ADDIS ABABA UNIVERSITY
Addis Ababa Institute of Technology
Department of Civil and Environmental Engineering

Impact of sedimentation on hydropower energy generation

(*The case of Gilgel Gibe I Reservoir*)

A thesis submitted to School of Graduate Studies, Addis Ababa University in partial fulfillment of the degree of Master of Science in Civil Engineering (Major Hydraulic Engineering)

By

Mitiku Muliye Bekele

Advisor: Dr. Bayou Chane.

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SCHOOL OF GRADUATE STUDIES

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External Examiner	Signature	Date

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I, the undersigned, certify that I have read and hear by recommended for acceptance by Addis Ababa Institute of Technology a thesis entitled “Impact of sedimentation on hydropower energy generation

(The case of Gilgel Gibe I Reservoir)” in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering Specialization in Hydraulic Engineering.

Dr. Bayou Chane

(Advisor)

Date

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ABSTRACT

The most important practical and critical problem related to the performance of reservoirs is the estimation of storage capacity loss due to sedimentation process. The problem to be addressed is the rate of sediment deposition and the period of time at which the sediment would interfere with the useful functioning of a reservoir. Modeling of hydrology and sediment yield at watershed level is important for better understanding of the processes that are used for identifying appropriate measure to reduce soil erosion.

This study was conducted to simulate sediment yield in the watershed using Soil and Water Assessment Tool (SWAT) was applied to Gilgel Gibe River, which comprises an area of 402181.775 hectares and distribution of sediment deposit in the reservoir using area-reduction methods. The model was calibrated and validation on Gilgel Gibe River at gauging station. The coefficient of determination (R^2) and Nash-Sutcliffe efficiency (E_{NS}) was used in the model evaluation and validation. Sensitivity analysis, was also performed to assess the model performance.

Fifteen highly sensitive parameters were identified for stream discharge flow and twelve sensitive parameters of stream sediment for calibration and validation. The results found for stream discharge flow ($R^2 = 0.83$, $E_{NS} = 0.83$ for calibration and $R^2 = 0.74$, $E_{NS} = 0.68$ for validation) and for sediment yield ($R^2 = 0.79$, $E_{NS} = 0.75$ for calibration and $R^2 = 0.75$, $E_{NS} = 0.73$ for validation) were satisfactory for the gauging station. The model prediction estimated 27.56 ton/ha/year.

The storage capacity of reservoir is gradually depleted due to sediment accumulation. In this research, sediment distribution concerning reservoir dam of Gilgel Gibe I was estimated by area reduction method. The experimental area reduction method is a technique for predicting sediment distribution in dam's reservoir and its parameters (c, m, n) have been obtained by Borland and Miller on the information from a limited number of dams in America. The reservoir will lose its capacity due to sediment deposition. After a period of 41 years, it will be completely filled and the estimated sediment load is $4.179*10^6$ m^3 per year with the trap efficiency of 96%.

The dam was originally expected to serve at least for 50 - 70 years. The reservoir storage capacity will be lost at an average rate of 0.58 % per year. The total storage lost due to sediment deposit within 41 years from its operation, be $170.97*10^6$ m^3 million m^3 or 28 years was left from 2017 till data used. The total annual economic loss due to the live storage loss found to be 2.289 million kwh/year.

Key words: SWAT, Gilgel Gibe I dam, sedimentation, Empirical method, sediment distribution

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LIST OF ABBREVIATIONS

DEM	Digital Elevation Model
EEPCO	Ethiopian Electric Power Corporation
FAO	Food and Agricultural Organization
FSL	Full Supply Level
GIS	Geographic Information System
HRU	Hydrologic Response Unit
Ha	Hectare
Kg/s	kilogram per second
Km	Kilometer
Kwh	Kilo Watt hour
Masl	Mean above Sea Level
Mm^3	Million meter cubic
Mm	millimeter
M	meter
M^3/s	Meter cube per second
MoWIE	Ministry of Water, Irrigation and Electricity
MW	Mega Watt
SUFI2	Sequential Uncertainty Fitting, Version 2
SWAT	Soil and Water Analysis Tool
SWAT-CUP	Soil and Water Analysis Tool Calibration and Uncertainty Program
T/ha/yr.	Tons per hectare per year
NSE	Nash-Sutcliffen Efficiency
PBIAS	Percent Bias
R2	Coefficient of Determination
RMSE	Root Mean Square Error
USLE	Universal Soil Loss Equation

CHAPTER ONE

INTRODUCTION

1.1. Background

One of the most effective ways of developing surface water is to construct reservoirs. When the reservoirs are built on the sediment laden rivers, however, their useful lives are often reduced unless special measures are taken in its planning and management to minimize reservoir sedimentation.

Sedimentation is the major problem which endangers and threatens the performance and sustainability of reservoir. Sedimentation in a reservoir can be defined by trap efficiency, which is the ratio of the deposited sediment quantity to the total sediment inflow. The impounded reach will accumulate sediment and lose storage capacity until a balance is again achieved, which would normally occur after the impoundment has become silted up with sediment and can no longer provide water storage and other benefits. Declining storage reduces and eventually eliminates the capacity for flow regulation and with it all water supply and flood control benefits, plus those hydropower, navigation, recreation, and environmental benefits that depend on releases from storage. The worldwide loss in reservoir storage capacity is estimated to be between 0.5% and 1% per annum ((Mahmood, 1987).

Storage loss is one of many sedimentation problems that can affect reservoirs. Operation of storage reservoirs is severely impacted by the time half the volume has been sediment. As reservoirs age and sediments continue to accumulate, sediment-related problems will increase in severity and more sites will be affected. Sediment yield is the net result of soil erosion and processes of sediment accumulation, so it depends on variables that controls water and sediment discharge to reservoirs. Typically, sediment reflects the influence of climate (precipitation), catchment properties (soil type, topography), land use/cover, and drainage properties (stream network form and density) (Williams, J.R., 1975). Erosion is a natural process causing soil loss and generating sediment yield from catchment areas even in the absence of alterations of land cover.

Sedimentation is a large problem in the reservoir system within Ethiopia, existing condition of previously constructed reservoir shows that significant portion of their storage capacities are lost due to sedimentation every year. There are even cases where reservoir capacities were filled within few years of operation. Sediment can enter and obstruct intakes and greatly accelerate abrasion of hydraulic machinery, thereby decreasing its efficiency and increasing maintenance costs. Also, it affects the safety of dams, discharge capacity and flood attenuation capabilities. It increases loads on the dam and gates, damages mechanical equipment and creates a wide range of environmental impacts.

Conversion of sedimenting reservoirs into sustainable resources which generate long-term benefits requires fundamental changes in the way they are designed and operated. It requires that the concept of a reservoir life limited by sedimentation be replaced by s concept of managing both water and sediment to sustain reservoir function. Sustainable use is achieved by applying the following basic sediment control strategies: reducing sediment inflow, route sediments and sediment removal. Sedimentation problems and management techniques vary widely from one site to another, and by studying specific sites one can appreciate the complexity of sediment problems and the manner in which they can be addressed.

This study explores the impact of sediment on hydropower energy generation in Gibe I dam and discusses sedimentation management techniques and describes how they can be implemented to limit the impacts on hydropower. On the account of this matter, several empirical and mathematical methods have been developed to predict the temporal sediment distribution in reservoirs. Among those empirical methods, area-reduction method is the most popular one.

The Gibe I is the first conventional hydroelectric power plant with a capacity of 184 MW in Omo basin. Its storage capacity can be lost in a few years of operation if sediment problems are not handled efficiently. Therefore, it is important to predict sediment inflow and its distribution at Gibe I and evaluate its consequences on the reservoir and sustain the reservoir through a long term optimum sediment management program.

1.2. Statement of the Problem

Throughout Ethiopia, soil loss is a critical problem on agricultural land and without careful land management; erosion rates are likely to increase (Awulachew and Ahmed, 2008). A study conducted by kebede (2009), in Ethiopia’s Gilgel Abbay catchement concerning hydrological response to land cover change, using integrated remote sensing data and GIS techniques, for year 1976-2001 showed that forest cover decreased from 51 to 17% and agricultural increased from 28 to 62%. The result of this study implies that during the rainy period the observed increase inflow rate results in a high rate of sediment transport to reservoirs.

The major problem in hydropower reservoir sedimentation is one of the most important factors in the planning of a storage-dam, because uncontrolled soil erosion, Poor land use practices and improper mitigation management systems, land degradation resulting in heavy sediment transport in streams and rivers causes significant reduction of the capacity of reservoirs.

Many reservoirs which have been established for hydroelectric power, urban water supply and irrigation accumulate an alarmingly higher level of sediment than expected. Koka, Angereb, Legedadi, Gilgel Gibe-I and other reservoirs are threatened by this accelerated sedimentation.

Upstream Consequences of reservoir sedimentation include the reduction of storage capacity of reservoir, accumulation of sediment directly affects the operation of hydraulic structures. These effects include water supply shortages for human consumption, irrigation and hydropower, increased hydro-equipment maintenance and repair; a decline in water quality, the cost of removing sediment, blockage of navigational waters and loss of recreation opportunities.

Therefore, understanding the impacts of soil erosion and looking for solutions to minimize is essential, it is important to assess the magnitude of the problem so that effective measures can be implemented. The frequent power cuts and rationing based electric power distribution recently experienced in the country are partially attributed to storage loss due to sedimentation.

This study focuses on impact of sediment on hydropower energy generation in *Gibe I* Dam, Estimate annual loss in benefit due to sedimentation and proposing alternative management plan to minimize erosion rate in the hydropower reservoir.

The primary reservoir sediment problem is the deposition of sediment in the reservoir which leads to;

- Reduction in storage capacity.
- Blockage of hydropower intakes and power outage as a consequence.
- Increased flood risks due to upstream propagation of the deposited sediment deltas.
- River bed degradation and river bank erosion downstream of dam.
- Dam instability and impact on equipment.

Interruption in hydropower generation associated with degradation of water quality, as well as increased complexity in reservoir operation and maintenance. The determination of the sediment accumulation over the life of the project is important to control the operation of dam.

1.3. Research Questions

What is the benefit lost if reservoir storage capacity is reduced by sediment deposit, energy generation?

What is the sediment deposition pattern in the reservoir?

What is the rate of sediment deposition in the reservoir?

What is the trap efficiency of the reservoir?

What sediment mitigation method can we use in a Gilgel Gibe I dam?

1.4. Objective of the Study

1.4.1. General Objective

The overall goal of this study is to determine the impact of reservoir sediment deposition on energy generation of Gilgel *Gibe* I hydropower Dam and to identify most appropriate sediment management strategy that can be applied in the Omo Basin of Gilgel Gibe-I catchment.

1.4.2. Specific objectives

- Collect, collate and synthesize readily available data in order to have an overview of reservoir sedimentation in the Gilgel Gibe I reservoir.
- Predict sediment and deposition pattern in the reservoir
- Determination of the rate of sedimentation accumulation.
- To analyze the loss income due to sedimentation on annual income of hydropower.
- To propose sediment mitigation method to improve the existing life spans of the reservoir.

1.5. Significance of the study

Power interruption is common in years of severe drought over the country and shortages in water disrupt power plant operation. In the recent past; Ethiopia has faced with power shortage and hence forced to rationing power several times during dry season, while floods passing reservoirs have been caused considerable damages during wet seasons. This fact may mainly stems from impact of accumulate sediment and lose storage capacity.

The findings of the this thesis may help for Gilgel Gibe I Reservoir management authority, to take appropriate measure to reduce erosion from the catchment Area and sedimentation problem of the Reservoir to attain storage capacity of a reservoir purpose for which it was designed and to adapt appropriate generation of power based on the current revised reservoir capacity.

The result of this thesis might also serve as baseline information for those who are interested to conduct further research on the impact of sediment on hydropower energy generation using empirical area reduction methods.

1.6. Thesis Outline

Chapter one gives a general introduction to the study with its back ground of the problem objectives of the study and organization of the thesis. **Chapter two** describes the reviewed literature related to the study on the concept of sedimentation models, Empirical methods, sediment distribution, erosion management and overview of the SWAT model. **Chapter three** gives description of Gilgel Gibe I watershed and it outlines the research methodology employed in this study. The approaches used for this study are included and discussed. **Chapter four** result and discussions are presented in this chapter. Finally, in **chapter five** conclusion and recommendations based on the results of the models and the data used for this study.

CHAPTER TWO

LITERATURE REVIEW

2.1. Concept and definition of sedimentation

Reservoir sedimentation is a gradual accumulation of the incoming sediment load from a river. This accumulation is a serious problem in many parts of the world and has severe consequences on water management, flood control and production of energy. In the present situation, the worldwide loss of storage capacity in surface water reservoirs due to sedimentation is higher than the increase in storage volume achieved through construction of new reservoirs. The worldwide loss in reservoir storage capacity is estimated to be between 0.5% and 1% per annum (Mahmood, 1987); (W.R, 2010).

2.2. Soil Erosion and Reservoir sedimentation

Soil erosion is a major watershed problem in many developing countries. Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water. Soil erosion is the process whereby the earth or rock material is loosened or dissolved and removed from any part of the earth's surface (Morris, G. L., & Fan, J., 1998). Gross erosion is the sum of all types of erosion rill, gully, channel erosion, and mass wasting. Several factors affect soil erosion: which include climate, soil, topography, land use land cover and management practice. Among those land use land cover and management practice have direct link to soil erosion.

Sedimentation starts after damming a natural river and storing water in the reservoir behind the dam. Due to increased flow geometry of a river when it enters to the reservoir, the water flow velocity is reduced and sediment carrying capacity will diminish which cause dumping most of the sediment load carried into the reservoir. Two types of sedimentation occur in the reservoir, one due to normal deposition of the sediment load at the front upstream beginning of the reservoir, and the other due to formation of density current which brings more sediment to middle and downstream end of a reservoir.

Reservoir sedimentation in some African river basins, concluded that the design sediment inflow to some storage reservoirs had been underestimated (Saenyi W.W, 2002). As a result, those reservoirs have been filled with sediments faster than was expected. Also he investigated sediment deposition in a designed reservoir showed that there is significant influence of reservoir water management on distribution of deposited in the reservoir and backwater profile.

Generally, the sediment transport phenomenon is a function of many processes. Erosion of the land surface takes place in the form of sheet erosion, rill and inter-rill erosion, and gulley erosion. Eroded sediment particles that are transported to the river are called delivered sediment or sediment yield from a given watershed. The delivered sediment travels with the flow is suspended material. The other component of the sediment transport comes from the bed and bank material and travels with the flow as suspended or bed load. The transported particles move downstream as far as the hydraulic conditions permit. These conditions depend on the slope of the river, velocity, discharge, cross section, etc.

Throughout Ethiopia, soil loss is a critical problem. Sheet and rill erosion, is estimated to be very high, reaching levels of up to 100-200 Mt/ha/year, in 50% of agricultural areas (A review of hydrology, sediment and water resource use in the Blue Nile Basin, 2008). Population densities and herd size are the highest in Africa, and continue to grow rapidly. Thus, without careful land management, erosion rates are likely to increase.

2.3. Types of Reservoir Sedimentation

All reservoirs or natural lakes are subject to some degree of sediment inflow and deposition. When a river is dammed, the speed of the water is slowed down and thus the rivers ability to transport these sediments is reduced; hence sediment accumulates within a reservoir based on grain size, physical shape of the reservoir, and operational practices.

The amount of sediment deposition in a reservoir is controlled by the type of sediment deposited (suspended or bed load), the detention storage time, the shape of the reservoir, and operational practices. Sedimentation falls into three basic categories in a reservoir: (1) deltaic deposition of gravel or coarse sand deposited in the entrance, (2) deposition of fine sediments (silt-mud) from homogenous flow, and (3) deposition of fine sediments (silt-mud) from stratified flow. Horizontal strata or thin bands present across the bottom of a reservoir are where incoming sediment load is trapped and deposited most of the time (Van Rijin, 1993)).

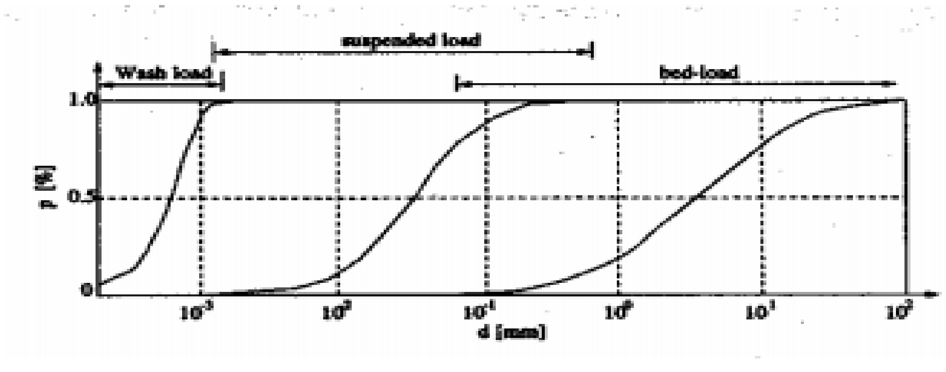


Figure 2. 1 Sediment transport mode, source: (Saenyi W.W, 2002)

Coarse sediment (gravel and sand) move near the bed and will settle out first, near the upstream end of the dam, and often Couse what is known as a backwater delta. A large part of the finer suspended colloidal (silts and clays) transported in suspension or as wash load will settle out closer to the dam where the velocities are even lower beyond the delta after which they settle out to form the bottom set bed. They are more evenly spread than coarse sediment, but the distribution is highly dependent on reservoir circulation and stratification. Some of the finer particles will remain in suspension and will flow through/over the outlet structures (ICOLD, 2009). The classification of reservoir sedimentation based on the location of deposition into three categories, the position of each type of reservoir sedimentation can be seen in the longitudinal profile of the reservoir is classified as Back water deposition, Delta deposition and Bottom set deposition.

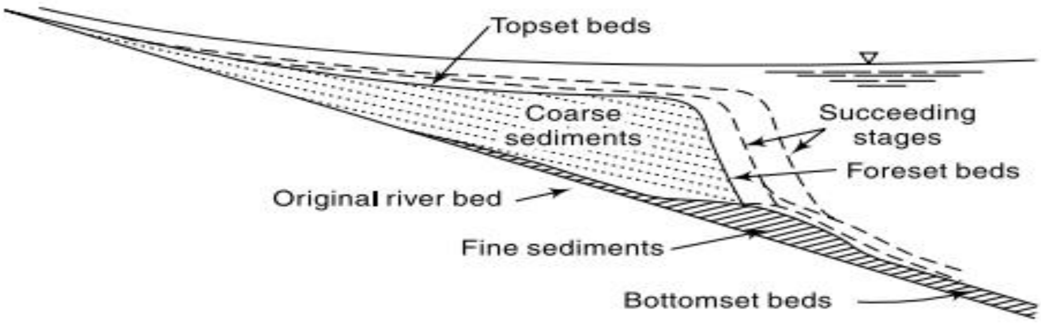


Figure 2. 2 Schematic Representation of Reservoir Delta (Subramanya, k., 1998)

The rate at which reservoirs lose capacity due to sedimentation is generally expressed as a percentage of initial storage capacity lost per year. For example, if the dam is silting up at a rate of 0.6%/year, this means that when the reservoir is 50 years old approximately 30% of the dam’s initial storage capacity would be lost (ICOLD, 1989).

2.4. Impact of Reservoir Sedimentation

Reservoir sedimentation is a process that has been going on since the first dams were build and is a consequence of creating a calm reservoir lake where there used to be a fast flowing river. It eventually starts to influence the reservoir capacity and the river morphology. The siltation of the reservoir could hinder the usage of the dam and interfere with the functionality of the reservoir. With the sediments taking up space in the reservoir, the storage capacity of the reservoir is decreasing. If the sediments settle all the way towards the dam structure, the hydropower installation can be influenced by the sedimentation process as well. 25% of the world’s existing fresh water storage capacity may be lost in the next 25 to 50 years in the absence of measures to control sedimentation. Study indicated that the problem is more severe in developing countries (World Commission on Dams, 2000).

The rate of the reservoir sedimentation and form of the deposition is affected by the rate of sediment transport and the method of its deposition in reservoir. The sediment management is challenging discipline in civil engineering especially in the many regions. The storage capacity of reservoirs decreases due to accumulation of sediment. By focusing on sediment impacts in hydropower plant the following impacts may be notified:

1. The effect of reservoir sedimentation on regulating water resources and its impact on power generation
2. The effect of sediment inflow to power intakes and its impacts on turbine system and other components of the hydropower plant.

2.4.1. Consequences of Reduction of Storage

The impact of reservoir sedimentation on economy and other social related services depends upon the the size and the characteristics of the soil deposits. Because of dams usually built to serve multiple objectives, the consequence are very complex. The loss of reservoirs storage capacity due to sedimentation is particularly felt in connection with energy production, water supply for domestic use, agriculture, and industry and flood control. Sedimentation also affects reservoir surface area, by reducing water depth and favoring for aquatic growth which affects public health, obstruct the access for marine vessels and hinder their movement.

Soil erosion is a serious problem in the Ethiopian highland areas that increased sedimentation of reservoirs and lakes. Similar study indicated that sediment concentration of 16.7 kg m^{-3} in Bilate river (Seleshi B. Awulachew, 2001) and 50 per cent of the studied reservoirs in Tigray will lose their economic life before half of the design period because of siltation (Haregeweyn et al., 2005). In another study, sediment deposition rate within the catchment showed that 9·2 t $year^{-1}$ in the north part of Ethiopia and 30 t ha^{-1} $year^{-1}$ in south-western Ethiopia (Hurni, H., 1983).

The Aba-Samuel dam was one of the first electric power generating stations in the country. Due to Sedimentation the reservoir's initial water carrying capacity has been reduced by half due to silt accumulation (4.45 tons of silt km^{-2}) and eutrophication (Devi, R., T. Esubalew, L. Worku, and Abebe, 2007). Another, estimate indicates that it is losing storage capacity at a rate of 664, 980 t per year for the 43 years following construction (Amare, 2005).

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 but the Angereb Reservoir has not lived up to the design expectations because of siltation, in which about 1.4 Mm^3 sediment has been accumulated (Amare, 2005). The mean annual sedimentation rate in Angereb reservoir is

1200 t/km^2/year. They predicted that the reservoir will lose 30% of its volume by the year 2015 (Musa, A.S., S. El-Zein, 2005).

Legedadi reservoir supplies 60% of water demand to Addis Ababa city, delivering 165, 000 cubic meters of water per day. A 20 years bathymetric survey (1978-1998) of this reservoir shows an average silt accumulation of 26, 000 m^3/year, which results water shortage (Gessese, A., 2008).

The research done on Gilgel Gibe catchment by (Devi, R., T. Esubalew, L. Worku, and Abebe, 2007) showed that the reservoir capacity has been reduced by annual sediment loads of 4.50x10^7 t year^{-1} which could occupy 3.75x10^7 m^3 year^{-1}. These researchers, estimated that the Gilgel Gibe I dam's volume will be reduced by half within 12 years and would be completely filled with sediments within 24 years unless timely remedial measures are taken. The dam was originally expected to serve at least for 70 years

2.4.2. Influence on Energy Production

Hydro-electric plants are used to provide the peak demands for energy because of the flexibility of their operation. The reservoir is, therefore, an energy accumulator and the larger the storage capacity the more efficient it is. Hence, any reduction of the storage capacity will adversely affect the energy output of the hydropower plant and the maximum power available during the critical period of consumption, when the water inputs is insufficient.

The impacts of the Koka reservoir sedimentation causes economic loss of 60 million birr (displacement of 481 Mm^3 of water by sediments translates into an energy loss of 128 M KWh, considering the average energy price of 0.45 Birr/KWh) and Flood control capacity was being reduced due to sedimentation, limiting the amount of retained water during the rainy season (Elias, E., 2003).

Deposition pattern of sediment entering the GERD reservoir was predicted based on Empirical Area Reduction method. The sediment deposition depth in the reservoir increases gradually and fills up the storage below the minimum water level which defines the life of the reservoir. According to the Empirical Area Reduction method, the GERD reservoir will have life of 116 years for the estimated annual sediment load of 245 million tonnes, trap efficiency of 100% and average deposit density 1.12t/m^3. The reservoir storage capacity will be lost at an average rate of 0.3 % per year. Consequences of storage capacity loss on production capacity were evaluated where the average annual energy loss due to active storage loss amounts 27 GWh. The estimated present value of economic loss indicates that the total economic values forgone due to the live storage loss was found to vary between 0.26% and 0.06% of the original dam cost, 4.33 billion USD when the discount rate varied between 5% and 13% respectively (Tadesse, 2013).

Generally, Damming created by a dam results in reduced sediment transport capacity of the dam and sediment deposition. Sediment deposition results in the loss of live storage capacity, Sediment impacts on stability, Sediment impacts on discharge capability, and Sediment impacts on equipment. As sediment deposition continues, the sediment delta grows higher and eventually flood levels start to rise. For hydropower, corresponding to more than 80 percent of the total storage, part of the sedimentation is an the dead storage, with little or no impact, and part affects the live storage, where the reduction of 50 percent means a much lower reduction in power production. A reduction of storage of 0.3 percent per year means a reduction of power of much less than 0.1 percent of production, that is, less than 10 percent in a century (ICOLD, 2009).

2.5. Concept of reservoir life

With reasonable levels of maintenance, the structural life of dams is virtually unlimited. Most reservoirs are designed and operated on the concept of a finite life which will ultimately be terminated by sediment accumulation rather than structural obsolescence. All reservoir formed by dams on natural water courses are subjected to some degree of sediment inflow and deposition. The problem facing the project planner is to estimate the rate of deposition and the period of time before the sediment will interfere with the useful functioning of a reservoir. At the time design, provisions should be made for sufficient sediment storage in the reservoir so as not to impair reservoir functions during the useful life or during the period of economic analysis of the project. Several concepts of reservoir life are summarized as: design life is the planning period used for designing the reservoir project based on an economic period not exceeding 50 years, whereas engineering studies a 100-year sediment storage pool in the design. Project life is the period during the reservoir can reliably serve the purposes for which it was originally constructed. When the reservoir can no longer serve its intended use because of sediment accumulation, it has reached the end of its design project life. Economic life is the period over which the economic benefits from project operation exceed costs. Usable life is the period during which the reservoir may be operated for either its original or a modified purpose, whether or not such use generates net benefits (Morris, G. L. & Fan, J., 1998).

2.6. Erosion and Sediment Problem in the Gilgel Gibe Catchment

Sediment deposition in reservoirs is serious problem affecting the lifespan of dams. It is important to have information about both the rate and pattern of sedimentation within the reservoirs to predict the expected problems which might take place. This will allow decision makers to put strategies and remedies in place to deal with expected future problems.

Landslides, river bank erosion and gullies were found to be the major sediment sources in the Gilgel Gibe catchment. More than 200 hectares of severe landslide areas are connected to the major rivers, more than 651 major gullies with a washed soil volume of about 12.3 million m^3 was investigated. About 78.6% of the gullies are connected to rivers (PHE, 2011).

The erosion process of the Gilgel Gibe catchment and its sedimentation impact on the hydroelectric power dam was evaluated and analyzed by EEPCo before the construction was undergone. According to the result, the solids flow in the reservoir and the calculation to determine the dead storage capacity of the dam was made in order to guarantee the power plant a useful lifespan of at least 50 years. Three different types of data were available for evaluation of solid flow, and a comparison was made in order to estimate a reliable field of variables for the measurements.

Direct measurements of sediment transport on the Gilgel Gibe carried out by ENEL/ELC association in May 1996 in correspondence to the dam section with a flow of 25 m^3/s. The sediment content has been found to be 0.255g/l and divided as follows: sand 5%; silt 23%; clay 22% and colloids 50%. The concentration of solid contents is exponentially proportional to the liquid flow of the river. In the reservoir the ratio between reservoir capacity and average annual inflow is about 0.45. The trap efficiency is therefore about 80% according to Churchill and about 95% according to Brune. An annual average silt weight comprised between 3.4 and 4.0 Mt may be considered as the specific weight of the sediment is generally 1.2 – 1.3 t/m^3.

Having this above data consideration, EEPCo determined the life span of the dam to be 50 years while integrated watershed management of the catchments of Gilgel Gibe is properly done its life span may extend to 70 years.

According to a study done on the assessment of siltation and nutrient enrichment of Gilgel Gibe dam, it was found that siltation and nutrient enrichment were the major problems in this reservoir also indicated that according to the 1997 Environmental Assessment on this reservoir, a high sedimentation load was anticipated. The expectation has proven to be true because investigation by (Devi, R., T. Esubalew, L. Worku, and Abebe, 2007) showed that the reservoir capacity has been reduced by annual sediment loads of 4.50×10^7 t $year^{-1}$ (from which Gilgel Gibe River contributes 277, 437 t $year^{-1}$) which could occupy 3.75×10^7 m^3 $year^{-1}$. Based on the results of physico-chemical parameters and data obtained using the observational checklists, these researchers, estimated that the Gilgel Gibe I dam’s volume will be reduced by half within 12 years and would be completely filled with sediments within 24 years unless timely remedial measures are taken. The dam was originally expected to serve at least for 70 years. The total soil loss into the rivers from landslide is estimated as 11 t / ha/ yr. for the last 20 years, therefore, landslides need to be point out as an important sediment source for rivers in the Gilgel Gibe catchment.

(Tufa, 2016) Study indicated that average annual sediment concentration of 10617.8 ton/km^2/yr or (106.178 ton/ha/yr) at Gilgel Gibe-I outlet dam site and other estimate of sediment yield over Gibe 1 was calculated to be 204.147 tones / km^2 / year (Yonas, 2018).

