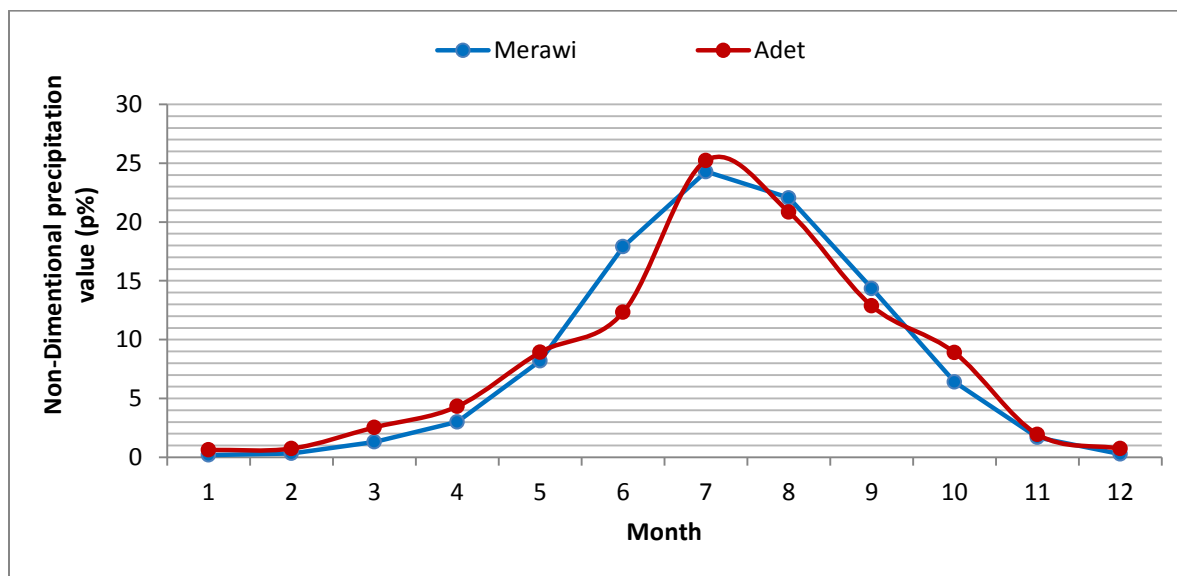
SEDIMENTATION PROBLEM AND MITIGATION MEASURE OF KOGA RESERVOIR

Years	Minimum Temperature	Maximum Temperature
1986	10.06520548	26.85671233
1987	9.332054795	28.3969863
1988	9.030874317	27.70874317
1989	8.195890411	26.92027397
1990	7.621917808	27.79150685
1991	12.1369863	26.7509589
1992	10.45956284	27.03360656
1993	8.588493151	26.37808219
1994	10.30547945	27.33178082
1995	11.03315068	27.67123288
1996	8.496448087	27.22650273
1997	8.662191781	27.60054795
1998	9.695616438	27.63205479
1999	8.45890411	27.35835616
2000	7.875409836	27.15355191
2001	9.337260274	27.57369863
2002	9.845479452	28.35726027
2003	9.836438356	28.61342466
2004	9.492076503	28.04371585
2005	10.17287671	27.28958904
2006	10.59561644	27.22
2007	10.52630137	26.97945205
2008	10.37814208	27.14398907
2009	10.3969863	27.90986301
2010	10.48739726	27.64684932
2011	10.6890411	27.43589041
2012	14.65628415	28.14344262
2013	9.444657534	28.09424658
2014	9.719452055	27.90684932
2015	10.21479452	28.89424658
2016	10.06775956	28.27726776
Average	9.865256557	27.59163473

Appendix 5 Merawi minimum and maximum temperature

SEDIMENTATION PROBLEM AND MITIGATION MEASURE OF KOGA RESERVOIR

Month	Merawi	Adet
Jan	0.186322	0.620666
Feb	0.323601	0.740928
Mar	1.310823	2.542795
Apr	3.011587	4.32221
May	8.209775	8.932171
Jun	17.90969	12.32661
Jul	24.28558	25.2313
Aug	22.05804	20.84715
Sep	14.35052	12.8665
Oct	6.394504	8.892169
Nov	1.682591	1.945872
Dec	0.276965	0.731637



Appendix 6 Homogeneity test by non-dimensional

SEDIMENTATION PROBLEM AND MITIGATION MEASURE OF KOGA RESERVOIR




Appendix 7 Koga river and reservoir




Appendix 8 Koga agricultural side and river side erosion





Appendix 9 Koga upstream and reservoir sediment sampling

		Ethiopian Construction Design & Supervision Works Corporation Research, Laboratory and Training Center Tel 0116 - 61 45 01 / 0116 - 61 01 05 ; Fax 251 - 116 - 61 53 71(6) 08 98; e-mail w.w.d.s.e@ecfionet.et ; P.O.Box 2561	
Company Name:		Document No: OF/RLTC/604	
Title: Soil Fertility Testing Report		Issue No.: 1 of 1	
Client:-Ermias Lemma Alemu		Client Ref:-SF/066/2018	
Project:-Koga catchement and reservoir Sediment Sample Identification			
Source of Sample:- Koga catchement and reservoir			
Location:-At koga watershed			
Date of Collection:-			
Date Received:- 16/02/2018			
Test Requested:- Texture			
Reported Date:-21/02/2018			
Laboratory Number	630/10	631/10	Test Method
Profile Code	Inside Reservoir	Up stream part of koga catchement	
Sand (%)	11.33	72.68	
Clay (%)	52.77	15.75	
Silt (%)	35.88	11.55	Hydrometer
Texture Class	clay	Sandy Loam	

REMARK: The Soil sample is collected and submitted to the laboratory by the client.

Reported by: 
 Lab Expert

Checked by: 
 Senior Soil Expert

Approved by: 
 Soil Fertility Lab S/P Manager



Among the major services rendered by the Soil Fertility Laboratory Testing S/Process of Ethiopian Construction Design & Supervision Works Corporation are: Testing Soil Fertility/ Agricultural Soil Testing and Plant Analysis, Sampling of soil, etc