2.7. Reservoir operation effects on sedimentation

A reservoir storage pool operated for water conservation captures irregular runoff flows to make subsequent deliveries to users at scheduled rates. Operation for hydropower production seeks to balance two conflicting objectives. To maximize energy yield per unit of water, the pool should be maintained at the highest possible level, yet the pool elevation should be low enough to capture all inflowing flood runoff for energy generation.

The operation of the reservoir pool will influence the sediment trap efficiency and the spatial distribution and unit weight of sediments that settle within the reservoir. The sediment trap efficiency will be greatest if substantial portions of the inflows are stored during floods when the sediment concentrations are highest. If the reservoir is normally kept full (run of the river operation), flood flows pass through the reservoir and sediment trap efficiency is reduced. When the reservoirs are frequently drawn down, a portion of the reservoir sediment (typically the delta) will be eroded and redeposited deeper in the reservoir pool. Fine sediments, that are exposed above the drawn down reservoir pool, will compact as they dry out (Strand, R.I. and E.L. Pemberton,, 1982). For example, fine sediment would be compacted during droughts that result in reservoir drawn down.

Therefore, Reservoir operation has significant effect on rate of sedimentation, sediment distribution and trapping efficiency of the reservoir. It is therefore important to examine effects of operation strategy on sedimentation of the reservoir.

2.8. Sediment yield estimation methods

A hydrological model is the simplified representation of a complex process of the real world system which considers the hydrologic cycle and it is the quantitative expression of observing, analyzing or predicting a process by simulating it through the transformation of rainfall to runoff in catchments.

Erosion and sediment transport need to address as it leads to a number of problems which can be evaluated in conjunction with hydrologic simulation. Sediment yield depends on numerous factors, ranging from climate to geologic, topographic, and anthropogenic influences. Processes determining the sediment yield of a river are complex, making sediment yield estimation a difficult task best executed by experts. Reliable sediment yield estimates use multiple methods and careful evaluation of the results. This is the most important characteristic of defensible sediment yield estimates (Annandale, Morris, 2016). Numerous models have been used to estimate erosion and sediment yield from a watershed and to analyze land-use/change impacts to sediment generation (Schmidt, J., 2008). The most commonly used hydrological modeling tools for watershed analysis and stream flow estimation, are SWAT, HEC-HMS, MIKE-SHE, etc. and other some hydrological equations like sediment rating curves. SWAT model is more applicable for simulating continuous rainfall-runoff processes and also taken as a tool to develop a hydrological and surface erosion and sediment routing model for the study area. In general, spatially distributed models are advantageous for modelling of sediment delivery processes at a basin scale.

2.8.1. Sediment rating curve

Sediment rating curve describes the average relation between water discharge and suspended sediment concentration. A relationship between discharge and concentration can be developed which, although exhibiting scatter, will allow the mean sediment yield to be determined on the basis of discharge history (Morris, G. L. & Fan, J., 1998). Most river loads estimated by this method have been underestimated and the degree of underestimation increases with the degree of scatter about the rating curve and can reach 50%. (Wlling, D.E., 1977), has outlined some common sources of errors in applying sediment rating curve: Errors could also result from inaccuracies in stream flow data and/or in the techniques of sediment sampling and subsequent laboratory analysis. Mathematically fitted curve is a potentially poor fit at the high extreme, which will be represented by few data points.

There is no standard method for rating curve construction, and in some cases visual curve fitting give better result than mathematical curve fitting. The most commonly used mathematical rating curve is power function (Morris, G. L., & Fan, J., 1998).

$$C_s = aQ^b$$

Cs is sediment concentration in *mg/l*, Q is water discharge in m^3/s, *a* and *b* are coefficients.

A suspended sediment rating curve is usually presented in one form of the two basic forms, either as a suspended sediment concentration/stream flow or a suspended sediment discharge/stream flow relationship The relationship between discharge and sediment concentration or discharge and sediment load for a particular stream is not a fixed parameter but can considerably vary from one storm to another depending on factors including the intensity and areal distribution of the rainfall, and changes in the sediment supply. To avoid poor relationship between water discharge and sediment discharge separate curves may be developed for winter and summer, fine and course, falling and rising stages of discharge and different ranges of discharge (Morris, G. L. & Fan, J., 1998).

2.8.2. Survey of deposited sediment in reservoir

Survey of sediment deposition rate in reservoir can gives accurate estimate of sediment yield from upstream of the reservoir if trap efficiency is known. Considering reservoir sediment problem, reservoir survey are necessary to get more realistic data regarding the rate of siltation to provide reliable criteria for studying the implication of annual loss of storage over a definite period of time. Sediment surveys not only determine the volumetric loss but also provide other valuable information such as sediment distribution in the reservoir and changes in the stream channel in relation to transport and deposition (Vanoni, Vito A., 2006).

2.8.3. Soil and Water Assessment Tool (SWAT) Model

The SWAT model is long term, continuous simulation watershed. It operates on daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields. The model is physically based, computationally efficient, and capable of simulating a high level of spatial detail by allowing the division of watersheds into smaller sub watersheds. SWAT models water flow, sediment transport, crop/vegetation growth, and nutrient cycling. The model facilitates users to model watersheds with less monitoring data and to assess predictive scenarios using alternative input data such as climate, land use practice, and land cover, or on water movement, nutrient cycling, water quality, and other outputs. Major model components includes; weather, hydrology, soil, temperature, plant growth, nutrients, pesticides, and land management.

In SWAT, a watershed is divided into multiple sub watersheds, which are then further subdivided into Hydrological response Units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the sub-watershed area and are not identified spatially within a SWAT simulation. The water balance of each HRU in the watershed is represented by four storage volumes: snow, soil profile (0-2 meters), shallow aquifer (2-20 meters), and deep aquifer (more than 20 meters). The model calculates for each HRU separately and routes through channel, ponds, and or reservoirs the water, sediment and nutrients from HRU outlets to the sub-basin outlets and then to the basin outlet to obtain total basin loadings (Arnold, J.G. and Williams, 1998).

The SWAT model has been integrated with ArcView and ArcGIS software. AVSWAT-2000 which is an ArcView extension and a graphical user interface for the SWAT (Di Luzio, 2002) and Arc SWAT-ArcGIS interface was used for this study.

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

2.8.3.1. Calibration - validation applications

SWAT calibration and validation approaches used for verification of model accuracy for the simulated conditions. In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices the model must be first calibrated to measured data and should then be tested (without further parameter adjustment) against an independent set of measured data. Calibration is setting or correcting the output value by changing values of input parameters in an attempt to match these with field conditions or observations within some acceptable criteria. The model calibration requires that field conditions at the study area be properly characterized otherwise it may result in a model calibrated to a set of unrepresentative conditions of the study area.

Three calibration approaches are widely used by the scientific community. These include: 1) manual calibration, 2) automatic calibration and 3) a combination of the two. The most widely used approach is manual calibration. In manual calibration the modeler alters the model input parameters manually by comparing the simulated values with observed values until the two values come within a reasonable range. This process is time consuming and its success depends on the modeler expert judgment and his knowledge about the study area (Eckhard,K. and Arnold,.J, 2005). Auto calibration is usually preferred as it is less time consuming and can use an extensive set of input parameters possibilities. Auto calibration uses a predefined algorithm to obtain optimum input parameters.

Model validation is the final step for the components of interest (stream flow, sediment yield, and water quality) to ensure that the calibrated parameters set perform reasonably well under an independent data set. Validation is the process of demonstrating the capability of making a sufficiently accurate simulation, which may vary based on the aim of a project (Refsgaad, J.C. and Storm, B., 1996). Predicted and observed values are compared to determine whether the objective function satisfactory involves running a model using the parameters during the calibration, and comparing the results from the different periods of calibration to determine whether the model meets confidence limits.

2.8.3.2. Sensitivity Analysis for the SWAT model

Model sensitivity analysis helps to assess the relative sensitivity of model outputs with respect to the changing of model parameters, which is generally the first step of model calibration. Sensitivity analysis can determine which parameters in the watershed are most sensitive and these parameters need to be adjusted based on the sensitivity analysis. Sensitivity analyses are performed in different ways: local, which involves changing values one at a time, and global, which is the ability to change all the parameter values simultaneously.

Hydrological data (stream flow and sediment) are required for performing sensitivity analysis, calibration and validation of the SWAT model. Two statistical approaches were used to evaluate the model performance - coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (NEs). The R^2 value is an indicator of the strength of relationship between the observed and simulated values. Nash-Sutcliffe simulation efficiency (E_{NS}) indicates the degree of fitness of observed and simulated data.

Table 2. 1 General performance ratings for recommended statistics for a time step.

Statistics	**Very Good**	**Good**	**Satisfactory(Fair)**	**Unsatisfactory(poor)**
R^2	$0.86<R^2\leq1$	$0.75<R^2\leq0.86$	$0.65<R^2\leq0.86$	$R^2\leq0.65$
NSE	0.75<NSE≤1	0.65<NSE≤0.75	0.5<NSE≤0.65	NSE≤0.50
PBIAS	PBIAS<±10	±10≤PBIAS<±15	±15≤PBIAS<±25	PBIAS≥±25
RSR	0<RSR≤0.5	0.5<RSR≤0.6	0.6<RSR≤0`.7	RSR>0.7

Source: Moriati et al. 2007

$$R^2=\left[\frac{\sum_{i=1}^{N}(O_i-\bar{O})(S_i-\bar{S})}{[\sum_{i=0}^{N}(O_i-\bar{O})^2]^{0.5}[\sum_{i=0}^{N}(S_i-\bar{S})^2]^{0.5}}\right]^2$$

$$E_{NS}=1-\frac{\sum_{i=1}^{N}(O_i-S_i)^2}{\sum_{i=1}^{N}(O_i-\bar{O})^2}$$

$$\text{PBIAS}=\left[\frac{\sum_{i=1}^{n}(S_i-O_i)}{\sum_{i=1}^{n}O_i}\right]*100$$

Where: $\mathbf{O_i}$ is measured value, $\mathbf{O_{av}}$ is average measured value, $\mathbf{S_i}$ is simulated value, and $\mathbf{S_{av}}$ is average simulated value

The parasol Method: In any hydrological modeling work there are uncertainties in input (e.g., rainfall), in conceptual model (e.g., by process simplification or by ignoring important processes), in model parameters (non-uniqueness) and in the measured data (e.g., discharge). Uncertainty analysis was performed on SWAT2012. ParaSol is an optimization and statistical method for the assessment of parameter uncertainty that can be classified as being global, efficient and being able to deal with multiple objectives.

The Sequential Uncertainty Fitting (SUFI-2) Method: The sequential Uncertainty Fitting, version 2 (SUFI-2) is one of the uncertainty analysis programs that is incorporated in an independent program called SWAT calibration and uncertainty program (SWAT-CUP) (Abbaspour K. C, 2013) that perform uncertainty analysis due to both parameter and model uncertainties, except the outliers. SUFI-2 is developed for a combined calibration and uncertainty analysis. Parameter uncertainties reflects all sources of uncertainties, i.e. conceptual model, forcing inputs (e.g. rainfall), and parameter. The parameter uncertainty leads to uncertainty in the output which is quantified by the 95% prediction uncertainty (95PPU) calculated at the 2.5% (L9599U) and the 97.5% (U95PPU) levels of the cumulative distribution obtained through Latin hypercube sampling.

After each iteration, new and narrower parameter uncertainties are calculated where the more sensitive parameters find a larger uncertainty reduction than the less sensitive parameters. In deterministic simulations, output (i.e., river discharge) is a signal and can be compared to a measured signal using inbices such as coefficient of determination (R^2), root mean square error, or Nash-Sutcliffe. In stochastic simulations where predicted output is given by a prediction uncertainty band instead of a signal, two different indices were devised to compare measurement to simulation: the *P-facto*r and the *R-factor* (Abbaspour K. C, 2013).

Two stopping rules quantifying the uncertainty are defined: (1) bracketing ‘most’ of the measured data within the 95PPU band (P-factor) and (2) obtaining a ‘small’ ratio of the average distance between the 2.5th and 97.5th prediction percentiles and the standard deviation of the measured data (R-factor). These two measures quantify the model uncertainty.

2.8.3.3. Hydrological component of SWAT

The simulation of flow can be described in two hydrological components: the land phase and the routing phase. The land phase of the hydrological component controls the water movement in the land and determines the water, sediment, nutrient and pesticide amount that is loaded into the main stream. Canopy storage, infiltration, redistribution, evapotranspiration, lateral sub-surface flow, surface runoff, ponds and tributary channel return flow are simulated in this hydrological component.

The second component is the routing phase in which the water is routed in the channel network of the basin, carrying the sediment, nutrients and pesticides to the outlet. In the land phase, equation describes the hydrological cycle in the land phase.

$$SWt = SWo + \sum (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) P_{USLE} LS_{USLE} CFRG$$

Where SW_t is the final soil water content (mm), SW_o is the initial water content (mm), t is the time step (day), R_{day} is the daily precipitation (mm). Q_{surf} is the surface runoff (mm), E_a is the evapotranspiration (mm), W_{seep} is the seepage from the soil bottom layer (mm) and Q_{gw} is the groundwater flow (mm).

With regard to the sediment component, the SWAT computes erosion caused by runoff and rainfall with the Modified Universal Soil Loss Equation (MULSE) (Williams, D. T., and Theisen, M.S., 1996).

$$Sed = 11.8(Q_{surf} q_{peak} area_{hru})^{0.56} K_{USLE} C_{USLE} P_{USLE} LS_{USLE} CFRG$$

where *sed* is the sediment yield (tons/day), Q_{surf} is the surface runoff (mm/ha), q_{peak} is the peak runoff rate (m^3/s), $area_{hru}$ is the area of hydrological response unit (ha), K_{USLE} is the soil erodibility factor, C_{USLE} is the management cover, P_{USLE} is the support practice factor, L_{SUSLE} is the topographic factor and *CFRG* is the coarse fragment factor. The detailed description of all these parameters can be found in the SWAT manual and also from (Eckhard,K. and Arnold,.J, 2005).

$$A = 11.8 * \left(Q_{surf} * q_{peak}\right) * K * L * S * C * P \quad (William, 1975)$$

1. Erodibility Factor (K): is a function of the soil texture, structure, organic matter content and permeability which describes the difficulty of eroding the soil ranging from 0.05 for unconsolidated loamy sand to 0.75 for silt and clayey loam soils.

2. Topographic Factor (LS): it describes the susceptibility of soil erosion due to length and slope ranging from 0.1 for short, flat slopes to 10 for long, steep slopes.

3. Practice Factor (p): it describes the result of specific soil conservation practices which usually is taken as 1.

4. Cover and Land management Factor (C): it describes the pressure of plant canopy on surface erosion which taken 1 for bare ground (most susceptible to erosion), 0.1 for fully mulched or covered soils and 0.0001 for forest soils with a well-developed soil.

2.8.3.4. SWAT Advantages and Limitations

Advantages: Modelling based on physical processes associated with soil and water interaction, Flexibility to incorporate crop characteristics, cropping stage and duration, Flexibility on input data requirement, Capability of modelling the changes in land use and management practices, Computational efficiency, Capability of long-term simulations, Capability of modeling catchments areas varying between few hectares to thousands of sq.km. And the model is freely available and can be easily downloaded from the internet.

As limitation: Due to the heterogeneity of the catchments, a number of meteorological observation stations are required to present the spatial variation in the hydro-meteorological characteristics in the area. The lack of adequate number of observation stations affects the model output. Though SWAT is a free software tool, in order to represent the spatial variation in the catchments characteristics, GIS software is the pre-requisite to run the model.

2.9. Selection of the hydrologic model

The selection needs not only consider the objective study that determines the structure and complexity of the model, but also the data requirement for model development can be hindered by the data availability for calibration and validation of model.

Although there are no clear criteria for making a choice between models, some simple guidelines can be stated (Cunderlik, 2003). These criteria are always project dependent, since every project has its own specific requirement and needs. Availability of input data and required model outputs are the most important criteria for selection of sediment yield estimation.

Keeping in mind the above selection criteria, the Soil and Water Assessment Tool (SWAT) was selected to achieve the research objectives. It is physically based, spatially distributed, identify vulnerable (erosion prone areas) and adopt best management practice for the watershed. It requires information about weather, soil properties, topography, vegetation and land management practices.

SWAT can perform very well for sedimentation and hydrological studies for large as well as small catchments. The following form the SWAT model the rationale for its use in this study.

- Efficient performance for hydrological and sedimentation studies for large catchment.
- Good simulation for flows monthly, seasonally and annually with satisfactory simulation on a daily basis.
- Appropriate for use as a decision support model as it has the capability of modelling changes in land-use, management practices and climate changes.

2.10. Empirical Prediction of sediment Deposition Pattern

There are many indirect approaches developed to predict sedimentation within reservoir and some of them are empirical methods. The Empirical methods to distribute sediment below the normal pool elevation developed by the U.S. Bureau of Reclamation have been widely used. Both (area increment and area reduction) empirical methods were described by (Borland, W. M., and Miller, C. R.,, 1958).

Sediment is deposited in reservoir at all elevations, causing the stage-capacity curve to shift. Empirical methods have been developed to distribute sediment deposits within a reservoir as a function of depth, thereby projecting the shift in the stage-storage curve. These methods are much quicker and easier to use than mathematical modeling and also require less data. When sediment survey data are available for existing reservoir, the observed deposition pattern can be used to select the proper empirical relationship to compute the future shift in the stage-area and stage-capacity relationships.

As a limitation, empirical methods do not identify the specific location in a reservoir which will be affected by sediment; they predict only the change in the stage-area and stage-capacity curves. A significant shift in the operating regime, such as implementation of sediment management, will affect the deposition pattern. Empirical methods cannot be user to simulate these effects, and the evaluation of management alternatives requires numerical modeling. (Morris, G. L. & Fan, J., 1998).

The methods are based on a four-step process:

1. Determine the amount of sediment to be distributed. In an existing reservoir, the volume of sediment might be estimated by assuming that the observed historical rate of volume loss will continue into the future. At a new site, volume loss would be estimated from the predicted inflowing load, sediment release efficiency, and deposit specific weight.
2. On the basis of the site characteristics, select the appropriate empirical curve for sediment distribution. In an existing reservoir with surveyed sediment deposits, the historical deposition pattern is used as the basis for selecting the empirical curve for distributing future sediment deposition.
3. Determine the height of sediment accumulation at the dam, termed the *new zero-capacity elevation.*
4. Use the selected empirical curve to distribute sediment as a function of depth above the new zero-capacity elevation. These values are then subtracted from the original stage-area and stage-capacity curves to produce the adjusted curves. This entire procedure is repeated for

each sediment volume to be analyzed. These computations are readily adapted to solution by electronic spreadsheet. (Subramanya, k., 1998).

2.10.1. Area-increment method

(Cristofano EA. 1953, 1953) Was the first researcher who proposed a very simple method called ‘area increment method’ to take into account the sediment distribution throughout the reservoir. The first empirical method which uses the assumption that, an equal volume of sediment will be deposited within each depth increment in the reservoir. Reservoir geometry, operation, and sediment grain size all affect sediment distribution within the impoundment, and four different empirical type curves were developed on the basis of these characteristics. Use of the appropriate type curve can produce a more realistic sediment distribution than the area increment method.

2.10.2. Area reduction method

Experimental area-reduction method, first presented by (Borland, W. M., and Miller, C. R.,, 1958). The aim of the Borland and Miller technique is to establish volume/surface area/depth relationships for reservoirs after sediment has been deposited therein. The calculation procedure of this empirical method was developed from resurvey data of 30 American reservoirs. One of the most current methods of measuring the volume difference in a reservoir is using the elevation–area–capacity curves (Lara). Experimental method of area reduction can be mentioned as one of the Elevation–area–capacity curves to distinguish the sediment distribution manner.

2.11. Classification of reservoir by area reduction method

In order to make a general approach of sedimentation in the reservoirs, a classification of the different types of reservoirs has to be made using area-reduction methods. Because of the enormous variety within the reservoir, it is not possible to generate one overall parameter that can represent the complexity of a reservoir and make a distinction between reservoirs. Therefore, the classification is split up with the help of multiple parameters. These parameters represent the sediment distribution within the reservoir, the hydraulic conditions in a reservoir and take into account administrative aspects of the reservoir sedimentation problem.

The first method discussed to classify reservoir is the Empirical Area-Reduction method, developed by Borland and Miller in 1958. The basis of this method is the shape of the reservoir, which is determined by using the reservoir depth and reservoir capacity. The method divides the reservoir in four (4) standard types. Within these standard reservoir types, the parameter “m” divides the types in different classes and it represent the reciprocal of the slope of the line obtained by plotting the reservoir depth at the vertical axis against reservoir capacity at the horizontal axis on log-log paper. The typical distribution of sediment in these four types of reservoir is shown in table and Figure.

Table 2. 2 Classification of reservoirs (Borland and Miller 1958)

Reservoir Type	**Classification**	***m***
I	Lake	3.5~4.5
II	Floodplain	2.5~3.5
III	Hill	1.5~2.5
IV	Gorge	1~1.5

These types of reservoir can then be linked to the sediment distribution within these reservoirs. It is important to know where sediment settle if a decision has to be made between the different reservoir preservation techniques.

From the Figure below it is seen that Types I reservoirs, the sediment already starts to settle at shallower depths, close to the point where the river enters the reservoir. This makes sense since a type I reservoir is described as a Lake reservoir and has a relatively flat bottom slope. It reduces the flow velocity and therefore facilitates the setting of sediments. For type IV reservoirs, sediment starts to settle at the deeper parts of the reservoir, much closer to the dam. This is due to the steeper bottom slope of the reservoir, which results in a faster flow in the reservoir. Sediment will be kept longer in suspension and will settle further away from the point where the river enters the reservoir.

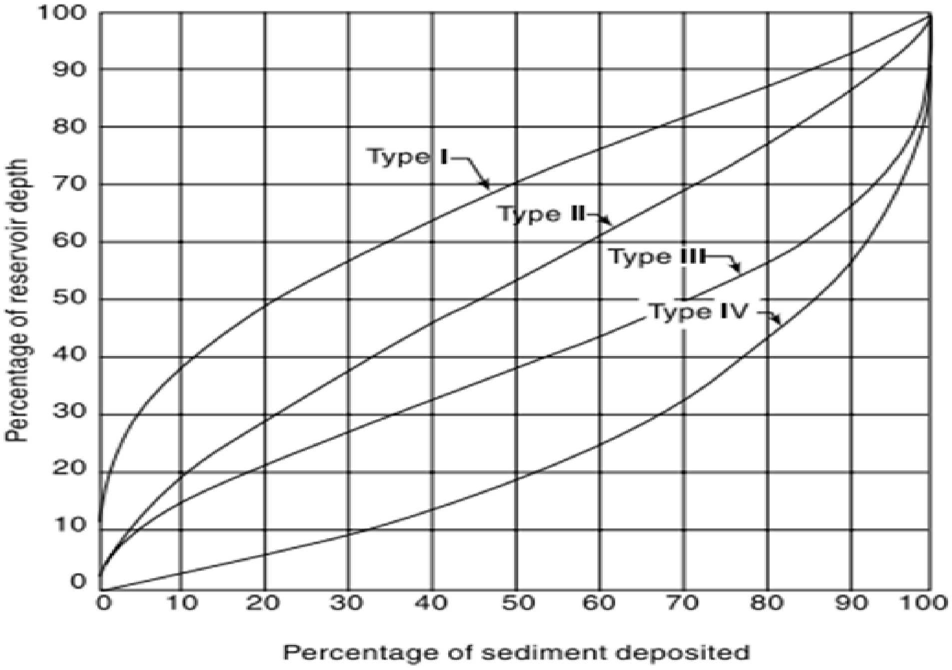


Figure 2. 3 Typical distribution of sediment in various reservoir types (Subramanya, k., 1998)

The majority of the sediments also settle close to the dam with type III reservoirs, but not as extreme as with type IV. A type II reservoir has a more or less constant dispersion of sediment throughout the reservoir.

Conversely, Type IV and III reservoirs have very low percentage of sediment at top portions when compared to Type I and II reservoirs. The shape factor of a reservoir does not change linearly with time and depends on many factors including the characteristics, age and operation mode of the reservoir (Borland, W. M., and Miller, C. R.,, 1958).

The deposition pattern of sediment depend on a host of factors which include the slope, geometry of the reservoir, particle size distribution of sediment and the operation pattern of the reservoir. On the basis of extensive field data of reservoir in USA, Borland and Miller classified the reservoir into four standard types as mentioned above.

2.12. Allowable Reservoir Operations

Whether or not it is permitted to (partially) draw down the water level in the reservoir determines which preservation method can be used and which cannot. Also, some methods can be used during full operational water level as well as during total draw down, but that has an influence on the effectiveness of that method.

Permission to draw the water level in a reservoir depends on the function of the dam and the time that it necessary to restore the water level after a draw down. If the dam is built to fact as fresh water storage for instance, drawing down the water level for a long period of time will not be an option since its primary function cannot be fulfilled then. Geo-technical instability and keeping the navigation of the river intact can also be reasons to maintain the water level of the reservoir.

Also, if the time that is necessary to restore the water level to the operational level is too long, the functionality of the dam will be lost for a long period and that makes the draw down very costly.

The possibility of a (partial) draw down is therefore depending on the functionality of the dam and the economic consequences of draw down. The decision finally has to be made by the owner of the dam, who will have to decide if drawing down the water level is allowed.

The classification based on the drawing down option is divided into three different groups.

- It is permitted to completely draw down the water level in the reservoir
- It is only permitted to partially draw down the water level in the reservoir
- It is not permitted to draw down the water level at all.

2.13. Capacity- Inflow Ratio

The last classification of the reservoir is based on the relation between the yearly inflow of water from the river and the capacity of the reservoir.

If the river has relative high discharge compared with the volume of the reservoir, it is easier to draw down the water level in the reservoir. The reservoir fills up relatively fast and the functionality of the reservoir can be restored more easily. Economic losses due to the water level drop are therefore in general much lower than the scenario where the discharge of the river is relatively low.

If, on the other hand, the ratio between the reservoir capacity and the river discharge, it takes much longer before the operational water level of the reservoir is restored again. Drawing down the water level can be very uneconomic in this case.

The ratio between the reservoir capacity (C) in m^3 and the inflow of water (I) in m^3/year has a significant influence on the amount of sediment that is caught in the reservoir. If the water retention time in the reservoir is large, and therefore, the C/I ratio is relatively high, the water remain within the reservoir for a long time and sediments will settle much more easily in the reservoir. When the C/I is small and the retention time of the water in the reservoir is small as well, the amount of sediments that settle in the reservoir will be lower as well.

A distinction can be made between reservoirs that are usually refreshed with water during a year and reservoirs that aren’t. With this approach, seasonal effects can be taken into account. A third distinction is made for reservoirs which have an average retention time that is less than half a year. These reservoir types have a relatively fast flowing water volume through their reservoirs.

Therefore, this classification can be divided into 3 types of reservoir:

- C/I > 1 year. The capacity of the reservoir is larger than the mean annual runoff from the watershed
- 0.5 < C/I < 1 year. It takes half a year to a year to completely refresh the reservoir volume. This is without taking into account the seasonal floods.
- C/I < 0.5 year. He average retention time in the reservoir is less than half a year.

2.14. Reservoir trap efficiency

An important aspect of managing the sedimentation problems in a reservoir is to determine the quantity of sediments that will settle in a reservoir. A quick way to make an estimation of the amount of sediments that settles in a reservoir is to calculate the Trap Efficiency. Reservoir trap efficiency is defined as the ratio of deposited sediment to total sediment inflow for a given period within the reservoir economic life. Trap efficiency is influenced by many factors but primarily is dependent upon the sediment fall velocity, flow rate through the reservoir, dam characteristics and reservoir operation.

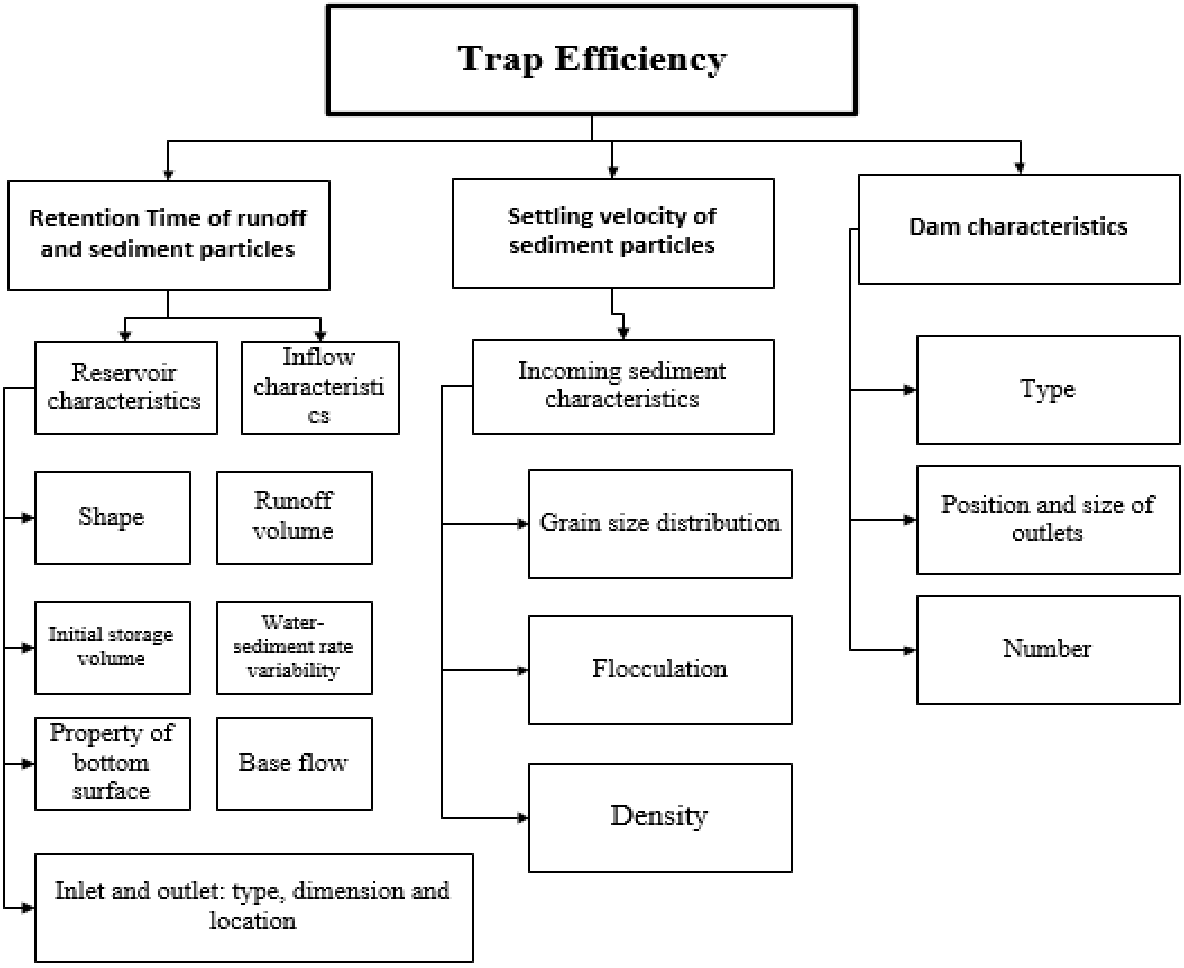


Figure 2. 4 Factors influencing the trap efficiency of reservoirs

Brune Curves: The first method explained is developed by Brune. It is the most widely used method to empirically determine the Trap Efficiency. The curves of this method are based on data from 44 reservoirs and are used worldwide to determine the Trap Efficiency. (Brune, 1953) developed an empirical relationship for estimating long-term trap efficiency in normally impounded reservoirs based on the correlation between the capacity to inflow ratio (C: I). This is probably the most widely used method for estimating the sediment retention in reservoirs, and gives reasonable results from very limited data: storage volume and average annual inflow. As a limitation, the method is applicable only to long-term average conditions.

It must be emphasized that these curves should only be used for normally situated reservoirs (reservoir which are completely filled by water and have their outlet at the top of the embankment). These curves are not suitable for floodwater-retarding structures, desilting ponds or semi-dry reservoirs (K. Bronsvoort, 2013).

Storage capacity(C) of the reservoir at FSL = 839 million m^3

Average daily inflow rate (I') = 50.4 m^3/s = 1589.4 million m^3 per year

Ratio of storage capacity/Inflow rate = C/I = 839 million m^3/ (1589414400m^3) = 0.5

With these information trap efficiency of Gilgel Gibe I reservoir was estimated to be 96% (Figure below) based on Brune's.

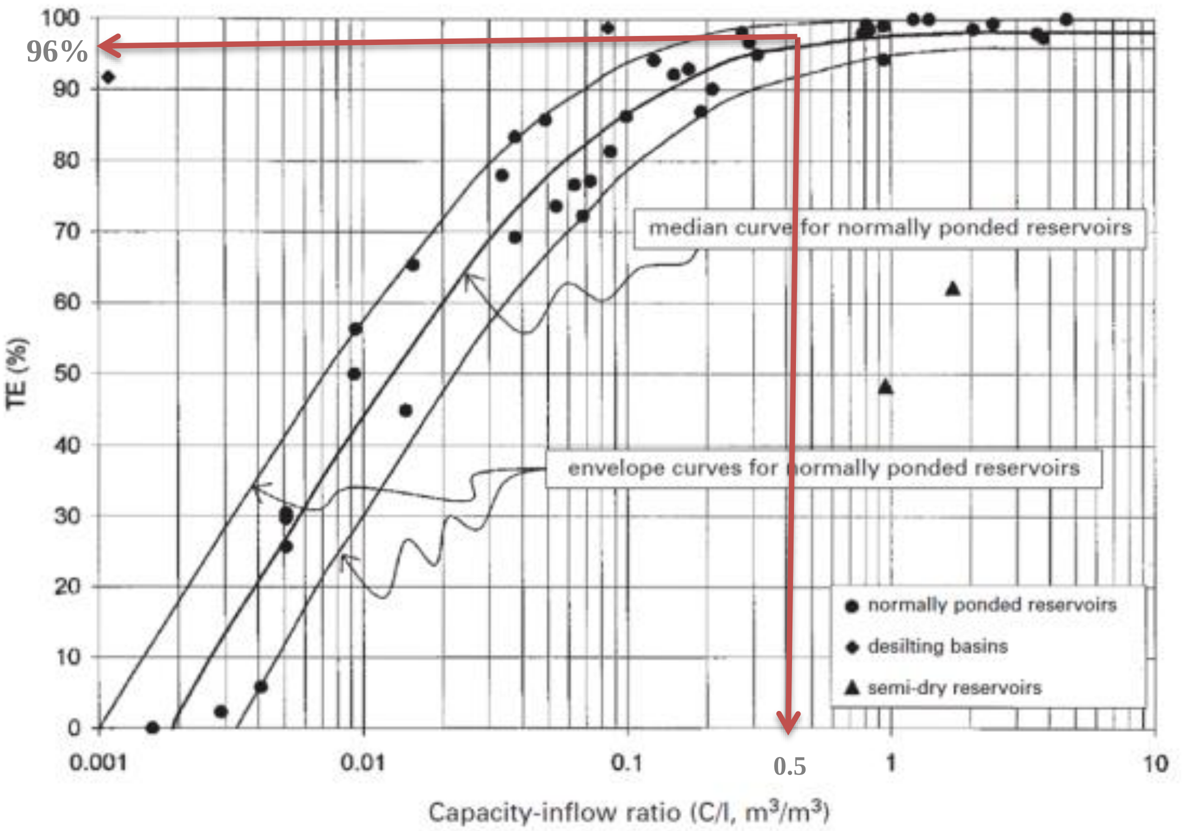


Figure 2. 5 Brune curves relating the Trap Efficiency to the capacity to annual inflow ratio.

On the horizontal axis is the the C/I ratio as used above, where C represents the capacity of the reservoir and I the average annual water inflow. The ration is expressed in years (which is incorrectly presented in Figure). When the C/I ratio is smaller than one year, it means that the amount of water in the reservoir is replaced totally during one year. If the C/I ration is bigger than one year, it means that the amount of water in a reservoir is bigger than the total amount of that yearly flows into the reservoir. The C/I ratio therefore describes the average retention time of the water in a reservoir. The upper curve yields for predominantly coarse-grained sediments/ the median curve yields for mixtures of grain sizes and the lower curve yields for primarily fine sediments.

According to (Brune, G.M., 1953), the higher the retention parameters (C/I) and the higher the trap efficiency, the faster the rate of reservoir sedimentation throughout approximately three quarters of the reservoir's range (Figure 4). In other words, smaller reservoirs will trap less sediment and last longer, while the converse is true for larger reservoirs. Brune's curve which equates capacity to inflow ratio requires little input data, is simple to apply and has been very widely used to estimate reservoir trap efficiency.

Churchill Curves: Another widely used method is the method developed by Churchill in 1948 (Borland, W. 1971). Churchill suggested that there is a relationship between the amount of sediments that passes a reservoir (100-TE (%)) and the sedimentation index. The sedimentation index of a reservoir is defined as:

$$Sedimentation\ Index = \frac{Period\ of\ retention}{Mean\ velocity}$$

Retention period **(**Reservoir capacity at the mean operating pool level for the analysis period (m^3) divided by Average daily inflow rate during study period (m^3/s). And the mean velocity **(**inflow divided by average cross-sectional area (the average cross-sectional area can be determined by dividing reservoir capacity by length) (m/s). Length is reservoir length at mean operating pool level (m).
With the sedimentation index, a ratio is added of two reservoir characteristic which both have a significant influence on the reservoir sedimentation. The bigger the retention time of the pool and the lower the mean velocity, the higher will be the sedimentation rate of the reservoir and with that the sedimentation index.

The Churchill curve may give a better prediction of Trap Efficiency than the Brune curve, the big disadvantage of this method is that it is very difficult to determine the sedimentation index. The data necessary to calculate sedimentation index is often not available, which makes the methods in that case useless. This is the main reason why the Brune curves are more widely used to determine the Trap Efficiency.

The sedimentation index computed used to estimate the sediment release efficiency. Churchill's method can be used to estimate the release efficiency in settling basins, small reservoirs, flood retarding structures, semi-dry reservoirs, or reservoirs that are continuously sluiced.

Brown Curves: A third method to determine the Trap Efficiency is by using the ratio between the capacities of a reservoir versus the watershed. This capacity versus watershed ratio is then connected to the Trap Efficiency. The Trap Efficiency is described as the capacity/watershed ratio is expressed in the capacity of the reservoir S_R per square mile of drainage area.

The use of the capacity/watershed ratio has the disadvantage that this parameter is not very reliable. The run-off production of the watershed (W) is highly dependent on the soil characteristics, which differs heavily per watershed. This is the reason why for low C/W ratios (and therefore a relatively high W) the span of the Trap Efficiency is large.

This method therefore is not preferred if an estimation of the Trap Efficiency has to be made. However of other methods can't be used, a considerable uncertainty has got to be taken into account if the Brown curves are considered (Brown, 1943).

2.15. Sediment Management in Hydropower Dam

Hydropower reservoirs are losing their capacity due to sedimentation processes, and are therefore seriously threatened in their performance. Approximately 1% of the storage volume of the world's reservoir is lost annually due to sediment deposition (Morris, G. L. & Fan, J., 1998). In some developing countries, where watershed management measures are not carried out effectively, reservoir storage is being lost at much larger rates.

Without any mitigation measures the viability of many reservoirs in the worldwide is questionable, as impacts and loses are not balanced by the profits. It is apparent that for mastering the reservoir sedimentation issues the use of strategies for controlling reservoir sedimentation becomes increasingly important because of sustainable development issues.

Multiple reservoir sedimentation management techniques exist and their technical viability have been proven Techniques may be categorized into groups representing catchment management, prevention of sediment deposition and removal of deposited sediment. Catchment management aims are reducing sediment yield, i.e., the amount of sediment that may flow into a reservoir (Annandale, G.W., 2011).

Techniques that may be used to accomplish this goal include reforestation (revegetation of catchments), construction of check dams, contour farming and warping. Prevention of sediment deposition in reservoirs can be accomplished through bypassing sediment around a reservoir (using tunnels, river modification, sediment exclusion and off-channel storage) and by sluicing and density current venting. Various techniques can be used to remove sediment that has already deposited in reservoirs. These include drawdown flushing, pressure flushing, dredging, dry excavation and hydro suction. Four general factors influence the magnitude of erosion and sedimentation are climate, soils, topography, and land cover.

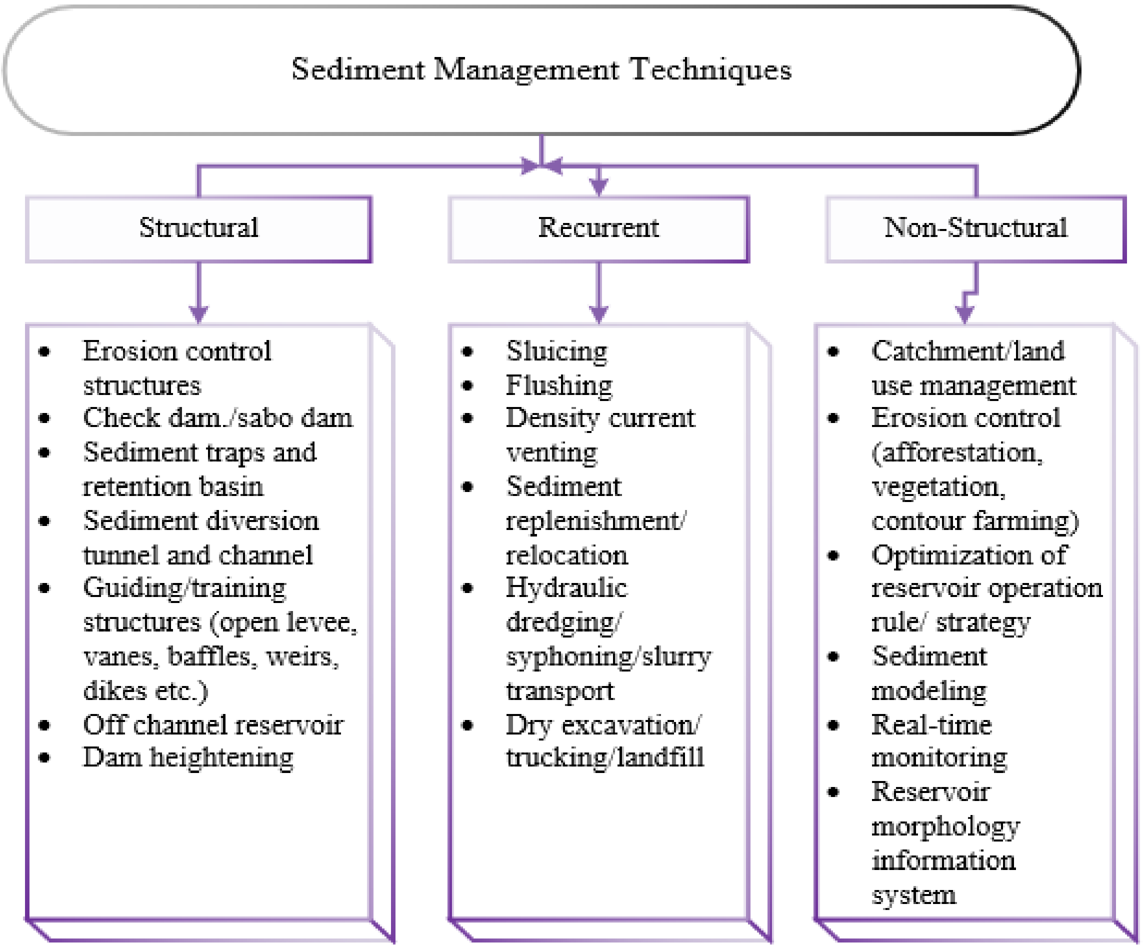


Figure 2. 6 Reservoir sediment management strategies

The best management practices refer to a variety of agronomic, biological and mechanical conservation measures to minimize the production and transport of sediment. Erosion and sedimentation can be reduced in three general ways (Blopal and Raipur, 2013):

- ✓ Stopping or minimizing erosion from disturbed areas by conservation measures
- ✓ Controlling the erosive impacts of increased or concentrate runoff
- ✓ Minimizing opportunities for sediments to be transported to streams

2.15.1. Reducing sediment inflow to the reservoir

In the upstream watershed of a reservoir, three basic patterns of soil conservation measures are commonly taken to reduce sediment load entering reservoir: structural measures, vegetative measures, and operational measures (Morris and Fan, 1998). **Structural measures** include structural terraces, flood interception and diversion works, channel protection and stabilization works, bank protection works, check dams and silt trapping dams. **Vegetative measures** includes growing soil and water conservation forests, reforestation, vetiver fencing. **Tillage practice,** include strategies such as scheduling construction and timber harvest activities (Tadesse, 2013), increasing the productivity of land like mixed cropping, strip cropping, cover cropping, crop rotations, cultivation of shrubs and herbs, contour cultivation conservation tillage, land leveling, control of overgrazing (PHE, 2011). Some of these measures are discussed below.

Structural measures

Engineering/mechanical measures of soil and water conservation includes various engineering techniques and structures constructed across the direction of the flow of rainwater with the objective of division of long slopes into a series of shorter ones in order to reduce the velocity of runoff water thereby reduce the soil and water losses. There are various structural measures of which some of the important measures are described below. It is always better to go for only the earthen structures with the locally available materials instead of high cost masonry structures.

Structural terraces: Terraces are broad channels across the slope which if well designed can control sheet and gully erosion. Terraces reduce slope length and deliver surface runoff through terrace channels that are designed to be non-erodible and to prevent deposition of sediment.

Reservoir bank protection works: Material eroded and flushed into a reservoir from the reservoir banks can have a significant role in reservoir sedimentation diminishing live storage of the reservoir. The methods of bank stabilization can be made of natural materials like riprap of quarry stone completed by appropriate vegetation in order to minimize cost of the protective measure.

Check dams: Check dams are small structures designed to trap bed load to prevent bed degradation and gully erosion on shallow rivers and streams with medium slope. Check dams reduce the stream slope by letting the inflowing sediment deposit, on the bed of the valley which also reduces flow velocity and its sediment transporting potential. The structural measures have the advantage that soil particles won’t reach the reservoir and therefore, they eliminate any siltation problems that could exist in the reservoir. However, the construction of the sediment capture structure is very costly.

Vegetative measures

Planting and establishment of quick growing vegetation can provide temporary and/or permanent stabilization of exposed areas. This is done by influencing the amount of sediment that is eroding away from the subsurface, when precipitation falls onto the subsurface and flows away. By reducing the amount of particles that are carried along by the water, the amount of sediments that enter the reservoir can be reduced as well. This is done by managing the soil erosion in the watershed and increasing the amount of vegetation in the watershed area. The roots of plants, grass and trees are capable of keeping the soil together and reduce the amount of particles that are eroding away from the subsurface. It is a relatively cheap method which is very environmentally friendly. Erosion cannot be reduced to zero. Therefore, vegetative measures alone cannot be a sustainable measure against reservoir sedimentation which can only be achieved by balancing sediment across the reservoir.

For a large watershed with poor natural condition, soil conservation can hardly be effective. However, vegetative measures can help reduce the cost of other management options if implemented jointly. It is however a very comprehensive method which will need a rather extensive rate of cooperation with local communities and stakeholders for it to be effective (G.W. Annandale, 1987).

Afforestation; Afforestation is the growing of forests where there is no forests earlier like abandoned cropland, pastureland, or grasslands, due to adverse factors such as unstable soil or aridity. In various arid, tropical and sensitive areas, once the forest cover is destroyed, the land quickly dries out and becomes inhospitable to new tree growth. Other critical factors include over grazing by livestock and over-harvesting of forest resources.

Reforestation; Reforestation is the re-establishment of the forest either naturally or artificially after its removal, or planting more trees. Reforestation is carried out on land where trees have been recently removed due to harvesting or natural disasters such as fire, land slide, flooding or volcanic eruption.

Strip cropping: two or more crops are grown in alternative strips with crops of different strips vary in their root/shoot characteristics to controls the soil erosion by reducing velocity of runoff to increase the rate of infiltration. Strip cropping includes several good farming practices includes crop rotation, contour cultivation, and proper tillage and cover cropping and is a very effective means for controlling soil erosion, especially in gently sloping lands.

Vegetative barriers: Vegetative barriers are narrow, permanent strip of stiff stemmed, erect, tall, dense perennial vegetation established in parallel rows and perpendicular to the dominant slope of the field. Dense vegetation raised across the slope, makes a live bund. The live bund help to reduce the length of field slope, check the run-off velocity, improve the soil moisture.

Grassed waterway: are used where the risk of channel erosion would be excessive if the area was cultivated. The need for a grass waterway should be recognized and acted upon early because it is much easier to prevent a gully from forming than it is to repair the land later. The easiest way to establish a grass waterway is simply to leave that portion of the field un-ploughed when other crops follow hay or pasture. This will work where the land is properly shaped for a waterway.

Land leveling: Land leveling and farm bunding were the predominant form of land management practiced in watershed management. Land leveling helped in soil and water conservation. During heavy rainfall velocity of water was reduced due to leveled fields. This, ultimately, reduced the chance of soil erosion. When water started flowing slowly along the fields the infiltration augmented ground water level. Farm bunds were created to prevent erosion of top soil and to retain rainwater in the farms of cultivation.

2.15.2. Methods that minimize the deposition of sediments in reservoirs

The basic principle of these methods is to avoid the settling of sediments that have already entered the reservoir. This can be done by using the hydraulics of the flow to avoid settling of the sediments and allows to pass through reservoirs, as quickly as possible, before deposition of sediments is one of the most effective and economic ways to preserve the storage capacity (Morris, G. L., & Fan, J., 1998). Or to induce erosion of the already settled sediments. To be successful, it is essential for these methods that the velocity of the flow stays sufficiently high and it is necessary that the dam has bottom outlets. This can only be achieved if the sediment carrying capacity of the stream flowing through the reservoir is kept as close to the original carrying capacity of the river as possible (G.W. Annandale, 1987). Some of the most commonly used methods of sediment deposition reduction are presented below.

Sediment routing

Sediment routing is the method to use reservoir hydraulics and/or geometry to pass the incoming sediment with the objective of minimizing deposition. Sediment routing techniques can be classified into two main categories (Morris and Fan, 1998): **(a)** Sediment pass through (sluicing): this is where the incoming sediment is discharged through deep sluice mainly during high sediment concentration season in the river. The high water floods, which usually occur during flood seasons, carry a substantial amount of sediments and are immediately let through the dam. Bottom outlets in the dam or flood channels are therefore necessary. It is essential that the sediments are kept in suspension and that means that the water flow cannot calm down. Because coarse sediments settle down more easily, this method is more successful with smaller particles, such as clays and silts, which have a much lower settling velocity. **(b)** Sediment bypass: is the technique in which the incoming sediment is diverted from the main storage area upstream the reservoir area. As the main process involved in sediment routing is to pass sediment laden flood and store water from less sediment carrying flow, it partially preserves natural sediment transport process in the river. It can be considered environmentally friendly management strategy when compared with other approaches.

As a limitation, it is not able to remove the previously deposited sediment or pass part of the coarsest part of inflowing load and significant amount of water must be released to transport sediment.

2.15.3. Removing deposited sediment

Flushing: Sediment flushing involves reservoir draw down by opening lower level gates in order to create flow capable of eroding and transporting the deposited sediment through the outlet. Unlike sediment routing which attempt to prevent deposition of sediment during flood, flushing uses draw downed water to erode the sediment after it has been deposited. The efficiency of drawdown flushing depends on the geometry of the reservoir, the characteristics of the outlet, the incoming and outgoing discharges, sediment concentrations, and other factors.

The method has its highest efficiency rate when the water level in the reservoir is brought completely down, so that the water can flow fast through the deposits and has its highest erosion rates. This is also the biggest disadvantage of flushing. (White, R., 2001) States that at least 10% of the mean annual run-off is required for effective flushing.

In hydraulic dredging system the sediment is mixed with water and transported from point of excavation to point of disposal as sediment-water slurry. Dry excavation which is also known as trucking uses conventional earth moving equipment on emptied reservoir to excavate the deposited material.

Conventional dredging: Equipment that is normally used for sediment removal within rivers or for sediment removal at the coast can be used to excavate submerged sediment and removes sediment particles out of a reservoir. The amount of water that is lost during this operation is very little, since the water level of the reservoir doesn’t have to be lowered. The only amount of water that used is necessary to transport the sediments from the excavation site towards the storage site (K. Bronsvoort, 2013).

2.16. Catchment management in Gilgel Gibe reservoir

Human activities like the burning of coal, deforestation and various agricultural activities like change in land use, mismanagement of land, grazing may also alter the composition of atmosphere contributing to climatic change. Previously, the EEPCo has made resettlement compensation for 10,000 people displaced from the perimeter of the Gilgel Gibe I reservoir. Moreover, quick growing plant species which are suitable for existing agro ecological condition of the project were planted around the perimeter of 500m^2 buffer zone. However, due to lack of attention and proper follow-up the buffer zone couldn’t serve its purpose as the displaced communities went back to their original place. Weak protective measure and poor management are to blame for this failure to sustain the buffer zone. Farmer are now carrying out normal agricultural activities within the buffer zone.

In addition to this, river bank erosion during flash floods and events of landslides in the up-stream of Gilgel Gibe River and its tributaries are important sources of suspended sediments, which get into the reservoir of the Gilgel Gibe I hydroelectric plant. Such phenomena pose major threats to the economic use and life span of the dam. Unless corrective measures are taken to alleviate these threats; it won’t be long before this important power plant goes out of use. To this end, different parties have been raising their concerns over the danger facing Gilgel Gibe I dam at different times. Several stakeholders have been involved in one way or another with little or no effort to bring synergy and coordination among the actions of all the different actors. Moreover, efforts to promote community participation and involvement have been very minimal. Consequently, most of interventions carried out have been successful.

Integrated Watershed Management (IWM) is more a philosophy of comprehensive integrated approach to natural resources management. It aims integration of social resources management with natural resource management. The approach is generally preventive, progressive and curative. Watershed management involves the sound thinking use of natural resource with active participation of institutions, organizations, in harmony with the ecosystem (Reid, R. K. and Y. Abebe, 2003). There are three main components in watershed management are land management, water management and biomass management. Land characteristics like terrain, slope, and formation, depth, texture, moisture, and infiltration rate and soil capability are the major determinants of land management activities in a watershed.

Mechanical conservation measures may become necessary in watershed management in the initial stages. Structural measure include interventions like contour bunds, stone bunds, earthen bunds, graded bunds, compartmental bunds, contour terrace walls, contour trenches, bench terracing, broad base terraces, centripetal terraces, field bunds, channel walls, stream bank stabilization, check dams etc. All these ecosystems have a specific role in nature. Vegetative measures include vegetative cover, plant cover, mulching, vegetative hedges, grass land management, vetiver fencing, agro-forestry, etc.

The production measures include interventions aimed at increasing the productivity of land like mixed cropping, strip cropping, cover cropping, crop rotations, cultivation of shrubs and herbs, contour cultivation conservation tillage, land leveling, use of improved verity of seeds, horticulture, etc. Protective measures like landslide control, gully plugging, runoff collection, etc. can also be adopted. Adoption of all the interventions mentioned above should be done strictly in accordance with the characteristics of the land taken for management (Blopal and Raipur, 2013).

Generally, Soil erosion is a serious problem in Ethiopian highland areas that increased sedimentation of reservoirs and lakes. Sediment export rates in the Ethiopian highlands are characterized by important changes in sediment supply. It is important to study, the key sources of sediment; causes of both natural and management related sediment production and source; quantify the magnitude of sediment delivery of Gilgel Gibe watershed. Serious land degradation (landslides, gullies),domestic animal grazing, agricultural plough in the buffer zone in the upper catchment needs great concern to stop and minimize the problem of siltation on the dam.

2.17. Hydropower

Hydroelectric power is called a renewable energy source because the water on the earth is continuously replenished by precipitation. In hydropower plants, energy of water is utilized to move the turbine which in turn run the electric generations. The energy of water utilized for power generation may be kinetic or potential. While the potential energy is the function of the difference in level or head of water between two points. In either case continuous availability of water is basic necessity; to ensure this, water collected in natural lakes or reservoirs at high altitudes may be utilized or water may be artificially stored by constructing dams across flowing streams. Rainfall is the primary sources of water and depends on upon such factors as temperatures, humidity, cloudiness, winds etc.

Hydropower is a mature technology, harnessing the energy moving from higher to lower elevations. It comes in various shapes and sizes from large reservoir projects to small run-of river facilities. Hydropower is renewable, and has low greenhouse gas emissions. It is a premium energy source, providing a range of services. These include baseload and peak load generation, and support for other forms of electricity generation, particularly renewables.

One aim of hydropower production is to maximize energy output. The estimation of the theoretical potential for hydropower or the optimization of future production is therefore of interest. The relationships governing the energy output of a river basin hydropower system include the following: Power generation as a function of discharge and head, Equation ($P = \eta Q \rho g h$), the reservoir water balance, Information regarding reservoir characteristics and the hydraulic behavior among hydropower plants, Meteorological and hydrological statistics, Power demand statistics (energy demand fluctuations).

2.18. Gilgel Gibe Hydroelectric Project Overview

The *Gilgel Gibe I Dam* is a rock-filled embankment dam on the Gilgel Gibe River in Ethiopia. It is located about 57 km northeast of Jimma in Oromia Region. The primary purpose of the dam is hydroelectric power production. The Gilgel Gibe I hydroelectric power plant has an installed capacity of 184 MW. The dam is 1,700 m long and 40 m tall. Construction on the dam began in 1988 but work was halted in 1994. In 1995 construction restarted with a new construction firm. The power station was commissioned in 2004. The project is located in Southern Ethiopia and basically consists of a rockfill dam with an impervious asphalt facing, an intake tower followed by a 9Km long power tunnel, three Francis turbines with an installed power of 184MW. Since then the Project has generated over 1 billion KWh, providing a major contribution to the present demand of electric power in Ethiopia. The detail characteristic of Gilgel Gibe Hydro power plant was shown in (Appendix).

The impounded water enters the power tunnel by means a 40m high intake tower equipped with a cylindrical gate and trash-racks. Control equipment is located on top of the tower. Through the 9Km long power tunnel the water is transferred to the 160m high vertical shaft, i.e. the penstock, that brings water down to the turbines. A 113m high surge shaft, with 14m internal diameter was provided before the penstock. The final part of the power tunnel and the vertical shaft are steel lined. The power tunnel is concrete lined and has an inner diameter of 5.5m as shown below.

Figure 2. 7 Intake and Spillways Locations

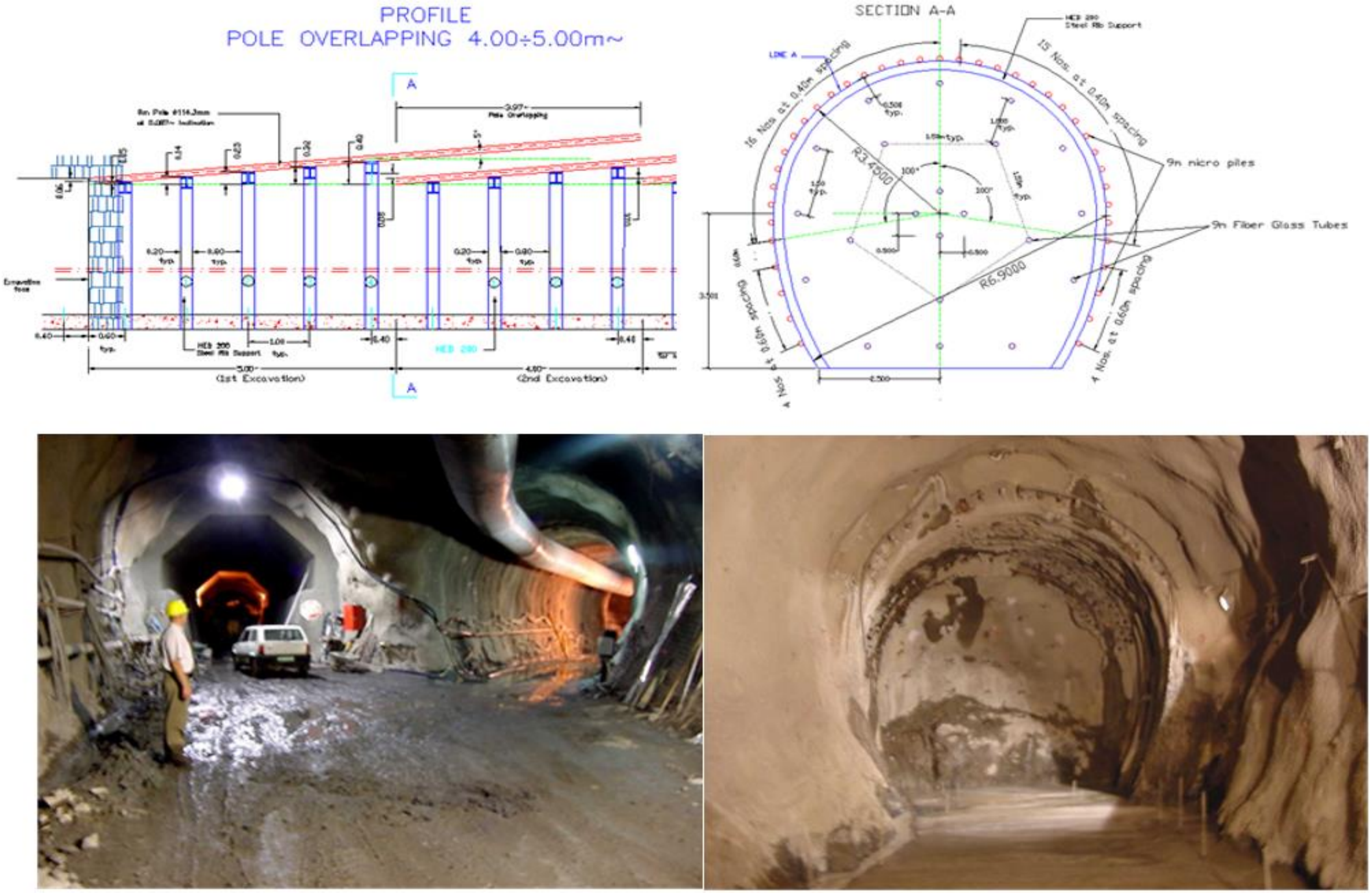
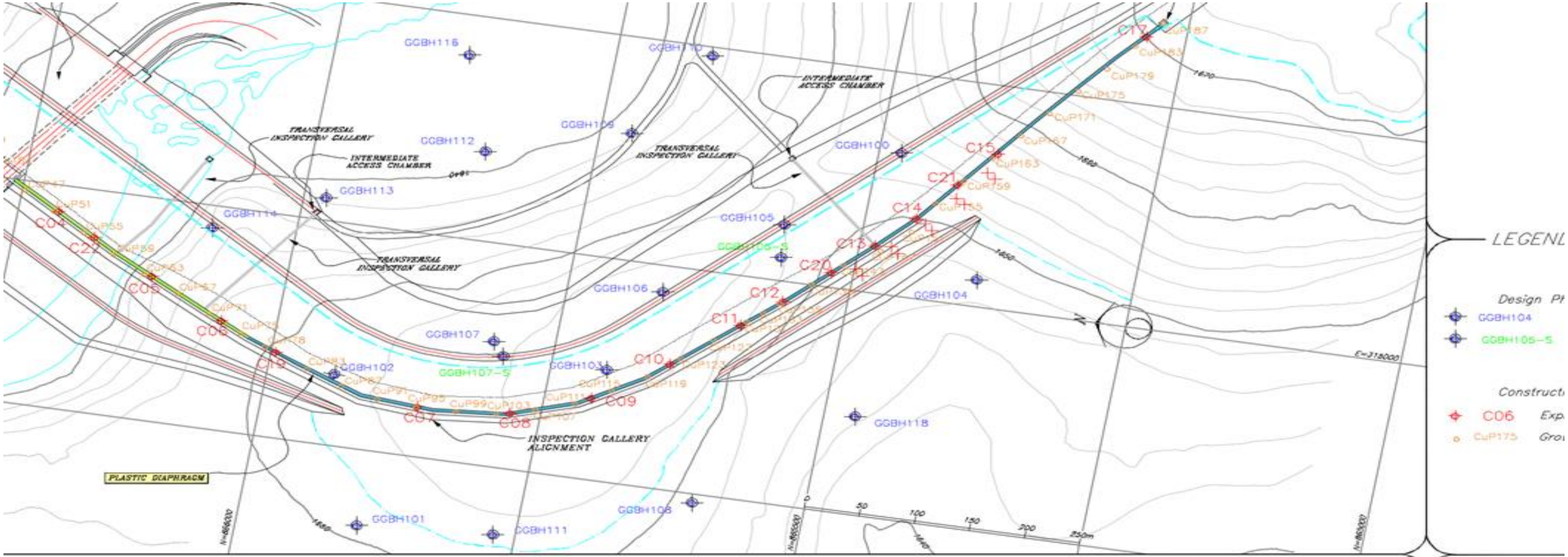


Figure 2. 8 Power Tunnel



STAGE EXPLORATORY BORE HOLES

	GROUND EL.	DEPTH	WATER TEST		
			1ST SECTION (NO TEST)	SECTIONS (?)	TOTAL LENGTH TESTED
	m a.s.l.	m	m	#	m
5.43	1653.54	23	1.5	4	21
0.23	1645.24	28	1.5	5	27
9.62	1641.89	45	5	8	40
3.58	1639.98	45	5.9	8	40
9.32	1644.49	51	7.5	9	43
9.72	1649.72	50	13.4	7	37
0.57	1653.57	57	6.6	10	50
7.67	1647.14	52	3	10	49
8.56	1646.87	58	1	12	57
5.29	1646.39	59	1	12	58
0.06	1646.12	54	2.5	12	51
5.94	1644.75	45	16.8	6	28
6.11	1649.99	50	5.1	9	45
9.91	1646.90	27	2.9	5	24
4.55	1657.90	45	5.5	8	40

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00	14/12/99	FMM
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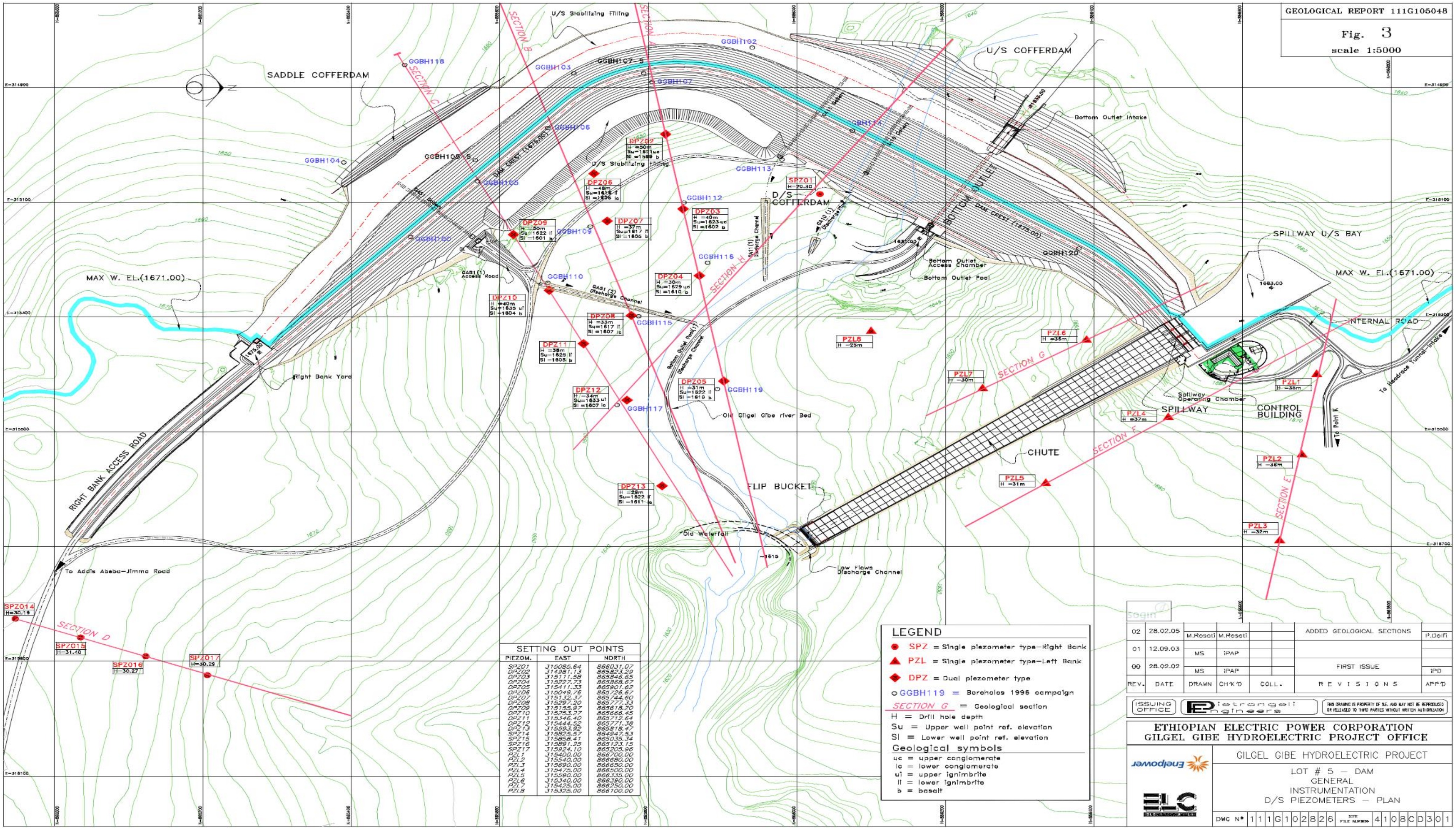

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Fig. 3

scale 1:5000

SETTING OUT POINTS

PIEZOM.	EAST	NORTH
SPZ01	315085.64	866031.07
DPZ02	314981.13	865823.29
DPZ03	315111.58	865846.65
DPZ04	315227.73	865868.67
DPZ05	315411.33	865901.62
DPZ06	315049.76	865726.67
DPZ07	315132.37	865744.60
DPZ08	315297.20	865777.33
DPZ09	315155.97	865618.20
DPZ10	315253.27	865666.45
DPZ11	315346.40	865712.64
DPZ12	315444.52	865771.38
DPZ13	315593.92	865818.47
SPZ14	315825.57	864947.53
SPZ15	315858.41	865035.34
SPZ16	315891.25	865123.15
SPZ17	315924.10	865205.96
PZL1	315400.00	866700.00
PZL2	315540.00	866680.00
PZL3	315690.00	866650.00
PZL4	315475.00	866500.00
PZL5	315590.00	866335.00
PZL6	315340.00	866390.00
PZL7	315425.00	866250.00
PZL8	315325.00	866100.00

LEGEND

● SPZ = Single piezometer type–Right Bank
▲ PZL = Single piezometer type–Left Bank
◆ DPZ = Dual piezometer type
○ GGBH119 = Boreholes 1996 campaign
SECTION G = Geological section
H = Drill hole depth
Su = Upper well point ref. elevation
Sl = Lower well point ref. elevation

Geological symbols

uc = upper conglomerate
lc = lower conglomerate
ui = upper ignimbrite
li = lower ignimbrite
b = basalt

REV.	DATE	DRAWN	CH'K'D	COLL.	REVISIONS	APP'D
02	28.02.05	M.Rosati	M.Rosati		ADDED GEOLOGICAL SECTIONS	P.Dolfi
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00	28.02.02	MS	iPAP		FIRST ISSUE	iPD

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ETHIOPIAN ELECTRIC POWER CORPORATION
GILGEL GIBE HYDROELECTRIC PROJECT OFFICE

GILGEL GIBE HYDROELECTRIC PROJECT

LOT # 5 – DAM
GENERAL
INSTRUMENTATION
D/S PIEZOMETERS – PLAN

DWG Nº 111G102826 SITE FILE NUMBER 4108CD301

Figure 2. 9 Dam and Appurtenant Works

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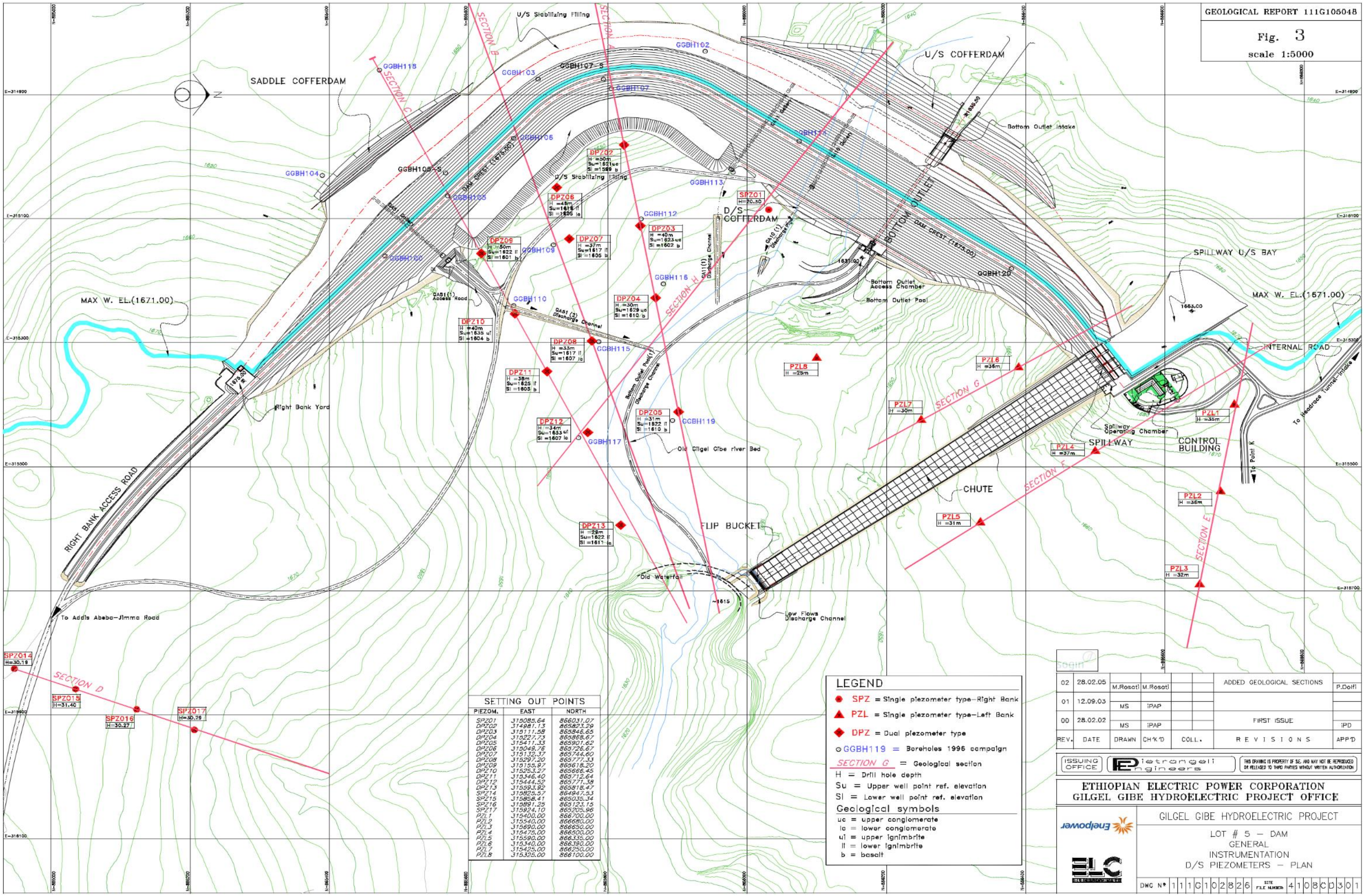
Fig. 3

scale 1:5000



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SPZ16	315891.25	865123.15
SPZ17	315924.10	865205.96
PZL1	315400.00	866700.00
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PZL3	315690.00	866650.00
PZL4	315475.00	866500.00
PZL5	315590.00	866335.00
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LOT # 5 – DAM
GENERAL
INSTRUMENTATION
D/S PIEZOMETERS – PLAN

DWG Nº 111G102826 SITE FILE NUMBER 4108CD301

CHAPTER THREE

METHODOLOGY

3.1. Description of the study area

3.1.1. Location, geology and topography

The Ethiopian government has doing a lot in order to meet the rising demand for electricity and exerts its effort through Ethiopian electric power corporation (EEPCo, 2009) for taping its abundant water resources for the production of electric power. Among several hydroelectric power plants constructed on the Omo-Gibe basin is a very significant potential hydropower and irrigation resource within Ethiopia, and a logical target for development. One of those projects is Gilgel Gibe I dam cascaded hydropower plants in the basin.

The Gilgel Gibe I dam the single plant adopted scheme is a purely hydroelectric project with capacity of 184 MW is located in Southwest Ethiopia in the Omo Gibe basin at about 260 km of Addis Ababa. The catchment covers an area of about 4,225 km^2 with an altitude that varies between 1,096m and 3,259m above sea level (figure 3.1). It is approximately located between 7° 22’ 72’’ and 7° 34’ 84’’ latitude N and between 37° 21’ 05’’ and 37° 28’ 80”longitude E. The bulk of the catchment is located in the south of Jimma zone, which is one of the zones of Oromiya region. This zone is subdivided in districts, called woredas, of which several, such as Kersa (major village is Serbo) or Dedo (major village is Dedo), cover part of the catchment. The project area proper, including the reservoir site and all project structures, is entirely located in the Jima Zone.

The Gilgel Gibe River, which stretches for about 176 km from its sources, is the major tributary of great Gibe River. The Gilgel Gibe power plant is started in 1998 and completed in February, 2004 (after being interrupted in the early 90’s) on this river by the Ethiopian Electric Power Corporation as part of the country’s general development plant with the aim of expanding the electric power generation capacity of the country.

There is limited information available on the geological formation of the study area. But according to master plan study of the basin the geology can be characterized by tertiary and quaternary age rhyolite and basalt volcanic in the north and middle part of the basin with quaternary alluvial overlying pre-Cambrian basement gneisses and granite in the south. Approximately 11% of the Omo-gibe basin is underlain by pre-Cambrian metamorphic gneisses and 80% of the Basin is underlain by Tertiary volcanic rocks. (Abdella, 2013).

The topography of the study area is characterized by its physical variation, with upper plateaus that are cut by deep V-shaped valleys in the flanks and flat river terraces around the Gilgel Gibe River in the center of the catchment.

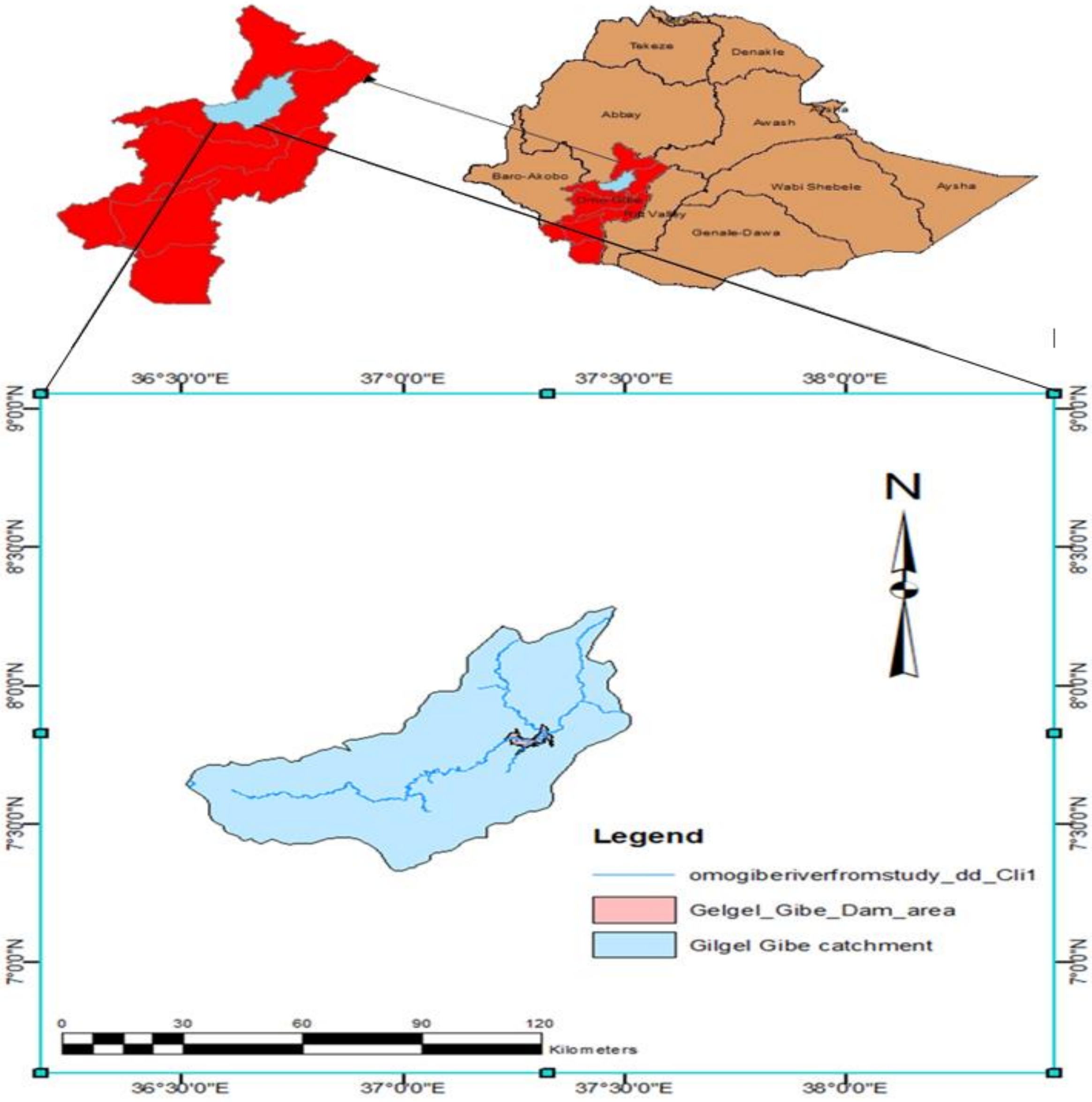


Figure 3. 1 Location map of study area

3.1.2. Climate of the study area

Though geographically Ethiopia lies in the tropical region, several factors give the country a particular set of different climates. The altitude, rift valley and Inter Tropical Convergence Zone (ITCZ) influence both the temperature and precipitation patterns across the country. The climate of Omo-Gibe River basin varies from a hot arid climate in the southern part of the floodplain to a tropical humid one in the highlands that include the extreme north and northwestern part of the Basin. Intermediate between these extremes and for the greatest part of the basin the climate is tropical sub-humid.

To study the response of the climatological factors on the Gilgel Gibe sub-basin, analysis for rainfall and temperature were carried out for Jimma, Asendabo, Sekoru, Dedo, Somodo and Chekorsa climate stations in the Omo Gibe part of the basin using the period from 1988-2017. The location of the gauging stations are shown in Figure below. Two different agencies collect the climate data in the basin, i.e., the Ethiopian metrological agency and Ministry of water Irrigation and energy.

Table 3. 1 Inventory of climate stations in and around the basin

Station Name	Station Name	Elevation	Latitude	Longitude	Data type collected					
					Precipitation	Tmax	Tmin	Humidity	Solar Radiation	Wind speed
1	Asendabo	1764	7.76	37.23	Yes	Yes	Yes	No	No	No
2	Jimma	1710	7.67	36.82	Yes	Yes	Yes	Yes	Yes	Yes
3	Sekoru	1937	7.93	37.42	Yes	Yes	Yes	Yes	Yes	Yes
4	Dedo	2281	7.50	36.87	Yes	Yes	Yes	No	No	No
5	Somodo	1988	7.77	36.8	Yes	No	No	No	No	No
6	Chekorsa	1770	7.61	36.73	Yes	No	No	No	No	No

3.1.3. Rainfall

In Gilgel Gibe I catchment there are about 20 rainfall stations in and near by the basin. However, most of the stations have established recently. Many of the stations have few years recorded value. Since climate change (Couse sedimentation) study needs long recorded data to get reasonable results, stations which have relatively long recorded value have been used for further analysis. In general 6 rainfall and 4 temperature gauging stations have been used for this research were obtained from the National Meteorological Agency (NMA).

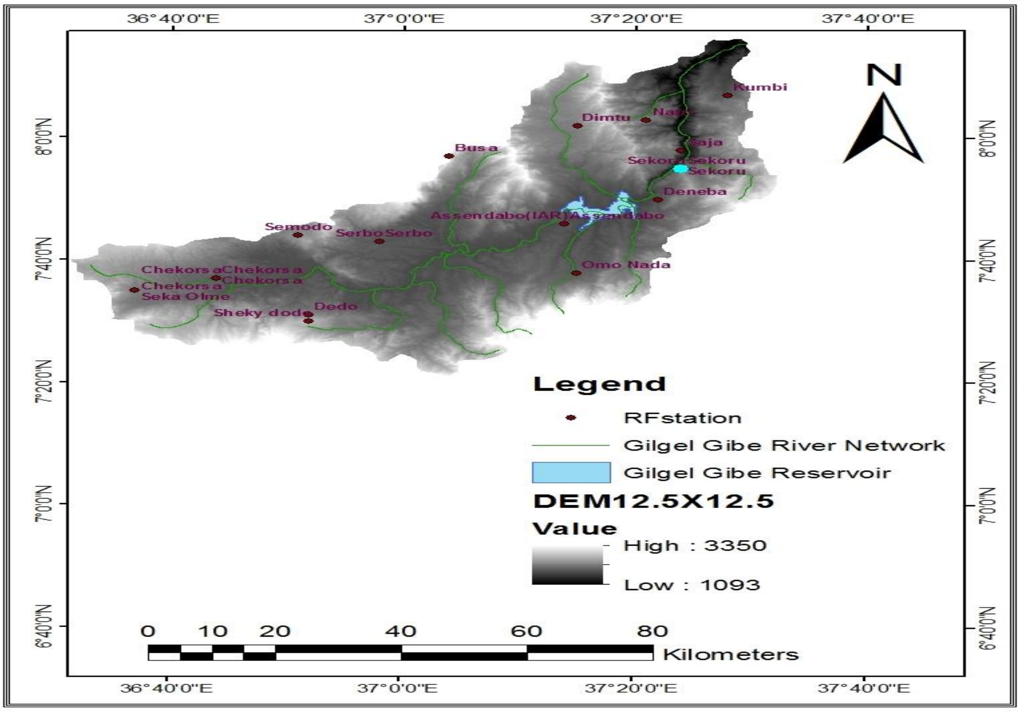


Figure 3. 2 Gilgel Gibe catchment rainfall station

A preliminary analysis was carried out of observed weather data daily depth of precipitation, maximum and minimum temperature roughly computed. Missing data is common problem in hydrology. To perform hydrological analysis and Sediment distribution in reservoir using data of long time series, filling in missing data is very vital. The missing data was completed by feeding -99 (negative ninety nine) to SWAT model to generate data.

The annual rainfall of the Gilgel Gibe catchment is a spatial rainfall variation from a minimum of 1,300 mm near the confluence with the great Gibe River, to a maximum of about 1,800 mm in the Utubo and Fego mountains. Rainfall decreases throughout the catchment with a decrease in elevation. The average annual rainfall calculated over the whole Gilgel Gibe basin where it joins the great Gibe River is 1,527 mm, over the Deneba catchment, it is 1,535 mm, over the partial catchment between Asendabo and Deneba, and it is about 1,479 mm. It appears that 60% of the total amount of annual rainfall occurs between June and September, 30 percent from February to May, and only 10 percent between October to January. The rainfall pattern in the Gilgel Gibe catchment is distributed over season.

3.1.4. Land use and land cover

Land use has been defined as “the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it” (FAO, 1997). According to this definition, land use describes the interaction between human activities and land cover. Although sometimes land use and land cover are mixed, there is a clear distinction between both. While land cover can be directly observed, as it is the upper layer on the surface of the earth, comprising soils, biomass and human structures, land use cannot. Land use is an inherently dynamic concept that is a function of both biophysical parameters, affecting the potential land cover, and socio-economic parameters, affecting the actual land cover at a certain moment in time.

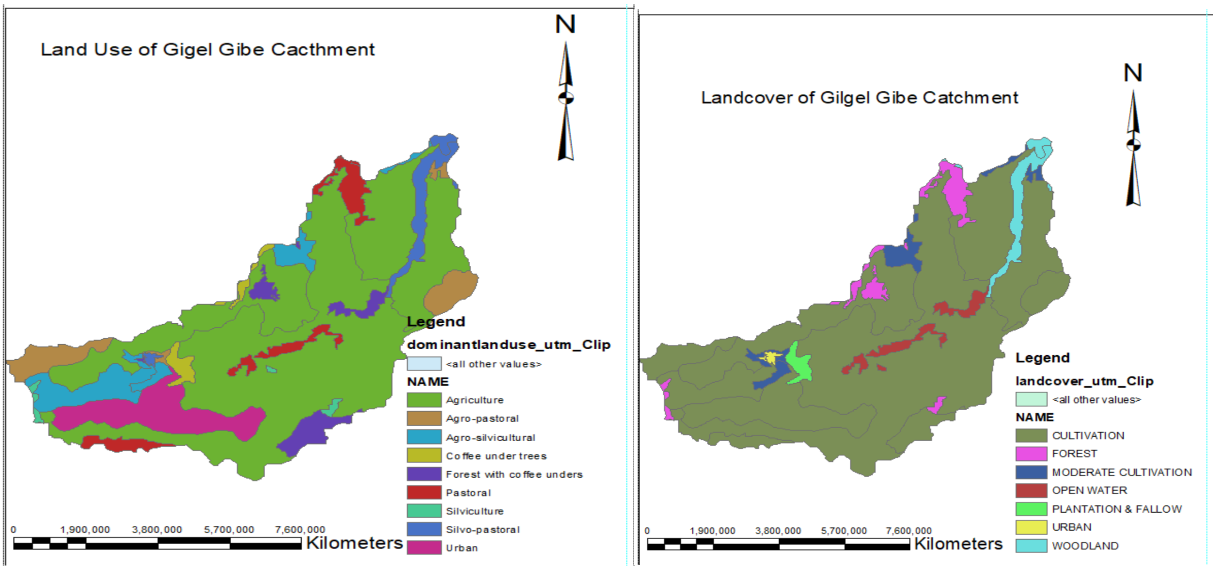


Figure 3. 3 Landuse Land cover of Gilgel Gibe Catchment

The dominant land use distribution of the Omo river basin is dominated by four land use categories namely Woodland, Agricultural, forest and bush land, grazing. Along the Gilgel Gibe River, the small amount of remaining riverine forest provides some habitat for wildlife and provides a source of fuelwood, building materials and other materials used for meeting a variety of domestic requirements.

3.1.5. Soils of the study area

The majority of the soils in the basin are deep to very deep, red and reddish brown clay looms over clays. They are wide spread over the whole of the northern basin. The predominant soils are generally characterized as vertisol, luvisols, and cambisols. They are moderately deep to deep, well drained, dark brown to dark reddish brown sandy clay loams to clays. Luvisols were found to be the dominant soil types in the catchment. Vertisols are poorly drained heavy clays soils with a characteristics dominated clay fraction which causes them to shrink and swell. The better drained vertisols are dominant to the northern west of Wolkite (Feasibility Report).

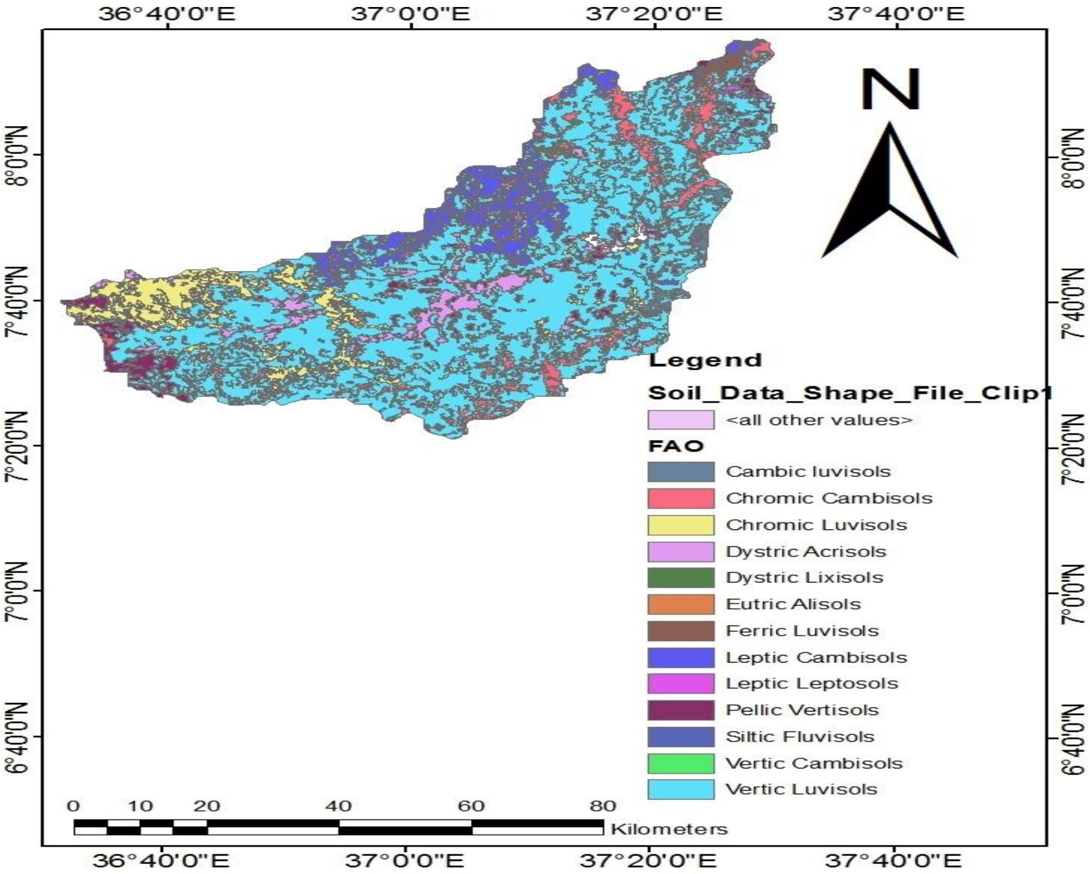


Figure 3. 4 Soil map of Gilgel Gibe Catchment

Erosion by rainfall occurs from raindrops striking soil, and water flowing over the soil. Several variables could be used to describe the capacity of falling or flowing water to erode land surfaces, which refers to be erosivity of rainfall. These variables include rainfall amount, kinetic energy, momentum, and intensity (Wischmeier, W.H., 1959).

3.2. Estimation of Stream discharge and sediment discharge using SWAT

The methodology is presented with a description of the study area and theoretical background for sediment generation model. This is followed by a description of different datasets and the process involved in model development and development of catchment area treatment plan. After that, steps of model setup, model calibration and sensitivity analysis of the model are presented, and finally, data uncertainties are presented.

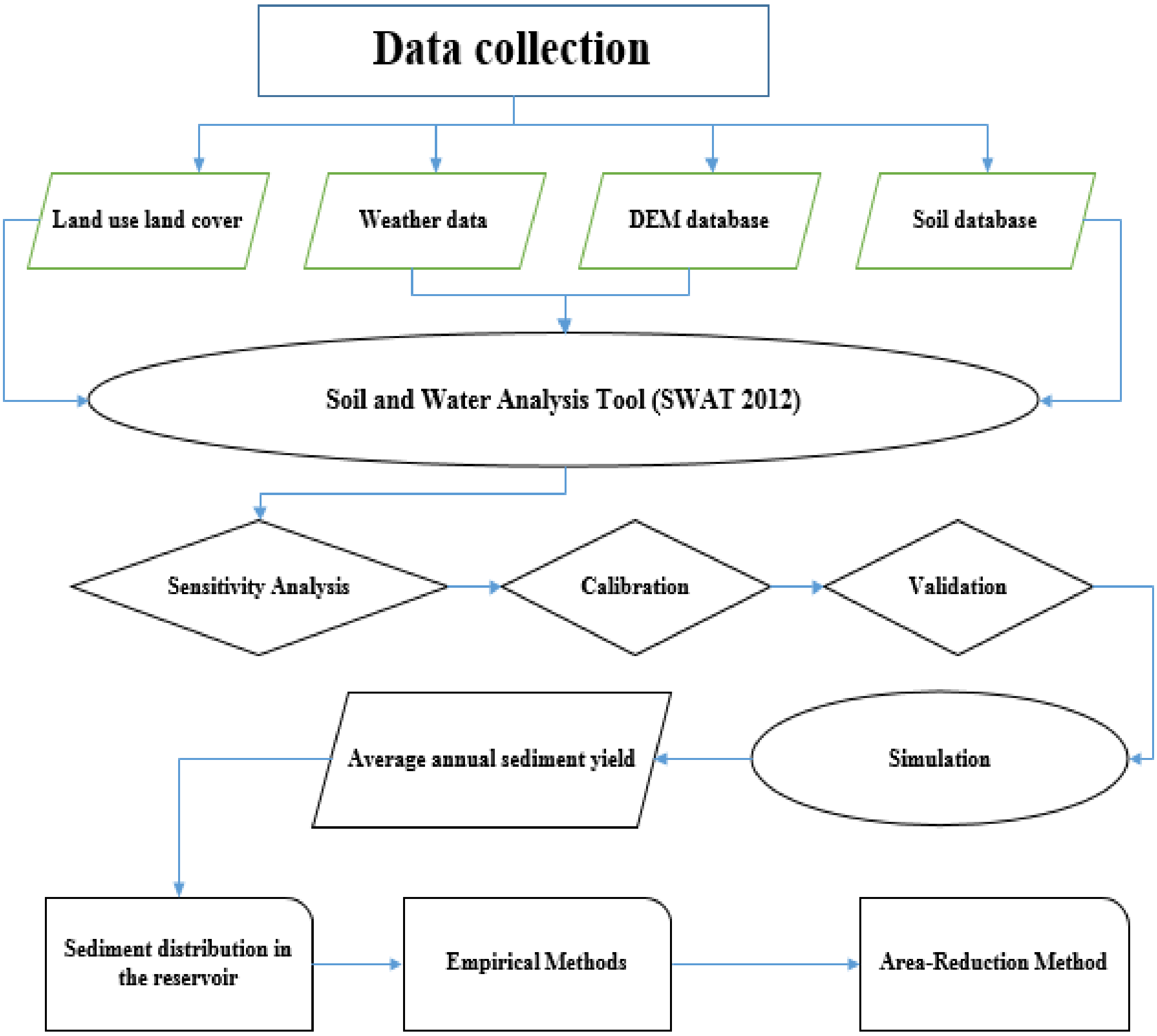


Figure 3. 5 Framework of the study

3.3. Input data of SWAT

The Arc SWAT is extension of Arc GIS which requires detail spatial (GIS input) and temporal input data, as physical model. The spatial information used were Digital Elevation Model (DEM), land use map, land cover map, and soil map. As for temporal data, daily metrological data, sediment data and stream discharge data were used for prediction of stream flow, sediment load and for calibration purposes.

3.3.1. Digital Elevation Model (DEM) Data

A DEM can be used to identify different basin characteristics such as: drainage area, elevation, slope steepness, slope length, and stream relief ratio. Topographic data in the form of Digital Elevation Model of Gilgel Gibe catchment area was used with at a 12.5m x 12.5m scale, which is a high resolution. DEM data were used to delineate the watershed and to analyze the drainage pattern of the land surface. For Ethiopia WGS_1984_UTM_Zone_37N projection of a shape file. After the point coverage of the stations was created, the coverage could be used in conjunction with the DEM to determine the Gilgel Gibe I watershed boundaries.

3.3.2. Meteorological data

Metrological data were obtained from different weather stations located in the catchment area of the Gilgel Gibe River which includes daily data of maximum and minimum temperatures, precipitation, solar radiation, wind speed and relative humidity from 1988 to 2017 data were used in SWAT model as shown above. These data were obtained from MoWIE and Meteorological Agency.

The Weather data generator (WGEN) database is used to generate continuous simulation climate files for use by SWAT. The WGEN input files include a station file and state files that contain the statistical representation of weather data for the station in each station. For each station, parameters describing the climate conditions on the monthly basis are used. A built-in weather dataset consists of simulated weather data input in the United State. I used the custom weather generator because the study site is outside the United State.

Table 3. 2 Variables required by the custom weather generator database

Variable name	Description
STATION	Weather station name
WLATITUDE	Latitude of weather station
WLONGITUDE	Longitude of weather station
WELEV	Elevation of weather station
RAIN_YEARS	Number of years of rainfall data

TMPMX(mon)	Mean daily maximum air temperature
TMPMN(mon)	Mean daily minimum air temperature
TMPSTDMX(mon)	Standard deviation of daily maximum air temperature
TMPSTDMN(mon)	Standard deviation of daily minimum air temperature
PCPSMM(mon)	Mean total precipitation
PCPSTD(mon)	Standard deviation of precipitation data
PCPSKW(mon)	Skew coefficient of precipitation data
PR_W1_(mon)	Probability of a wet day following a dry day
PR_W2_(mon)	Probability of a wet day following a wet day
PCPD(MON)	Average number of days of precipitation
RAINHHMX(MON)	Maximum 0.5 hour rainfall
SOLARAV(MON)	Average daily solar radiation
DEWPT(MON)	Average daily dew point temperature
WNDAV(MON)	Average daily wind speed

Metrological files were prepared in an excel sheet based on the format of SWAT using long term daily data of six stations. Statistical parameters were generated from these long term daily data. The custom weather generator in the SWAT simulation was engaged in order to simulate the missing observation and input data, the missing data were filled negative (-99) and saved in text format to generate missing data using the daily weather generator parameters. The pcpSTAT.exe calculates statistical parameters of daily precipitation data used by the weather generator of the SWAT model. pcpSTAT and average daily temperature, average daily humidity and dewpt data were calculated using program *dew02.exe* after input files were prepared in text format and the rest of parameters were calculated using excel.

3.3.3. Soil input data

Soil classification data based on the soil texture and physiochemical properties required by the SWAT model include soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for each soil data were obtained from (FAO, 1998b) Harmonized World Soil Database (HWSD). Harmonized World Soil Database from (http://www.fao.org/soils-portal/soil-survey/soilmaps-and-databases/harmonized-world-soil databasev12/en/) to get soil parameters.

http://www.fao.org/soils-portal/soil-survey/soil-maps-anddatabases/ FAO-UNESCO-soil-map-of the-world/en/) will be used for SWAT model, this website used to get soil name, Ministry of Water, Irrigation and Energy and also from previous studies of similar soil types. This could be easily used in SWAT with some minor modifications by using a lookup table for soil data.

3.3.4. Land use and land cover maps

The land use and land cover data were available from Ministry of water, Irrigation and Energy which consist of the water surfaces, vegetation, and cultural features on the land surface. The data were interpolated to the format that is applicable for SWAT by merging some of the similar land cover types and creating a look-up table.

Table 3. 3 Land use land cover classification

	Code	Name	Plant type
1	AGRL	Agricultural land-Generic	Warm season annual
2	AGRC	Agriculture land- close-grown	Cool season annual
3	AGRR	Agricultural land- Row-Crops	Warm season annual
4	FRSD	Forest - deciduous	trees
5	FRSE	Forest - evergreen	trees
6	FRST	Forest - mixed	trees
7	RNGE	Range - grasses	perennial
8	PAST	Pasture	perennial
9	WATR	Water body	Not applicable

Slope is also used as input data for the model. Land use, slope and soil data were used to create HRU by overlying them together. During the creation of it the slope was classified to the reasonable range. Accordingly, for this work to minimize complexity and to use manageable data and also considering the steepness of the area, the slope was classified into five classes. The classes were: 0 to 2%, 2% to 5%, 5% to 8, 8% to 15% and above 15%.

3.3.5. River discharge and suspended sediment load

The daily streamflow data needed to calibrate and validate the model were retrieved from records of the streamflow gauge station, operated by MoWE. The streamflow gauge records have a data series of 35 years (from 1982 to 2017) of daily streamflow, since there were some streamflow data missing, it was necessary to complete the data by linear regression. Precipitation data for the first two years (1988 and 1989) were used for model warm-up, whereas the remaining twenty seven years of precipitation data (1990- 2017) were used, along with streamflow data, for the model calibration and validation.

Suspended sediment load from Asendabo station were obtained from the Ministry of Water, Irrigation and Energy. There are few suspended concentration sediment data were measured in the Gilgel Gibe sub-basin for limited years. However, the Ministry of Water, Irrigation and Energy doesn't periodically collect sediment data from any of the tributaries joining the Gilgel Gibe I reservoir, which means suspended sediment sampling has been made at a section once or twice a month. Therefore, these data might not be sufficient for precise annual sediment inflow prediction. The Ministry has only been collecting suspended sediment yield of 25 times data from 1990 to 2017 in the catchment. Depending on the observed data the remaining values were generated from sediment rating curve for calibration and validation.

After filtration, suspended sediment concentration is given as parts per million (ppm), which also could be converted to values of tons/day by using the following equation.

$$Q_R = 0.864*Qs*Cs$$

Where; Q_R = sediment discharge (tons/day), Q_s = water discharge (m3/s), C_s = sediment concentration (ppm) (mg/l)

Sediment rating curve techniques have been used hydrologists to predict and determine long-term suspended load where there is no continuous set of data to estimate the quantity of suspended sediment load in a river over a period of time, can be calculated using equation (kisi 2007 (Santosh.K. Garg, 2005)).

$$logSSC = loga + blogQ$$

The equation can be expressed or transformed to a normal space in the form of a power curve as:

$$SSC = aQ^b$$

The values of ‘a’ and ‘b’ of the regression coefficients of the rating curves as stated by (Morgan. R.P.C., 1995), ‘a’ coefficient is an indicator of erosion severity and a high value representing easily transported and intensively weathered materials. He also stated that the ‘b’ coefficient represented the erosive power of a river, with high values indicating an increase in erosive power due to a small increase in the river’s discharge.

3.4. Filling of missing data

Precipitation data are important to many problems in hydrologic analysis and design. It is very important to have complete record at every station. Obviously, conditions sometimes prevent this. Any causes of failure of observer to make the necessary visit, vandalism of recording gages and instrumental failure may result incomplete data records in length and information content of the record.

The quantity, quality and characteristics of hydrological data should be checked carefully in order to make a sound decision on the objective of this study. For frequency analysis of rainfall data, a sufficiently long record is required. It may so happen that a particular rain-gauge is not operative for part of a month or so (since it is broken or some other reason), when it becomes necessary to supplement the missing record by one of the following methods: station average method, normal ratio method, inverse-distance weighting method and regression methods. In this study, filling of the missed data has been conducted by developing correlation between the station with missing data and any of the nearby station and the missing data were filled by considering a good correlation.

Linear regression model: the linear regression equation of Y on X_1, X_2, X_3,…,X_n can be written as:

$$Y = a_0 + a_1X_1 + a_2X_2 + \cdots + a_nX_n + e$$

Which represent a hyperplane in n dimensional space and where Y is the dependent variable and X_1, X_2, Xn are the independent variables. a_0 is the is the least square estimate of the intercept while a1, a2, …, an are the least squares estimates of the population data regression coefficients for X_1, X_2, …, Xn respectively. e is the residual term. The sample correlation coefficient, R, is an index of overall model fit. It seeks to define how well a linear or other equation describes the relationship between variables. Correlation coefficient measures the goodness of fit of the equation actually assumed to data. In this equation the expected value of the residual term is zero as assumption in order to apply ordinary least squares analysis.

3.5. Checking the Consistency of recording stations data

Estimating missing data is very important part of research and is problem that hydrologist need to address. A second problem is non homogeneity when the catchment at the gages is inconsistent over the period of the time and adjustment of those missed data is necessary to provide homogenies record. A consistent record is one where the characteristics of the station record have not changed with time.

Homogeneity analysis is used to identify a change in the statistical properties of the time series. The causes can be either natural or man-made. These include alterations to land use and relocation of the observation station, adjustment may be necessary due to changes in observation procedures, changes in exposure of the gages and where vandalism frequently occurs.

$$\mathrm{P'_x} = \mathrm{P_x}\frac{\mathrm{M'}}{\mathrm{M}}$$

Where: - P'_x = Corrected precipitation at station x

P_x = Original recorded precipitation at station x

M' = Corrected slope of the double mass curve

M = Original slope of the double mass curve

Double-mass-curve analysis is the method that is often used to test for an inconsistency in a gauged record. The procedure is that accumulated rainfall at the rain gage of interest whose record is in doubt is plotted as ordinate versus the cumulative catches of one or more gauges in the regions that has been subjected to similar hydro-meteorological occurrences and is known to be consistent.

To check the consistency of the recorded data, double mass curve method was used. The cumulative annual rainfall of base station was plotted against cumulative annual rainfall of neighboring stations.

Outliers Test: - an outlier is an unusually small or unusually large value in a data set, a data value with a z-score less than -4 or greater than +4 might be considered on outlier. It might be an incorrectly recorded data value, a data value that was incorrectly included in the data set was checked according to Log Person III stated in (Ven Te Chow, 1988).

3.6. SWAT Set Up and Simulation stream flow and sediment yield

Automated watershed delineation embedded in Arc SWAT interface was used to delineate the watershed was done using Digital Elevation Model data. A mask DEM used to delineate the boundary of the watershed and digitize the stream network in the study area, which reduce the time of processing and the minimum threshold area was used to define the minimum drainage area and to decide the number of sub-watershed within the watershed.

Sub-watershed were subdivided, after watershed delineation into areas having unique land use, soil and slope so called hydrologic response unit (HRUs). The individual fields with specific land use, soil and slope were lumped together to form HRUs to define the number of HRUs within the sub watersheds. The HRUs of the watershed were derived from the combination of DEM, soil, slope and LULC data of 10% soil, 15% land use land cover and 10% slope thresholds have been used to create 232 HRUs.

Weather data definition requires weather data including precipitation, temperature, wind speed, solar radiation, and relative humidity. Since the study area is outside of United States, I used custom weather generator. In this study, daily climate data for 30 years data were obtained and used for six climate stations within the catchment area called Asendabo, Jimma, Sekoru, Somodo, Dedo and chekorsa. The missing records were filled by using a statistical weather generator file based on the Jimma climate station. Variables required by custom weather generator database were created by the programs and excel.

Once all the types of the data were loaded into the model, the ‘write all files’ was selected to write all required input files. Default value can also be altered after all the default input dataset is generated by using the ‘Edit SWAT Input’.

The Run SWAT icon, which is located under the SWAT simulation menu was set to 01/01/1988 and 12/31/2017 with a daily printout option and war-up period to 2 years for the model to run the simulation and the data on the watershed statistics were obtained through the ‘output.std’ text file and the document in Microsoft Access format.

3.7. Sediment distribution by area reduction method

In order to evaluate the sediment distribution within the reservoir, the Empirical Area Reduction method, developed by (Borland, W. M., and Miller, C. R.,, 1958) based on survey of 30 reservoir in USA to establish volume-surface area depth relationship of reservoirs after deposition of sediment was used. This method includes four main steps as outlined in Morris and Fan:

- Determine the amount of sediment to be distributed.
- Select the appropriate empirical curves for sediment distribution
- Determine the height of sediment accumulation at the dam, termed the new zero capacity elevation
- Use the selected empirical curve to distribute sediment as a function of depth above the new zero capacity elevation. These values are then subtracted from the original stage-capacity to produce the new stage capacity

This method was developed based on field survey data gathered from reservoirs in the USA with capacities ranging from 49 million m^3 to 36.9 billion m^3 (G.W. Annandale, 1987). The method may not predict deposition pattern well for reservoirs with capacity out of the range. The reservoir capacity of the Gilgel Gibe I reservoir is within this limit.

As limitation, similar to area incremental method the distribution of sediment as a function of longitudinal distance cannot be calculated using empirical area reduction method and the method may not predict deposition pattern well for reservoirs with capacity out of the range.

CHAPTER FOUR

RESULT AND DISCUSSION

Hydrological modelling requires a hydro-meteorological data (precipitation, temperatures, relative humidity and sunshine hours) and hydrological (stream flow) data for analysis. But the reliability of data significantly affects the quality of the model input data and as a result, the model simulation. Therefore the quality of the data is directly proportional to the output of the model.

4.1. Filling of missing data

A number of station in the study area have incomplete records. Such gaps in the record are filled by developing regression correlation between the station with missing data and any of adjacent stations with the same hydrological features and common data periods. Also, the missing records from climatic data, a statistical weather generator-.wgn files were used, based on data derived from Jimma meteorological stations were used to fill no data with values of a negative 99.0 (-99.0), this value tells SWAT to generate data for all weather variables for that day and SWAT would then fill missing data based on its weather generator program.

I select Jimma meteorological station as weather geberator due to its principal station with almost full data record than others in precipitations, temperature, relative humidity, wind speed and solar radiation.

I plotted an average rating curve, which is also known as a sediment rating curve, in order to express the relationship between sediment discharge and stream flow. Sediment rating curves have been commonly used to compute an average sediment discharge for periods of time during which records of sediment discharge do not exist but records of stream discharge are available.

Data for construction of the rating curves for the Asendabo measuring sites have been abstracted from the continuous records of sediment concentration and discharge to represent a combined periodic and aperiodic sampling scheme. The data set available for rating curve construction represents a near-optimum data collection scheme and that estimates of the errors involved in calculating sediment loads will be minimum estimates.

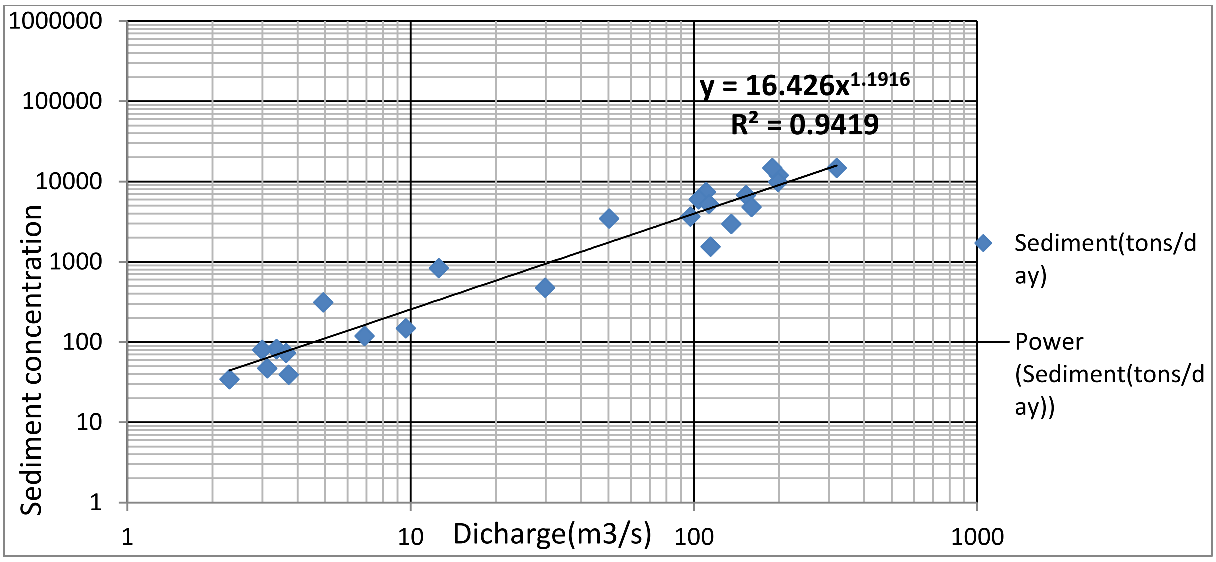


Figure 4. 1 Sediment rating curves

Suspended sediment concentration is given as parts per million (ppm), which also could be converted to values of tons/day by using the following equation.

$$Q_R = 0.864*Qs*Cs$$

Where; Q_R = sediment discharge (tons/day), Qs = water discharge (m3/s), Cs = sediment concentration (ppm) (mg/l)

$$logSSC = loga + blogQ$$

The equation can be expressed or transformed to a normal space in the form of a power curve as:

$$SSC = aQ^b$$

The values of ‘a’ and ‘b’ of the regression coefficients of the rating curves as stated by (Morgan, Duzant, J.H., 2008), ‘a’ coefficient is an indicator of erosion severity and a high value representing easily transported and intensively weathered materials. He also stated that the ‘b’ coefficient represented the erosive power of a river, with high values indicating an increase in erosive power due to a small increase in the river’s discharge.

4.2. Consistency test

The selected stations are also plotted for comparison with each other show as shown below, were the result of homogeneity analysis and check similarity of the other selected group stations. If a rainfall record is a consistent over the period of record, the double-mass-curve will have a constant slope. A change in the slope of the double mass curve would suggest that an external factor has caused changes in the character of the measured values. Then the record needs to be adjusted, with either the early or later period of record adjusted.

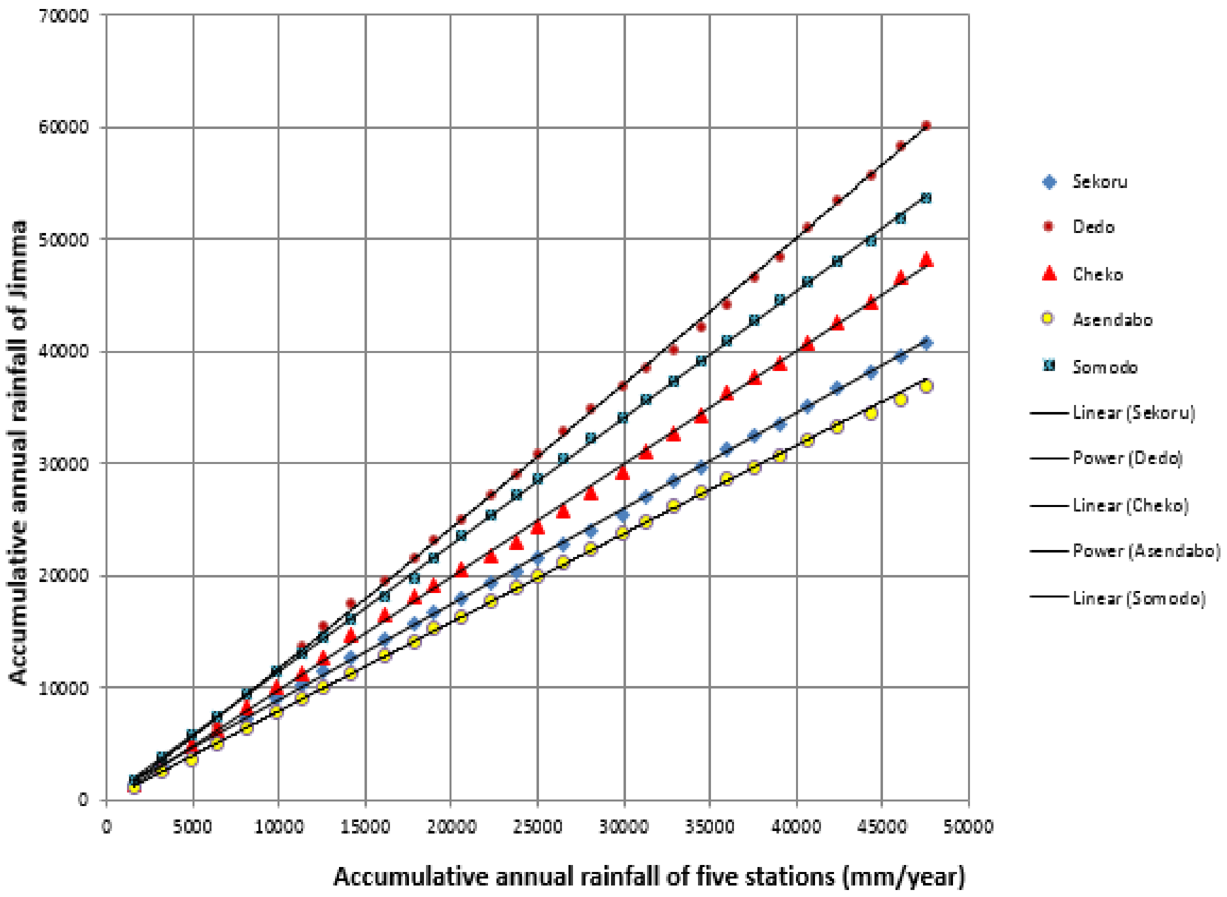


Figure 4. 2 Consistency test for selected station

In this method, groups of neighboring stations were chosen nearby Jimma station, which is principal station consisting almost full data. The yearly rainfall values reported from this group of stations was taken, and their mean yearly values are worked out for each consecutive year’s available records. Therefore, the selected rainfall stations in my study area were all consistent, also as shown in appendix.

4.3. Testing the data for outlier

Outliers are the data points that make tracks significantly from the style of the remaining collected data. The retention or deletion of these outliers can considerably affect the amount of the statistical parameters computed from the data. According to Log person III, tests for bigger outliers are measured early if the station bias is bigger than +0.4 by using;

Table 3. 4 Outlier test analysis

Annual yrs.	Max RF,mm/yr	Descending order	Rank	Log(RF)
1988	59.3	74.6	1	1.773
1989	41.6	69.7	2	1.619
1990	36.3	69	3	1.560
1991	57	67	4	1.756
1992	55.4	65.5	5	1.744
1993	46.2	64.8	6	1.665
1994	60.7	63	7	1.783
1995	47.8	62.5	8	1.679
1996	48.8	62.3	9	1.688
1997	69	60.9	10	1.839
1998	62.5	60.7	11	1.796
1999	49.9	59.3	12	1.698
2000	50.5	59.1	13	1.703
2001	56.2	57	14	1.750
2002	42.5	56.2	15	1.628
2003	42.6	55.4	16	1.629
2004	46.2	54.9	17	1665
2005	60.9	52.8	18	1.785
2006	44.5	50.5	19	1.648
2007	44.6	49.9	20	1.649
2008	62.3	48.8	21	1.794
2009	69.7	47.8	22	1.843
2010	74.6	46.2	23	1.873
2011	65.7	46.2	24	1.818
2012	54.9	44.6	25	1.740
2013	63	44.5	26	1.799
2014	59.1	42.6	27	1.772
2015	67	42.5	28	1.826
2016	64.8	41.6	29	1.812
2017	52.8	36.3	30	1.723
Sum		**1656.4**		**52.057**
Mean, Y_{mean}		**55.21**		**1.74**
Standard Deviation, δ_{n-1}		**9.799**		**0.079**
Skewness coefficient, SC				**-0.295**
Number of data	**30**			

As per (U.S. Army Crops of Engineers, 1981) recommended, it is possible to check for outliers based on skew value. If value of skew lies between +0.4 & -0.4 the outliers are checked for both lowest & highest values.

Higher Limit, $Y_h = Y_{mean} + K_n * \delta_{n-1}$, **where K_n is 2.563 for 30 years of data**

Y_h = 1.74 + 2.563*0.079 = **1.938**

Lower Limit, $L_l = Y_{mean} – K_n * \delta_{n-1}$ L_l = 1.74 - 2.563*0.079 = **1.533**

Upper limit of rainfall = $10\wedge^{Yh}$ = $10\wedge^{1.938}$ = 86.667 mm

Lower limit of rainfall = $10\wedge^{Ll}$ = $10\wedge^{1.533}$ = 34.086 mm

Lowest & highest value in the given data series is 34.086 & 86.667 So, all of the data values lies between the lowest & a highest calculated value, Hence, there is no any data that can be rejected.

Check for variance

$$\alpha = \left(\frac{\delta_{n-1}}{\sqrt{N * Mean}}\right) * 100\%$$

Where δ_{n-1} = Standard deviation = **9.799**

N = Number of year = 30 Mean = 55.21

δ = Standard error

δ = 3.2407 which is less than 10% Acceptable. Therefore, the data shows no variability.

For all of the rest of station the outliers were done as above procedures, hence, there is no any data that can be rejected according to Log person III formula.

4.4. Sensitivity Analysis to flow

The parameter sensitivity analysis was done using the ArcSWAT interface for the catchment area. Model set up the sensitivity analysis was carried out for the period of 1988 to 2017 years which included the warm-up periods. Twenty four hydrological parameters for the sensitivity analysis for the simulation of stream flow were used in the study area. The most global sensitive parameters considered for calibration of stream flow were those short listed in Table 4.1 were found to have meaningful effects on the monthly stream discharge and sediment flow simulation of the Gilgel Gibe watershed. Generally, the selected sensitive parameters were within the range of parameters used by (Mutenyo, 2013) for the evaluation of SWAT performance.

Table 4. 1 Description of SWAT 2012 input parameters selected for simulation.

Parameters	**Description**	**Initial range**		**Final range**	
		min	max	min	max
v__HRU_SLP.hru	Average slope steepness	0	1	-0.3252	0.56124
v__CN2.mgt	Curve number for moisture condition II	35	95	62.2462	62.7148
v__SOL_K.sol	Soil hydraulic conductivity	0	200	155.621	156.227
v__EPCO.bsn	Plant uptake compensation factor	0	1	0.00052	0.00548
v__RCHRG_DP.gw	Deep aquifer percolation fraction	0	1	0.00397	0.55174
v__EPCO.hru	Plant uptake compensation factor	0	1	0.26895	0.80771
v__CH_N2. rte	Manning's *n* value for the main channel	0.1	0.5	0.07260	0.07293
v__ESCO.bsn	Soil evaporation compensation factor	0	1	0.654238	0.65659
v__REVAPMN.gw	Threshold water in shallow aquifer	0	500	475.6827	616.892
v__Biomix.gw	Biological mixing efficient	0	1	1.38949	1.40973
v__TRNSRCH.bsn	Fraction of transmission losses from main channel that enter deep aquifer.	0	1	0.63473	0.63893
v__ALPHA_BF.gw	Base flow alpha factor	0.15	0.5	0.31938	0.32069
r__SOL_AWC.sol	Available water capacity of the soil layer	-0.2	0.1	0.28882	0.29361
v__CH_K2.rte	Main channel conductivity	0.01	173	39.03675	39.4432
v__USLE-P.mgt	USLE equation support practice factor	0	1	-0.01237	0.00169

4.5. Parameters sensitive to sediment

In case of sediment yield sensitivity analysis, the most sensitive parameters were identified through global sensitivity analysis. It was found that some of the same parameters were used in both stream flow and sediment yield calibration and validation. The summarized global sensitive analysis result of the model in the Gilgel Gibe watershed were listed in Table 4.2

Once the SWAT model for Gilgel Gibe watershed was compiled using ArcGIS interface, a stream flow sensitivity analysis was performed on the model parameters. This was done to identify the influential parameters to avoid problem of over parameterization using SWAT-CUP program. The global sensitivity analysis with observed data for a period of 1988-2017 were considered for 24 parameters to identify most influential parameters on the SWAT model output, but only fifteen parameters were selected for monthly flow simulation analysis as shown in table 4.2.

Table 4. 2 Summary of parameter sensitivity analysis result for sediment

Parameters	Description	Initial range		Final range	
		min	max	min	max
v__CN2.mgt	Curve number for moisture condition II	35	95	49.345	49.6168
v__USLE-P.mgt	USLE equation support practice factor	0	1	-0.0123	0.00169
r__USLE-K.sol	USLE soil erodibility factor	0	0.65	0.2982	0.30606
v__SPEXP.bsn	Exponent parameter for calculating sediment re-entrained in channel	1	1.5	1.3207	1.32844
v__SPCON.bsn	Linear parameter for calculating sediment that can be re-entrained during channel sediment routing	0.0001	0.01	0.0029	0.00312
v__Biomix.gw	Biological mixing efficient	0	1	1.3894	1.40973
v__CH_COV2.rte	Channel cover factor	-0.00	1	0.0245	0.03041
v__CH_COV1.rte	Channel erodibility factor	-0.05	0.6	0.2904	0.30154
v__HRU_SLP.hru	Average slope steepness	0	1	0.0458	0.07480
v__SLSUBBSN.hru	Average slope length	10	150	152.766	153.737
v__Lat-sed.hru	Sediment concentration in lateral and groundwater flow	0	5000	8.8167	9.8570
v__PRF.bsn	Peak factor for sediment routing chann.	0	2	1.8548	1.9899

Based on a t-test that was used to identify the relative significance of each parameter that was a value larger in absolute value was most significant and p-value the significance of the sensitivity, a value close to zero is more significant. From the model output, the most sensitive parameters were selected as t-test and p-value responses.

4.6. Model stream flow calibration and validation

The application of the SWAT model involved data processing, model setup, sensitivity analysis, calibration and validation of the model. The model was calibrated and validated on the monthly basis to compare the modelling output with the observed flow and sediment yields from the Gilgel Gibe watershed using a time series dataset of 30 years from 1988 to 2017 in order to run the model. The watershed was subdivided into 25 sub-basin and these sub basins were further divided into 232 hydrological response units based on many input parameters related to the DEM, soil, land use/land cover, weather data.

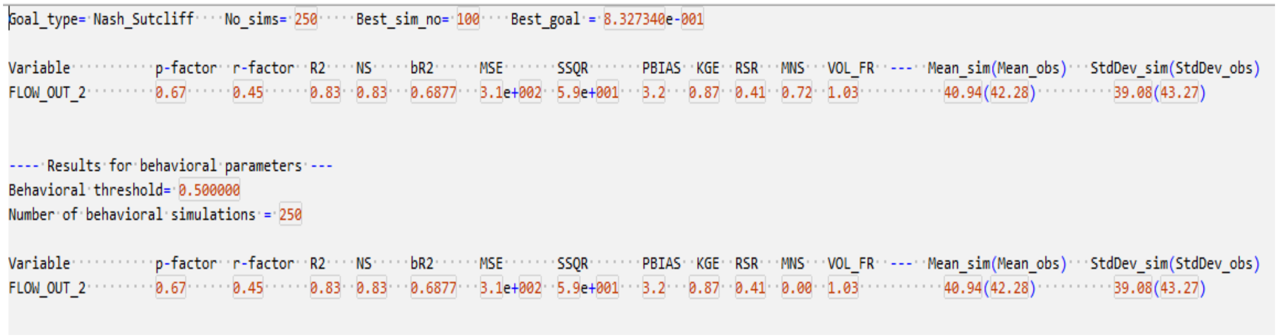
Table 4. 3 SWAT calibration and validation periods

Data	Application	Measurement data details	Source
Stream discharge measurements	Calibration(1988-2003)	Discharge data were measured at Asendabo stream gauge within the catchment	Ministry of Water,Irrigation and Energy
	Validation(2004-2013)		
Stream Sediment measurement	Calibration(1988-2003	Suspended sediment samples for concentration of SS (25events), were also measure at asendabo stream gauge within the catchment	Ministry of Water,Irrigation and Energy
	Validation(2004-2013)		

There are three calibration approaches widely used. These are manual calibration, automatic calibration and a combination of the two. Automatic calibration involves the use of a search algorithm to determine best-fit parameters. It is desirable as it is less subjective and can give results better than if done manually. The simulated hydrograph were compared to the observed data at Asendabo gauging site.

The model calibration was carried on monthly bases until the required limitation point obtained. The calibration was, therefore performed for a period of fourteen years (1990 to 2003) stream flow data. Calibration resulted in Nash-Sutcliffe simulation efficiency (E_{ns}) of 0.83, correlation coefficient (R^2) of 0.83, and mean deviation of 3.2 showing a good agreement between observed and simulated monthly flows (table below) using SUFI-2 algorithms.

Table 4. 4 Summery of stream flow calibration outputs



```
Goal_type= Nash_Sutcliff    No_sims= 250     Best_sim_no= 100    Best_goal = 8.327340e-001

Variable          p-factor  r-factor  R2    NS     bR2      MSE        SSQR         PBIAS  KGE   RSR   MNS    VOL_FR  ---  Mean_sim(Mean_obs)   StdDev_sim(StdDev_obs)
FLOW_OUT_2        0.67      0.45      0.83  0.83   0.6877   3.1e+002   5.9e+001     3.2    0.87  0.41  0.72   1.03         40.94(42.28)         39.08(43.27)


---- Results for behavioral parameters ---
Behavioral threshold= 0.500000
Number of behavioral simulations = 250

Variable          p-factor  r-factor  R2    NS     bR2      MSE        SSQR         PBIAS  KGE   RSR   MNS    VOL_FR  ---  Mean_sim(Mean_obs)   StdDev_sim(StdDev_obs)
FLOW_OUT_2        0.67      0.45      0.83  0.83   0.6877   3.1e+002   5.9e+001     3.2    0.87  0.41  0.00   1.03         40.94(42.28)         39.08(43.27)
```

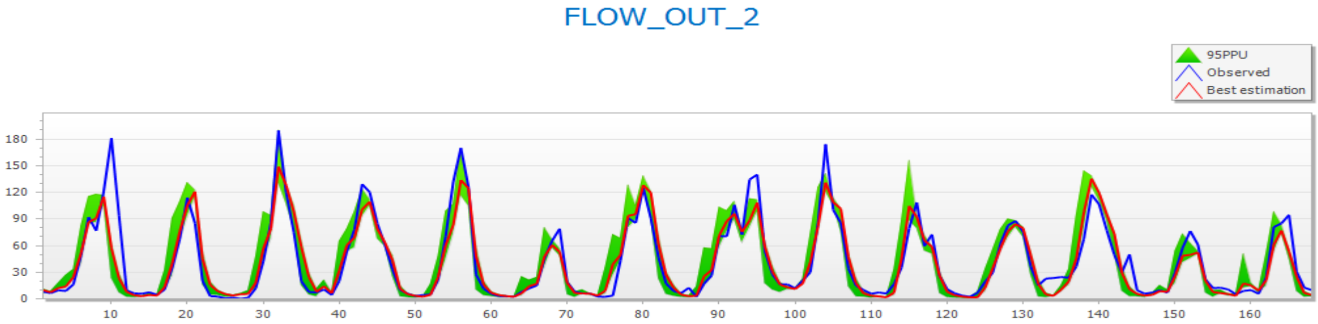
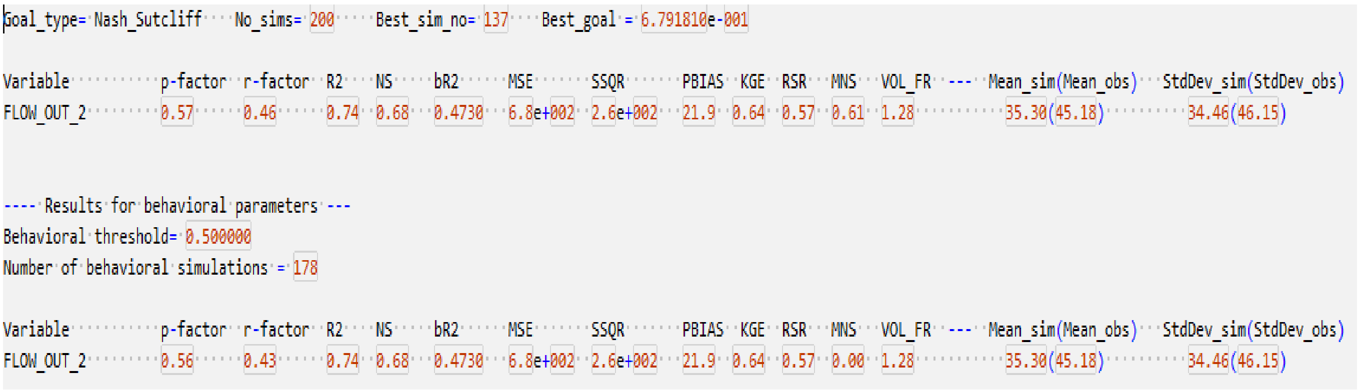


Figure 4. 3 Times series of observed vs. simulated discharge for stream flow calibration period from 1990 to 2003 years.

Model validation was done using the calibration parameters. The validation involved re-running the model with unchanged parameter set against an independent set of data series as further analysis of model performance. Good match between monthly measured and simulated flows in the validation period were demonstrated by the correlation coefficient (R^2) of 0.74, Nash-Sutcliffe simulation efficiency (E_{NS}) of 0.68 as shown table 4.5 and Figure 4.4.

Table 4. 5 Summery of stream flow validation outputs



```
Goal_type= Nash_Sutcliff   No_sims= 200    Best_sim_no= 137   Best_goal = 6.791810e-001

Variable          p-factor  r-factor  R2   NS    bR2     MSE       SSQR      PBIAS  KGE  RSR  MNS  VOL_FR  ---  Mean_sim(Mean_obs)   StdDev_sim(StdDev_obs)
FLOW_OUT_2        0.57      0.46      0.74 0.68  0.4730  6.8e+002  2.6e+002  21.9   0.64 0.57 0.61 1.28          35.30(45.18)         34.46(46.15)


---- Results for behavioral parameters ---
Behavioral threshold= 0.500000
Number of behavioral simulations = 178

Variable          p-factor  r-factor  R2   NS    bR2     MSE       SSQR      PBIAS  KGE  RSR  MNS  VOL_FR  ---  Mean_sim(Mean_obs)   StdDev_sim(StdDev_obs)
FLOW_OUT_2        0.56      0.43      0.74 0.68  0.4730  6.8e+002  2.6e+002  21.9   0.64 0.57 0.00 1.28          35.30(45.18)         34.46(46.15)
```

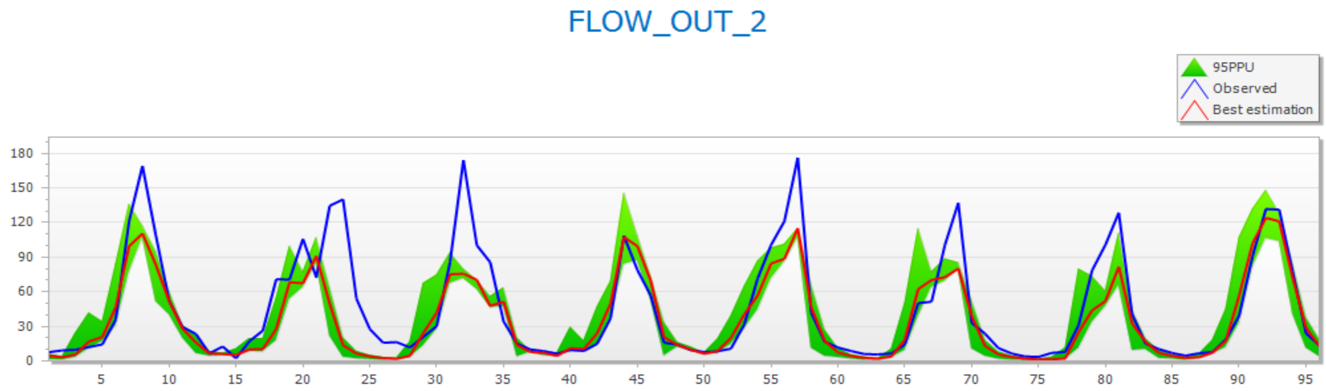


Figure 4. 4 Times series of observed vs. simulated discharge (monthly) for stream flow validation period from 2004 to 2013 years.

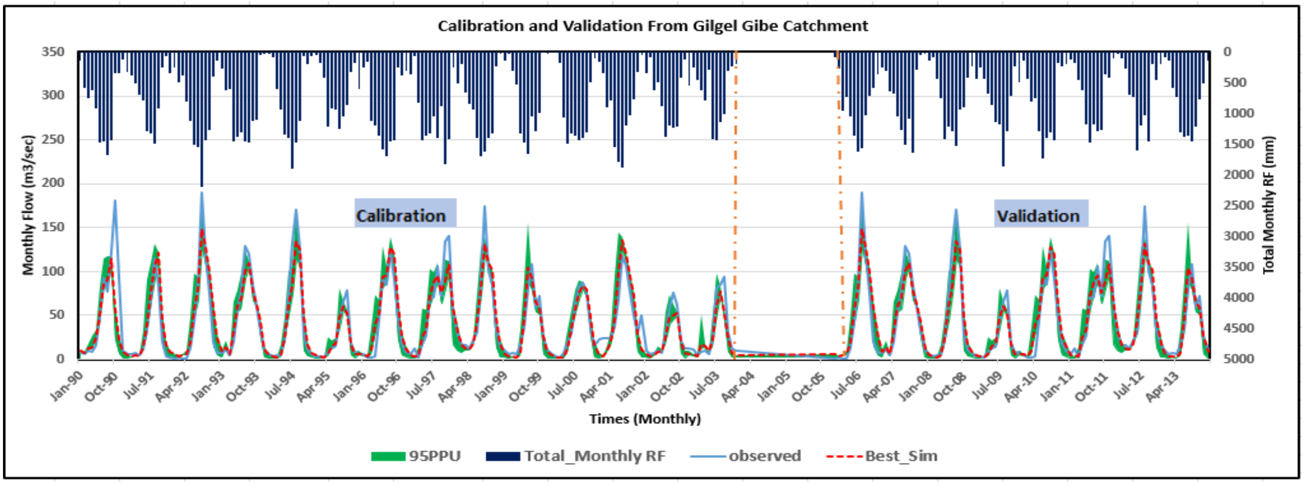


Figure 4. 5   Hydrograph of the observed and simulated monthly discharge flow of Gilgel Gibe Catchment in Excel

4.7. Sediment yield modelling from Gilgel Gibe I watershed using SWAT2012 model

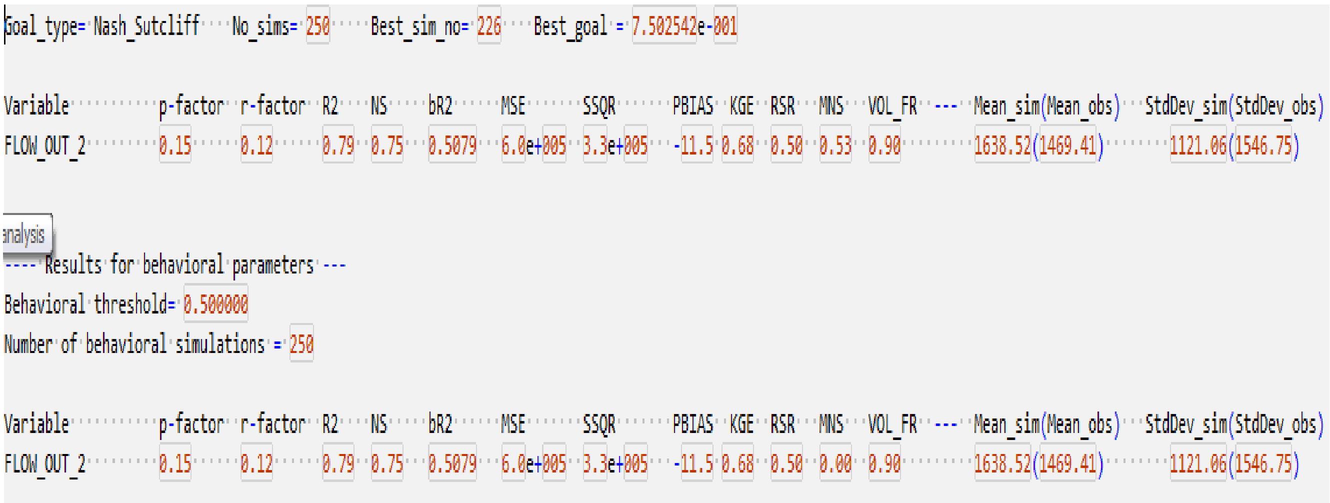
In this study the physically based model applied to Asendabo gauging station for prediction of sediment yield. There are limited data in Ethiopia to do large scale calibration and validation of watershed sediment yield. Model output varies for different sub-basin delineations that can be a main source of model uncertainty. The ArcSWAT interface lets the user to decide the initial area the model resulted in 25 sub basin areas that gave 27.56 tons per hectare per year. As the threshold area increased from one to other hectares the model produces larger sediment yield.

Subdividing the sub basin into areas having unique land use, soil and slope combinations. In multiple slope the slope discretization that consists of broad range of class gave higher sediment yield. Since, the deposition of sediment during transport process and the majority of the soil particles eroded by surface runoff are transported into the reservoir. The results shows that slope gradient and slope length (topographic factor) parameters used in the MUSLE equation are sensitive factors that can affect the sediment output of the SWAT2012.

4.8. Sediment flow calibration and validation

The model was calibrated for sediment by comparing monthly model simulated sediment loads against monthly measured sediment load from Asendabo station. The calibration was, therefore performed for a period of fourteen years (1990 to 2003) stream solid flow data. Calibration resulted in Nash-Sutcliffe simulation efficiency (E_{NS}) of 0.79, correlation coefficient (R^2) of 0.75, showing a good agreement between measured and simulated monthly flows (table below).

Table 4. 6 Summery of stream sediment flow calibration outputs



```
Goal_type= Nash_Sutcliff   No_sims= 250   Best_sim_no= 226   Best_goal = 7.502542e-001

Variable        p-factor  r-factor  R2   NS    bR2     MSE      SSQR      PBIAS  KGE  RSR   MNS   VOL_FR --- Mean_sim(Mean_obs)   StdDev_sim(StdDev_obs)
FLOW_OUT_2      0.15      0.12      0.79 0.75  0.5079  6.0e+005 3.3e+005  -11.5  0.68 0.50  0.53  0.90       1638.52(1469.41)     1121.06(1546.75)

analysis
---- Results for behavioral parameters ---
Behavioral threshold= 0.500000
Number of behavioral simulations = 250

Variable        p-factor  r-factor  R2   NS    bR2     MSE      SSQR      PBIAS  KGE  RSR   MNS   VOL_FR --- Mean_sim(Mean_obs)   StdDev_sim(StdDev_obs)
FLOW_OUT_2      0.15      0.12      0.79 0.75  0.5079  6.0e+005 3.3e+005  -11.5  0.68 0.50  0.00  0.90       1638.52(1469.41)     1121.06(1546.75)
```

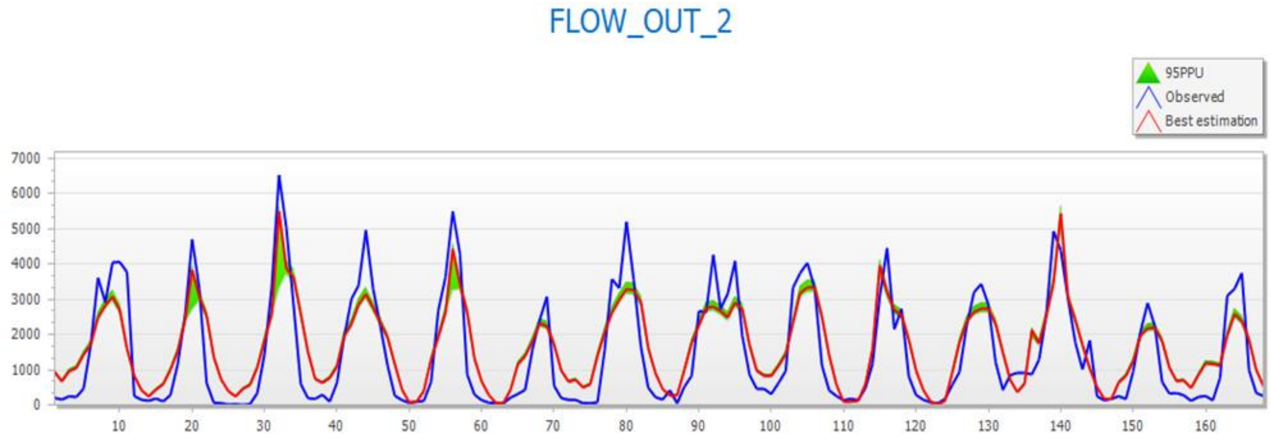
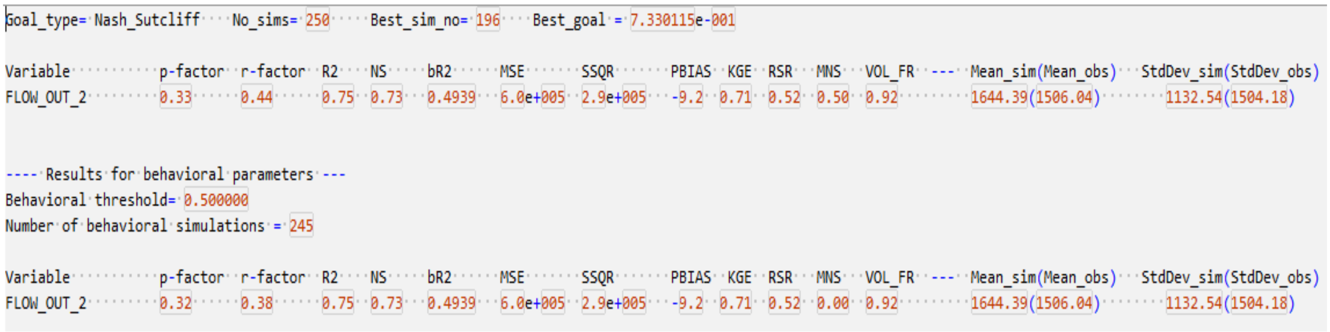


Figure 4. 6 Monthly sediment calibration-Gilgel Gibe I watershed.

Sediment Validation: Validation is undertaken to assess the model adequacy and to determine whether the simulation period of stream flow and sediment confirmed that the model performs satisfactorily. A variety of models has been developed for this purpose, but the automatic calibration method was used for validation in research. The SWAT model stream flow and sediment load outputs were validated against monthly stream flow and sediment load at the gaging station of Asendabo.

Table 4. 7 Summery of stream sediment flow validation outputs



```
Goal_type= Nash_Sutcliff   No_sims= 250    Best_sim_no= 196    Best_goal = 7.330115e-001

Variable          p-factor  r-factor  R2   NS    bR2     MSE      SSQR      PBIAS  KGE  RSR   MNS   VOL_FR  ---  Mean_sim(Mean_obs)   StdDev_sim(StdDev_obs)
FLOW_OUT_2        0.33      0.44      0.75 0.73  0.4939  6.0e+005 2.9e+005  -9.2   0.71 0.52  0.50  0.92         1644.39(1506.04)      1132.54(1504.18)


---- Results for behavioral parameters ---
Behavioral threshold= 0.500000
Number of behavioral simulations = 245

Variable          p-factor  r-factor  R2   NS    bR2     MSE      SSQR      PBIAS  KGE  RSR   MNS   VOL_FR  ---  Mean_sim(Mean_obs)   StdDev_sim(StdDev_obs)
FLOW_OUT_2        0.32      0.38      0.75 0.73  0.4939  6.0e+005 2.9e+005  -9.2   0.71 0.52  0.00  0.92         1644.39(1506.04)      1132.54(1504.18)
```

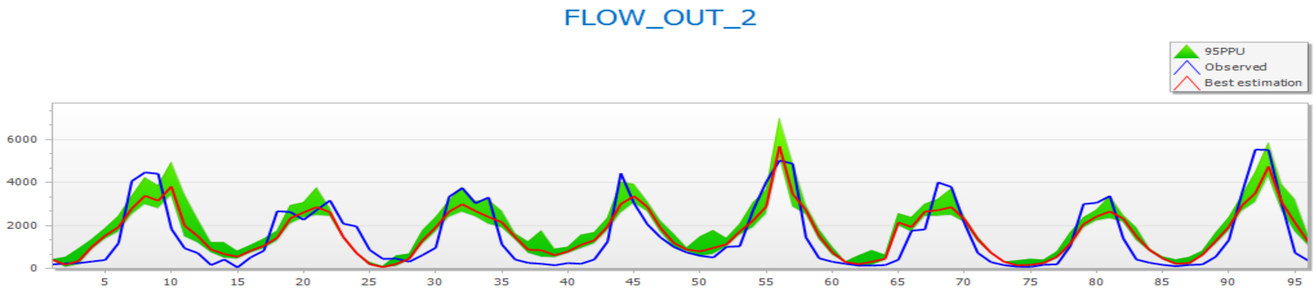


Figure 4. 7 Monthly sediment validation-Gilgel Gibe I watershed.

The result of validation result are also within an acceptable range for the observed 10 years of sediment. As a result, the simulated monthly stream solid flows represent observed values for the validation period with a N_{SE} of 0.75, R^2 of 0.79, RSR of 0.5.

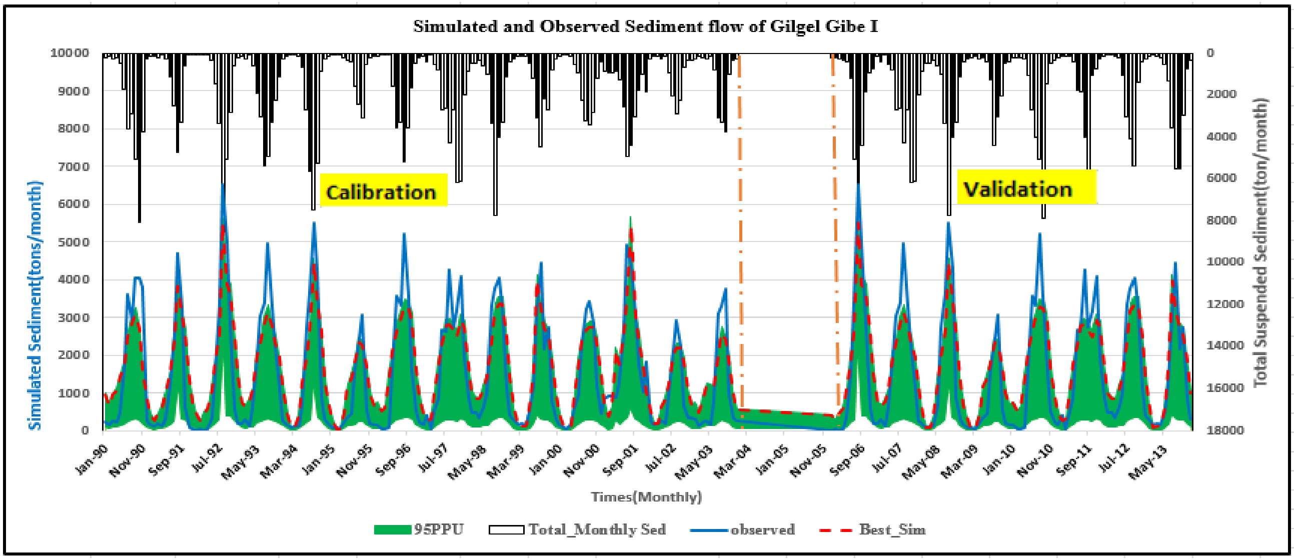
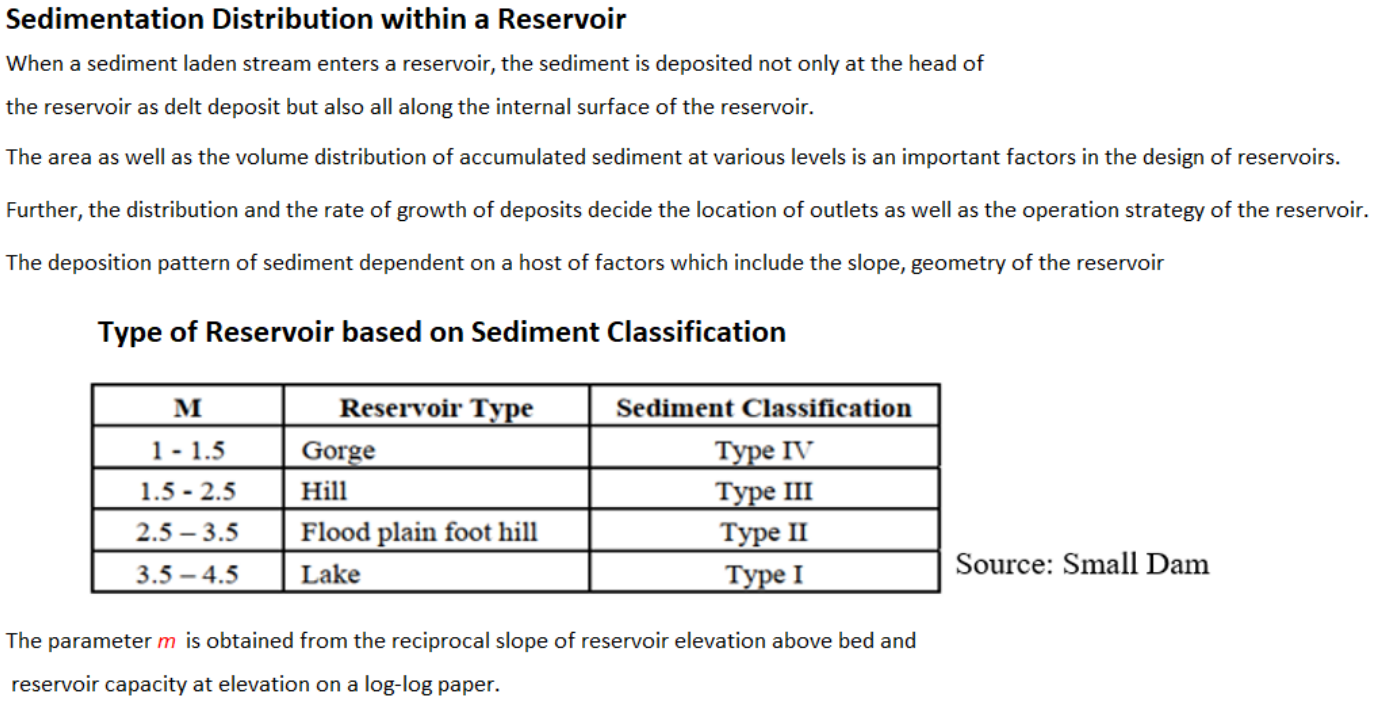


Figure 4. 8 Hydrograph of observed and simulated sediment flow in excel

Generally, an evaluation of the performance of the SWAT 2012 version of Arc-SWAT was used to conduct in order to simulate stream flow and sediment in the upstream portion of the Gilgel Gibe river watershed. A general recommendation is that more attention be given to the spatial parameters and input data. First, the model requires higher resolution data such as DEM, land use and soil type. Second, more recent and accurate daily flow and sediment input data are critical for model performance, so government minister need to establish more sediment gaging stations and observe quality data on a regular basis.

4.9. Reservoir Sediment Distribution using Area-Reduction Method

Once the estimated sediment inflow to a reservoir has been established, attention must be given to the effect the deposition of this sediment will have upon the life and daily operation of the reservoir. The mean annual sediment inflow, the trap efficiency of the reservoir and the distribution of the sediment within the reservoir, all must be considered in the design of the dam. Sediment accumulations in a reservoir are usually distributed below the top of the conservation pool, or normal water surface. This sediment will be held within flood control pool for significant periods of time if the reservoir has a flood control pool. Once the quantity of sediment that will deposit below the normal water surface has been determined by SWAT model, the empirical area-reduction method used to estimate the distribution in the Gilgel Gibe I reservoir as shown below by using formula programmed in the excel.



Sedimentation Distribution within a Reservoir

When a sediment laden stream enters a reservoir, the sediment is deposited not only at the head of the reservoir as delt deposit but also all along the internal surface of the reservoir.

The area as well as the volume distribution of accumulated sediment at various levels is an important factors in the design of reservoirs.

Further, the distribution and the rate of growth of deposits decide the location of outlets as well as the operation strategy of the reservoir.

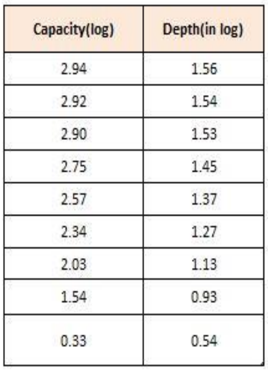
The deposition pattern of sediment dependent on a host of factors which include the slope, geometry of the reservoir

Type of Reservoir based on Sediment Classification

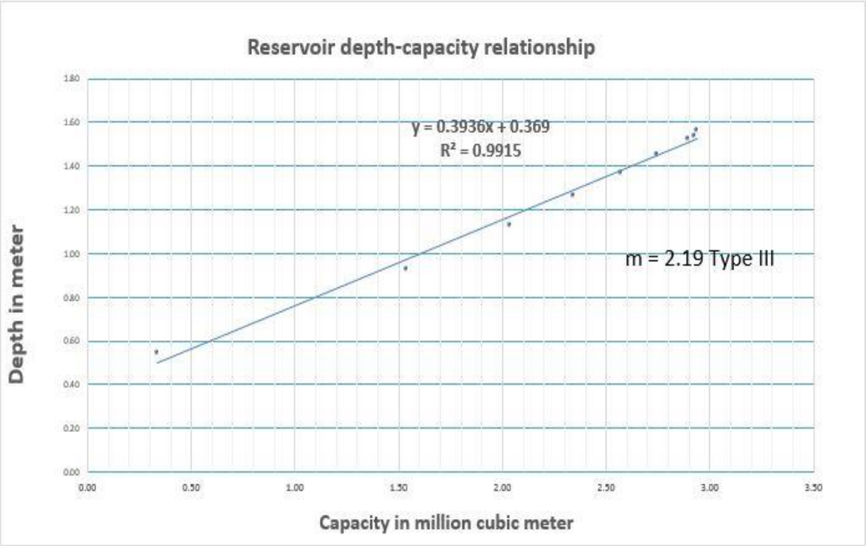
M	Reservoir Type	Sediment Classification
1 - 1.5	Gorge	Type IV
1.5 - 2.5	Hill	Type III
2.5 – 3.5	Flood plain foot hill	Type II
3.5 – 4.5	Lake	Type I

Source: Small Dam

The parameter *m* is obtained from the reciprocal slope of reservoir elevation above bed and reservoir capacity at elevation on a log-log paper.



Capacity(log)	Depth(in log)
2.94	1.56
2.92	1.54
2.90	1.53
2.75	1.45
2.57	1.37
2.34	1.27
2.03	1.13
1.54	0.93
0.33	0.54



According to the result of above Figure the Gilgel Gibe I Reservoir type is III wich means Hill reservoir type. See Figure 2.3 for reservoir types

Lower portion of the reservoir slightly fall in the Reservoir type III

Computation of the elevation of Sediment deposited at the dam

$$F = \frac{S - V_h}{HA_h}$$

F = dimensionless function of total sediment deposition, capacity, depth, and area

S = total sediment deposition(Mm^3)

S 170.9 Mm^3 **SWAT output**

Vh = reservoir capacity (m^3) from column 5 at each elevation h from column 4

H = original depth of reservoir below normal pool (38.9 m) 38.9 m

Ah = reservoir area (m2, from column 3) at a given elevation h.

The value of **F** was calculated as shown in the Area-reduction method on Table 4.8 column #7

Final sediment load 27.56 ton/hac/year

items	Quantity	unit	
Area	402181.8	ha	
years	40.89	to be filled by sediment from operation or	
	28	years left to fill dead storage from 2017 till data used	
ρs	2650	kg/m3	
	2.65	ton/m3	
	0.377	m3/ton	
Qs	27.56	t/hac/year	170867734 ton
Sediment deposit(Mm3)	170.9*10^6 M3		

Operation date	2004

Calculate the P value, relative depth at each elevation(h)

$$p = \frac{h - h_{min}}{H}$$

where $hmin$ = original bottom elevation (1639.4 m).

h_{min}	1634	m
H	38.9	

Plot the data point of the *F* and *p* values (columns 6 and 7) on the type curves

The intersection of the plotted *F* values with the type curve selected for the reservoir defines the *p0* value for the new zero-capacity elevation at the dam p_o **0.044** from (Strand and Pemberton, 1987).

Determine the new zero-capacity elevation by the equation below

$$h_0 = (p_0 H + h_{min})$$

corresponding to New zero elevation,ho

h_o	***1635.71***	*m*		
A_o	0.352	km^2	35.202	ha

Ao is the new area completely filled with sediment at new zero elevation

Ao	0.352	km2
a1	0.543	
k1	0.65	
k	0.825	
	0.272	

Reservoir capacity 839

0.204

Determine relative sediment area(column # 8) at each relative depth is computed from the original area-elevation curve

Type I: $a = 5.047p^{1.85}(1\text{-}p)^{0.36}$

Type II: $a = 2.487p^{0.57}(1\text{-}p)^{0.41}$

Type III: $a = 16.967p^{1.15}(1\text{-}p)^{2.32}$

Type IV: $a = 1.486p^{-0.25}(1\text{-}p)^{1.34}$

Source: Small Dam

Also compute the relative sediment area *a* at the new zero elevation.

a 0.42

Compute the area correction factor as Ao/a ***83.81*** ha

Trendline	**linear**	Logarithmic
slope	0.3936	**0.4572**
m	2.54	**2.19**
Reservoir Ty	Type II	**Type III**

a

0.421

0.00

Compute the area at each pool elevation occupied by sediment by multiplying the area correction factor (k) by the relative sediment area (column 8) at each level above the new zero-capacity elevation.

Compute the sediment volume for each stage increment above the new zero-capacity elevation using the end area method.

Table 4. 8 Sediment distribution in Gilgel Gibe I reservoir by Empirical Area Reduction Method. Sediment inflow 27.56 ton/hec/year

St.no	Elevation	Original water spread area (km2)	Height above original bed	Original reservoir capacity (MMC)	Relative depth (p)	Dimensionless Function (F)	Relative Area (a)	Sediment Area (kAp)	Incremental sediment volume (mmc)	Accumulated sediment volume (mmc)	Reservoir capacity at the end of 41years (mmc)
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	1634	0	0	0	0.00	4.393	0.000	0.000			
	1635.71	0.352	2	1.525		4.354	0.543	0.448	0.122	1.525	0.00
2	1640	1.234	6	4.85	0.15	4.269	0.800	0.660	3.324	4.849	0.00
3	1645	11.618	11	35.29	0.28	3.486	1.056	0.872	8.424	13.272	22.02
4	1650	17.906	16	108.1	0.41	1.614	1.206	0.995	14.933	28.205	79.89
5	1655	27.242	21	220.97	0.54	-1.287	1.273	1.050	21.477	49.682	171.29
6	1660	32.982	26	371.53	0.67	-5.158	1.257	1.037	27.137	76.819	294.71
7	1665	42.298	31	559.73	0.8	-9.996	1.137	0.938	30.611	107.430	452.30
8	1670	49.066	36	788.14	0.93	-15.867	0.821	0.677	29.067	136.498	651.64
9	1671	53.034	37	839.19	0.95	-17.180	0.701	0.578	23.225	159.722	679.47
10	1672.9	54	38.9	870.6	1.00	-17.987	0.000	0.000	11.248	170.970	699.63

4.10. Gilgel Gibe I Reservoir Life

$$\text{SWAT model out put} = 27.56\ \text{ton/hac/year}$$

$$\text{Sediment density} = 2650\ \text{kg/m}^3 = 0.377\ \text{m}^3/\text{ton}$$

$$27.56\ \text{ton/hac/year} * 0.377\ \text{m}^3/\text{ton} = 10.39\ \text{m}^3/\text{hac/year}$$

$$10.39\ \text{m}^3/\text{hac/year} * 402{,}181.77\ \text{hac} = 4.179 * 10^6\text{m}^3/\text{year}$$

$$Therefore, 40.89\ years * 4.179 * \frac{10^6 m^3}{year} = 170.9 * 10^6 m^3$$

$$Reservoir\ dead\ storage\ capacity = 171 * 10^6 m^3$$

$$\text{SO, the reservoir will filled with sediment within } \mathbf{41} \text{ years from its operation}$$

$$\text{or, from operation to till data used, } 2017 = 13 \text{ years}$$

$$41 \text{ years} - 13 \text{ years} = 28 \text{ years were left to completely filled from } 2017$$

4.11. Economic loss due to sedimentation

Consequence of storage loss on energy production loss, reduction in efficiency of power generation due to sedimentation, downstream effects of reservoirs on the river bed, contamination due to sediment are some of problems on economic and environment (G.W. Annandale, 1987). The Gilgel Gibe hydropower project is 1,700m long, 41m high rock fill embankment dam comprise 3 Francis units each with 73 MW capacity. Maximum net head of 223.4 m. a maximum output of 184 MW and rated discharge of 100m^3/s. (EEPCO). The reservoir of the power plant has a live storage of 668 million m^3, operating between 1,671.0 and 1,653.0 m.a.s.l. below the minimum normal level, some 171 million m^3 is available as dead storage that will be filled by sediment along the economic life period of the plant.

To get the economic loss due to sedimentation the volume of live storage replace by sediment was converted to energy (kwh) using energy equivalent of 0.5478 kwh/m^3 obtained from equation below i.e. Net Head (Hn) 223.4 m and overall efficiency (η) of the power plant, 90%. The energy equivalent is the amount of energy produced from each m^3 and is computed as: (R.K.Rajput, 2006).

$$\text{EE} = \eta * \rho * g * \frac{\text{Hn}}{3600}, \text{ in kWh/m}^3$$

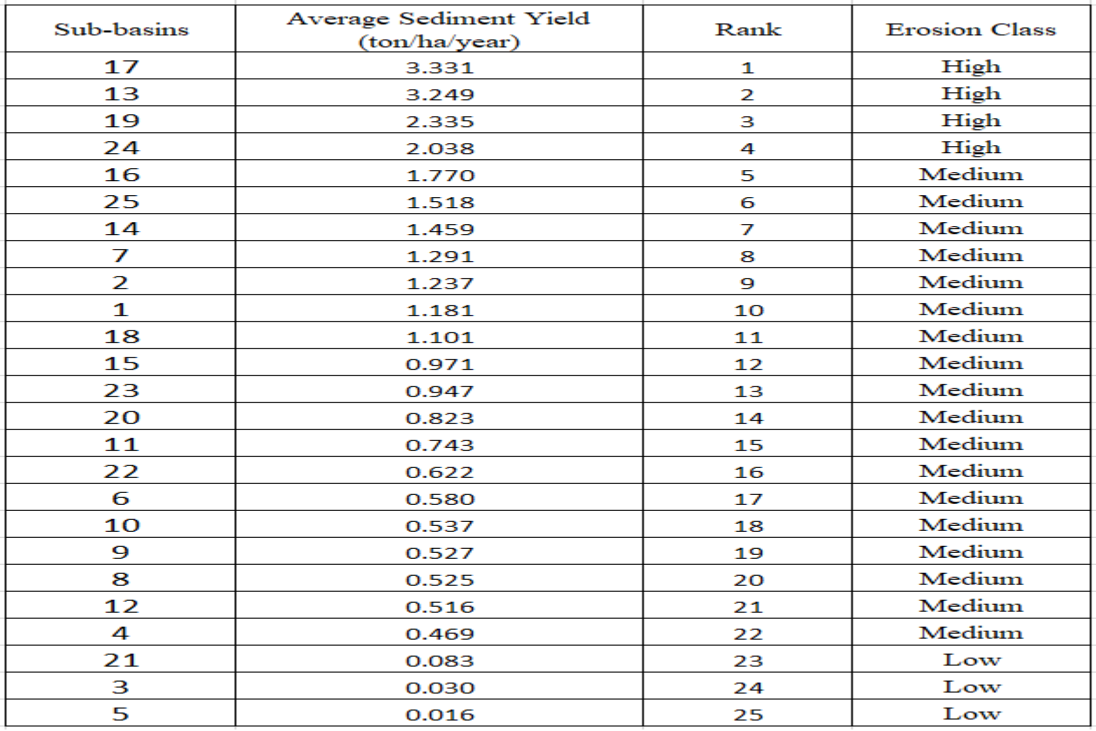
In order to predict economic loss from sedimentation it is necessary to specify firm and surplus power price which defines water value is required with time. However, to make accurate estimate of seasonal storage loss must be obtained which is not possible with available sediment data and data on seasonal variation power price is also not available. Therefore, an average energy price of 0.6943 birr/kwh was obtained from EEPCO.

The Gilgel Gibe reservoir losses 4.179Mm^3 live storage annually due to sedimentation. Therefore, annual economic loss due to reservoir sedimentation is equal to annual live storage loss multiplying by energy equivalent (kwh/m^3) and by average energy price (birr/kwh), which is equal to 4.179 Mm^3/year * 0.5478 kwh/m^3 = 2.289*10^6 kwh/year. Since, there is always electricity price escalation from time to time which may result from increase in maintenance cost, increase in demand and some other factors, the energy lost due to sedimentation were expressed by kilowatt hour per year.

Therefore, the appropriate remedial measures that reduce sediment field to increase life span of the dam is given priority.

4.12. Sources of Suspended Sediment in Gilgel Gibe Catchment

Study of Sanjeet Kumar, (2001) confirmed that sub basins can be classified as low, medium and high erosion class depending on their sediment yield. This classification is used to give priority for critical sub basin. Table below shows, After the model calibration and validation of sediment, we identify the model simulation of the spatial sediment distribution in the Gilgel Gibe catchment.



Sub-basins	Average Sediment Yield (ton/ha/year)	Rank	Erosion Class
17	3.331	1	High
13	3.249	2	High
19	2.335	3	High
24	2.038	4	High
16	1.770	5	Medium
25	1.518	6	Medium
14	1.459	7	Medium
7	1.291	8	Medium
2	1.237	9	Medium
1	1.181	10	Medium
18	1.101	11	Medium
15	0.971	12	Medium
23	0.947	13	Medium
20	0.823	14	Medium
11	0.743	15	Medium
22	0.622	16	Medium
6	0.580	17	Medium
10	0.537	18	Medium
9	0.527	19	Medium
8	0.525	20	Medium
12	0.516	21	Medium
4	0.469	22	Medium
21	0.083	23	Low
3	0.030	24	Low
5	0.016	25	Low

Among this sub basins, sub basin 17, 13, 19 and 24 were falls under high erosion class and ranking 1st to 4th respectively in their sediment yield. As presented in the previous chapter land use of this sub basin which fall under high erosion class, due to the dominance of agricultural areas and additionally the soil around these areas contain silt materials and the catchments are relatively having steeper slopes. This shows that the cultivation practices in the area accelerate runoff which leads to high sediment susceptibility of the watershed.

4.13. Reservoir sedimentation remedial measures

Sediment management measures which do not have considerable impact on the reservoir and downstream uses can only be implemented. Numbers of reservoirs were constructed as cascade on the Omo River. These reservoirs can operate jointly with an objective of minimizing storage loss due to sedimentation and maximizing the net benefit from the operation. Therefore, appropriate sediment management should be should to increase the life span of the reservoirs.

Successful sluicing depends on the availability of excess water and relatively large bottom outlets at the dam. For the successful flushing the reservoir capacity-mean annual runoff ratio should be quite small less than 0.2 year. However, in the case of Gilgel Gibe I reservoir the reservoir capacity to mean annual runoff ratio is equal to 0.52 years which is larger than 0.2 year. In addition to the impact of eroded and transported sediment on downstream dam, sluicing is not feasible for the reservoir.

Structural measures under favorable condition, sediment trapping before it enters the reservoir can be a highly effective measure for sediment yield reduction. However, all structural measures are very costly to construct. And other measures are Sediment removal by mechanical means in dry excavation or hydraulic dredging are usually much more expensive, therefore this mechanism may affect the continuous operation of downstream dam of Gilgel Gibe II and other cascaded dam, since those dam depends on the operation of upstream dam. So, removal through mechanical dredging systems are not feasible for Gilgel Gibe reservoir.

Vegetative measures can provide temporary and/or permanent stabilization of exposed areas. Using grasses, brush and trees on small land parcels can offer ground cover, and soil protection with inexpensive and aesthetic natural vegetation. Also socially and environmentally friend. Therefore, vegetative measures in upstream of reservoir is most prominent remedial measures to preserve the soil erosion in the catchment.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The ArcGIS interface soil and water assessment tool was used to simulate water discharge and suspended sediment yield in the Gilgel Gibe River watershed with monthly data. The model use some input data like DEM, land use/land cover map, soil map and metrological data. Hydrological flow and sediment data were also used in SWAT-CUP program for calibration and validation of modeling output.

Sediment rating curve was used with daily flow data for a period from 1990 to 2017 years hydrological data to estimate suspended sediment load. The average sediment concentration for the period of measured data was also used to make sediment yield estimate. The sediment yield based on the rating curves is highly overestimated than the sediment estimated with the SWAT model. The relationship between discharge and sediment concentration for a particular stream is not a fixed parameter but can considerably vary from one storm to another depending on factors including the intensity and areal distribution of the rainfall and changes in the sediment supply. The fitted line for the discharge and sediment calibrations and validations shows a good correlation of sediment and water discharge. However, good fit doesn’t imply an accurate representation of the process. Since, the effect of irregularity of the data: it’s common for sediment measuring stations in Ethiopia to have data for few days of a given month or no data at all. The measured data are not collected on equally space time step basis, these problem affects the accuracy of the result.

This research demonstrates that physically based model, specifically the SWAT model, can reasonably estimate suspended sediment yields at a basin scale. However, detail sensitivity analysis, calibration, and validation should be used to improve the accuracy of the model results. SWAT reasonably simulates water discharge and suspended sediment yields in the Gilgel Gibe River catchment because the results obtained from the model satisfactorily predict stream flow and sediment yields in this region, with monthly discharge R^2 of 0.83, N_{SE} of 0.83 and RSR of 0.41, and monthly suspended sediment yield R^2 of 0.79, N_{SE} of 0.75, and RSR of 0.52.

The most sensitive input parameters in the watershed are hydraulic response unit and curve number for sediment yield, and alpha base flow and Soil hydraulic conductivity for water discharge.

The reservoir life estimated depends on how fast the dead storage of the reservoir is completely filled with sediment deposit. The empirical area-reduction method for sediment distribution depends on the reservoir types. The reservoir life of Gilgel Gibe I dam was estimated to be forty one years from start of operation for type II reservoir. With this type II reservoir the average annual storage loss of the Gilgel Gibe I dam will be 0.58 %.

Economic loss due to live storage loss was estimated as the total live storage lost in the forty one years after start of operation, February, 2004 was determined as the difference between the original and the revised storage capacity at minimum water level, 1653 masl. The total storage lost due to sediment deposit after 41 years was be 170.97 * 10^6 m^3 with $4.179*10^6$ m^3 per year. The total annual economic loss due to the live storage loss found to be 2.289 million kilowatt hour per year.

Landslides, river bank erosion and gullies were found to be the major sediment sources in the catchment, (PHE) threatens the economic life span of the Gilgel Gibe I dam. If the appropriate measure couldn't be taken the reservoir will be lost. Therefore, in order to improve its hydroelectric power generation Watershed management with vegetation is recommended and to be applied in the catchment with continuous follow up by involving the community around the dam and making these community beneficiaries.

5.2. Recommendations

- Watershed management is the best method to reduce the sediment yield and its entry into the reservoir. Vegetative screens at the upstream of the reservoirs may withhold a significant part of the entering sediment. So, Step up provision of supplies of tree seeds and seedlings for agro-forestry and forestry planting as the community income sources by selling trees and planting annually, this duty initiates the communities to feel as stakeholder to protect the catchment from soil erosion. By providing the technical support, training, supervision, materials, financing in cash and equipment required to achieve realistic work programmes targets.
- Use economical and efficient structures like check dam within a water course to capture sediments from the flow.
- The bottom outlet of the dam should be put in operation to help in scouring sediment deposit in dam by considering the impact of sediment sluicing on the downstream cascaded dam. Sustainability of downstream dam may depend on the management of Gilgel Gibe I watershed.
- Also more research is necessary to forecast sediment yield of each sub basin for daily and monthly time step under different land use/land cover scenario to decide a type of coverage and extent of application on different sub-basin to improve decision making of the stakeholder.

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APPENDIX

Appendix I

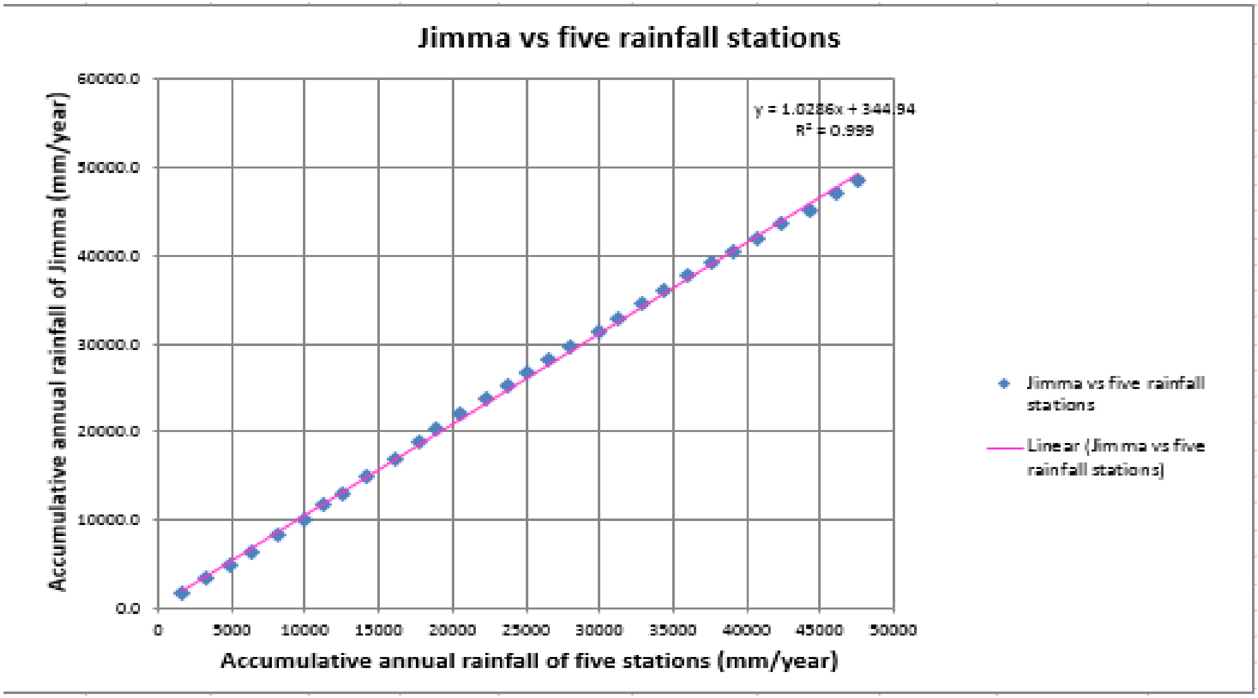
General Gilgel Gibe I reservoir characteristics

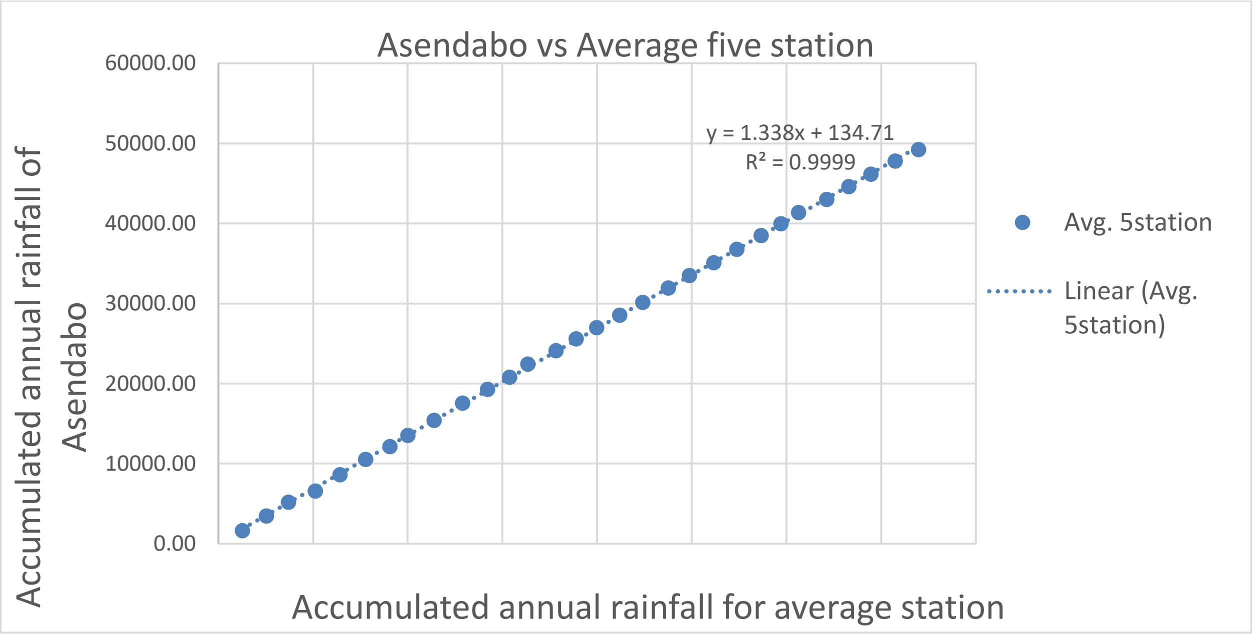
Feature	Specification
Reservoir	
Maximum normal water level	1,671m.a.s.l
Average water level	1,665 m.a.s.l
95% water level	1,651 m.a.s.l
Minimum normal water level	1,651 m.a.s.l
Total storage	839 million m^3
Live storage	711 million m^3
Dead storage capacity	171Mm^3
Catchment area	51 sq. km
Lowest river bed	1634 m
Water spread area at F.R.L.	4,225 sq.km
Water spread area at M.W.L	4248.86 ha
Geology	Eocene and Paleocene volcanic materials
Spillway	
Peak design outflow	2,570 m^3/s
Type of structure	Gated crest, open chute and terminal
Crest sill level	1,665 m.a.s.l
Gates	
Type	Piston operated flatv gates
Number	Four
Dimensions (wxl)	12m x 5.8m
Chute dimensions	57.10/35.00m/598m
Hydrological data	
Annual Rainfall	1,527mm
Annual average flow	50.4 m^3/s
Annual run-off	1589 million m^3
Power Intake	
design flow	102m^3/s
.type	tower with access bridge
gate type and dimensions (w x h)	cylindrical, 4.00m high x 6.50m diameter
Concrete Lined Power Tunnel	
.length	8,950m
.diameter	5.50m
Invert elevations	
.at the intake	1,638.00m asi/l
at the surge tank	1,605.55masl
.slope	0.36%
Surge Shaft	
type	cylindrical, base throttle, upper expansion tank
.shaft diameter	16m

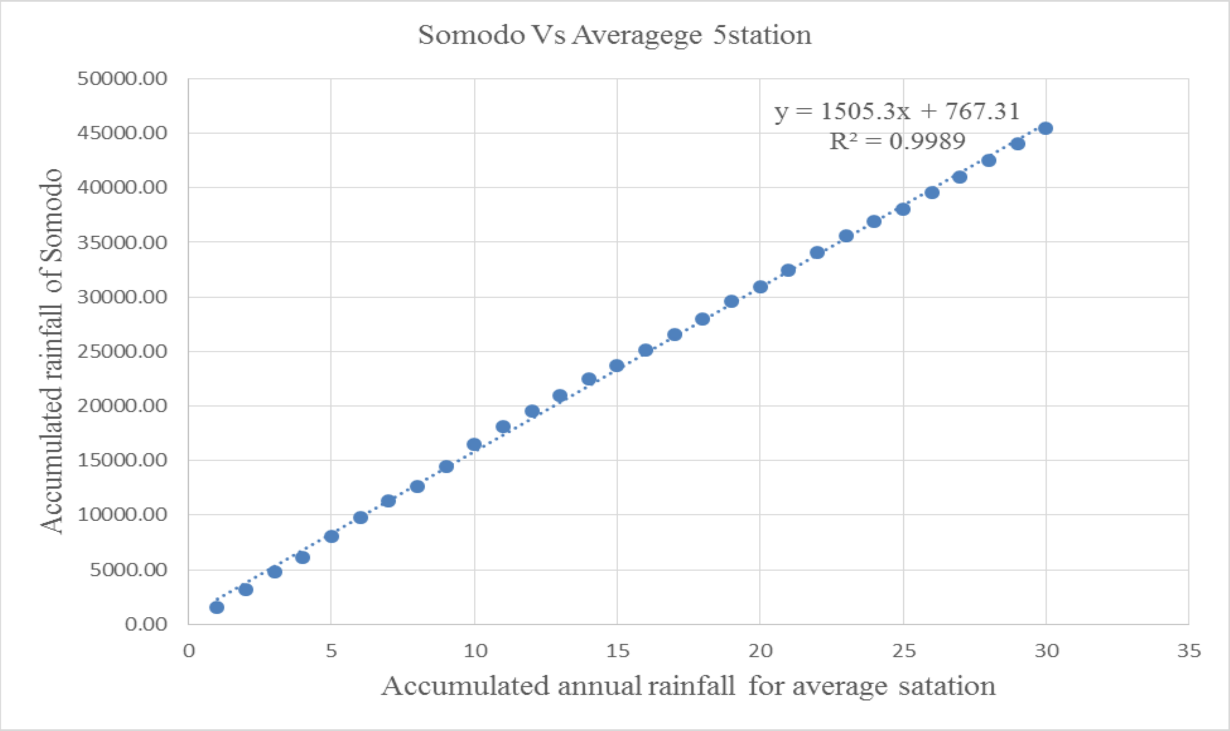
maximum dynamic level	1,683.00m asl
minimum dynamic level	1,612.80m asl
Penstock and Terminal Manifold	
diameter	variable: 5.00/2.80/2.1Om
length	250m
Powerhouse	
.type	underground
.length	78.60m
.width	22.Om
main floor elevation	1,441.00masl
.average tail water level	1,437.90masl
Downstream Surge Shaft and Tailrace Tunnel	
Downstream surge shaft	
diameter	20.Om
max dynamic level	1,447.70m
.min dynamic level	1,434.20m
Tailrace tunnel	
.length (including initial manifold)	530m
diameter	6.50m
Main Equipment	
Number and type of generating units	**three vert. Francis turbines& synchronous generator**
Inlet valve. Type and diameter	**rotary,2.1Om**
Turbine	
.max net head(Q=Qmax/3)	232.3m
.max net head(Q=Q_{max})	212.8m
.aver.net design head (Q=0.987Q_{max})	207.3m
.95%net design head (Q=O.967Q_{max}	199.2m
.min net head(Q=0.957Q_{max})	194.6m
.rotational speed	**428.57rpm**
.max cap.(1 unit at max head)	67MW
Installed cap.(3 units at max head)	184MW
Generator	
.maximum capacity	**75mVA**
frequency	**50Hz**
.number of poles	**14**
.Main transformers	
.number	**3**
.no-lead voltage	**220/15k**
apparent capacity	75mVA
.main cranes, number and capacity	two,60/5teach

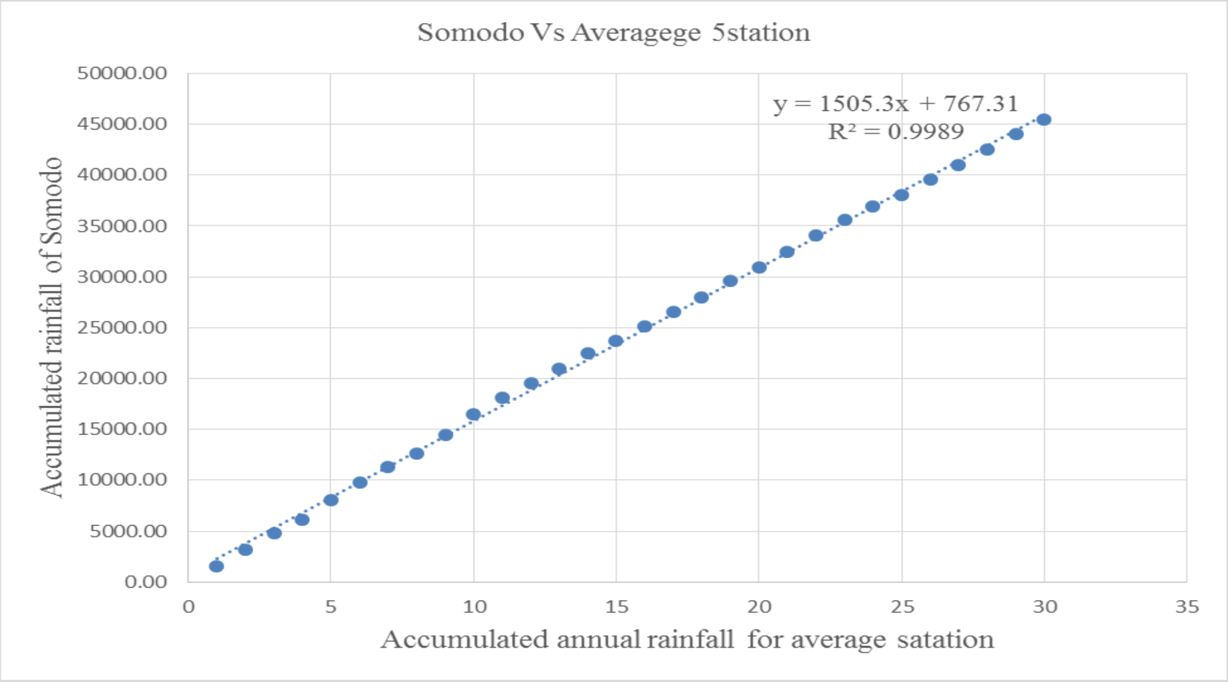
Appendix II

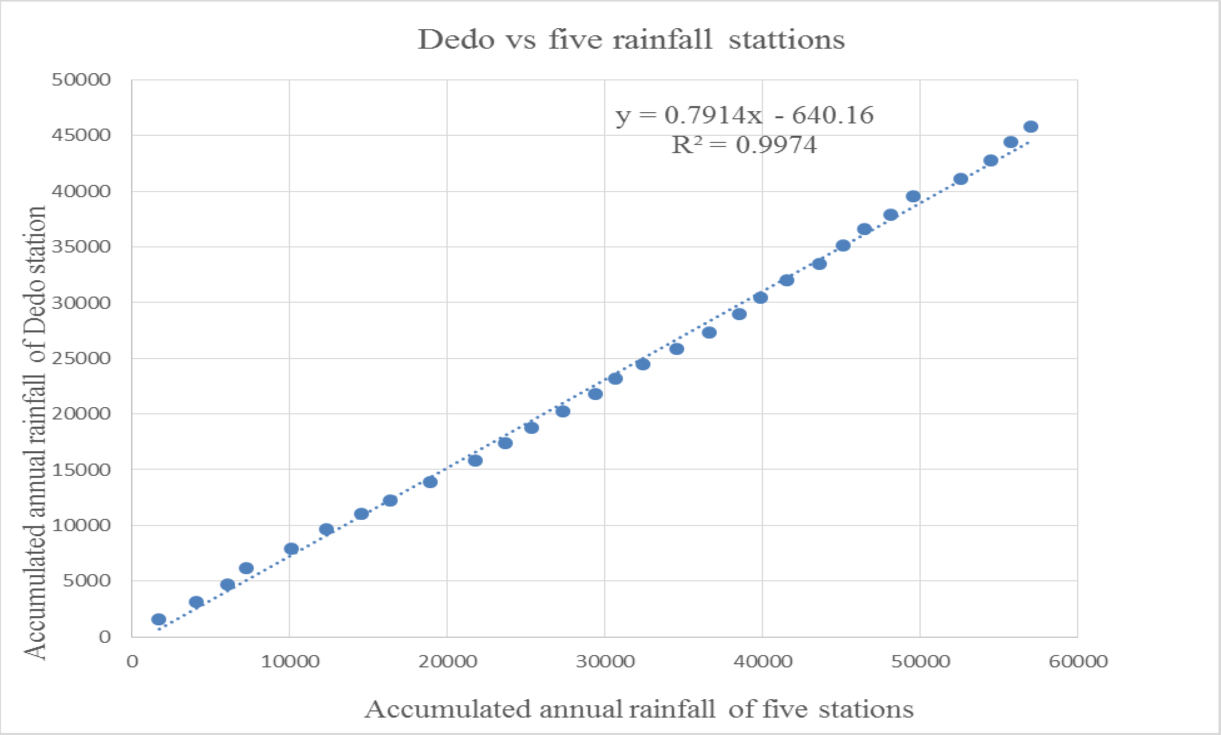
Data Consistency



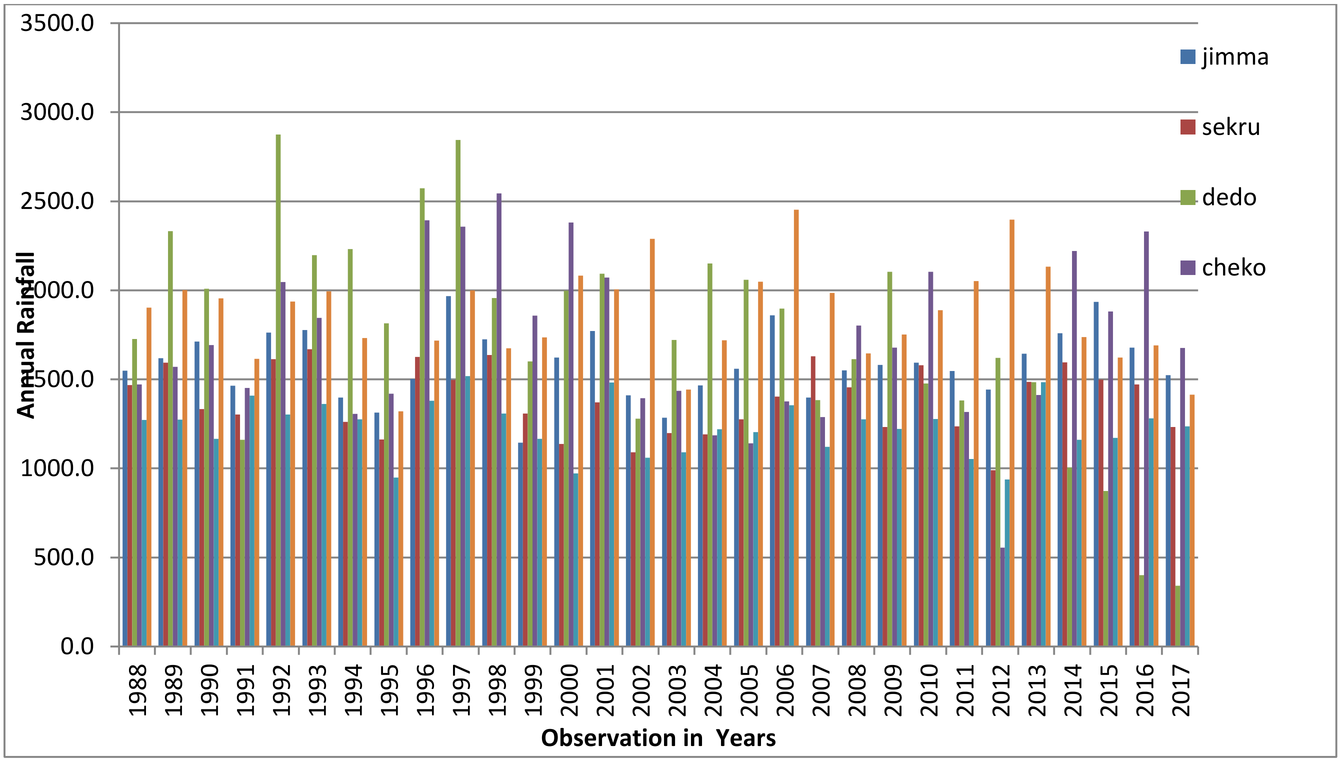



Somodo Vs Averagege 5station
y = 1505.3x + 767.31
$R^2 = 0.9989$
Accumulated rainfall of Somodo
50000.00
45000.00
40000.00
35000.00
30000.00
25000.00
20000.00
15000.00
10000.00
5000.00
0.00
0
5
10
15
20
25
30
35
Accumulated annual rainfall for average satation


Somodo Vs Averagege 5station
y = 1505.3x + 767.31
$R^2 = 0.9989$
Accumulated rainfall of Somodo
50000.00
45000.00
40000.00
35000.00
30000.00
25000.00
20000.00
15000.00
10000.00
5000.00
0.00
0
5
10
15
20
25
30
35
Accumulated annual rainfall for average satation



Gildel Gibe I Catchment annual rainfall



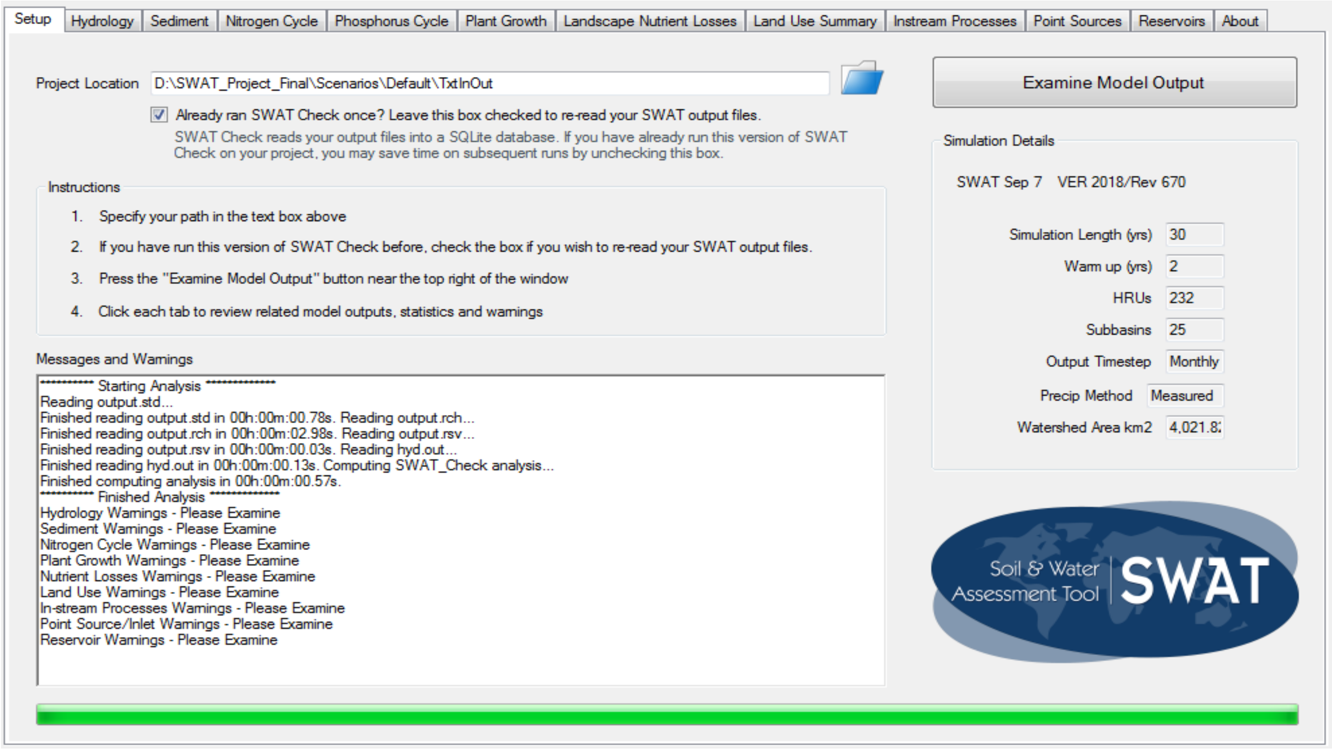
Appendix III

Area covered by land use, soil and slope

```
                                                             Area [ha]           Area[acres]
Watershed                                                   402181.7749          993811.2748

                                                             Area [ha]           Area[acres] %Wat.Area
LANDUSE:
               Agricultural Land-Close-grown --> AGRC       297712.3156          735662.0175     74.02
                                     Pasture --> PAST        12048.2419           29771.8081      3.00
                                      Coffee --> COFF         6143.9589           15182.0295      1.53
                   Agricultural Land-Generic --> AGRL        14389.6629           35557.5765      3.58
                            Forest-Deciduous --> FRSD        28560.8620           70575.3180      7.10
                                Forest-Mixed --> FRST        41477.5396          102493.0742     10.31
                           Forest-Evergreen --> FRSE          1849.1941            4569.4510      0.46

SOILS:
                                          To6-2bc-257       302901.8634          748485.6495     75.31
                                           Be49-3c-20        43656.9742          107878.5661     10.86
                                          Ne12-3b-156        32811.0526           81077.7515      8.16
                                            Bh4-2c-34         9969.2734           24634.5731      2.48
                                          Ne13-3b-158        10550.6897           26071.2817      2.62
                                           Be48-3c-18         2291.9216            5663.4529      0.57

SLOPE:
                                              15-9999       220747.3445          545477.7256     54.89
                                                 8-15       128290.4444          317012.1027     31.90
                                                  5-8        35287.6539           87197.5571      8.77
                                                  2-5        17317.5777           42792.6005      4.31
                                                  0-2          538.7544            1331.2890      0.13
```

Appendix IV

Output of Arc swat model by Arc swat model checker software



Project Location: D:\SWAT_Project_Final\Scenarios\Default\TxtInOut

☑ Already ran SWAT Check once? Leave this box checked to re-read your SWAT output files.

SWAT Check reads your output files into a SQLite database. If you have already run this version of SWAT Check on your project, you may save time on subsequent runs by unchecking this box.

Instructions

1. Specify your path in the text box above
2. If you have run this version of SWAT Check before, check the box if you wish to re-read your SWAT output files.
3. Press the "Examine Model Output" button near the top right of the window
4. Click each tab to review related model outputs, statistics and warnings

Messages and Warnings

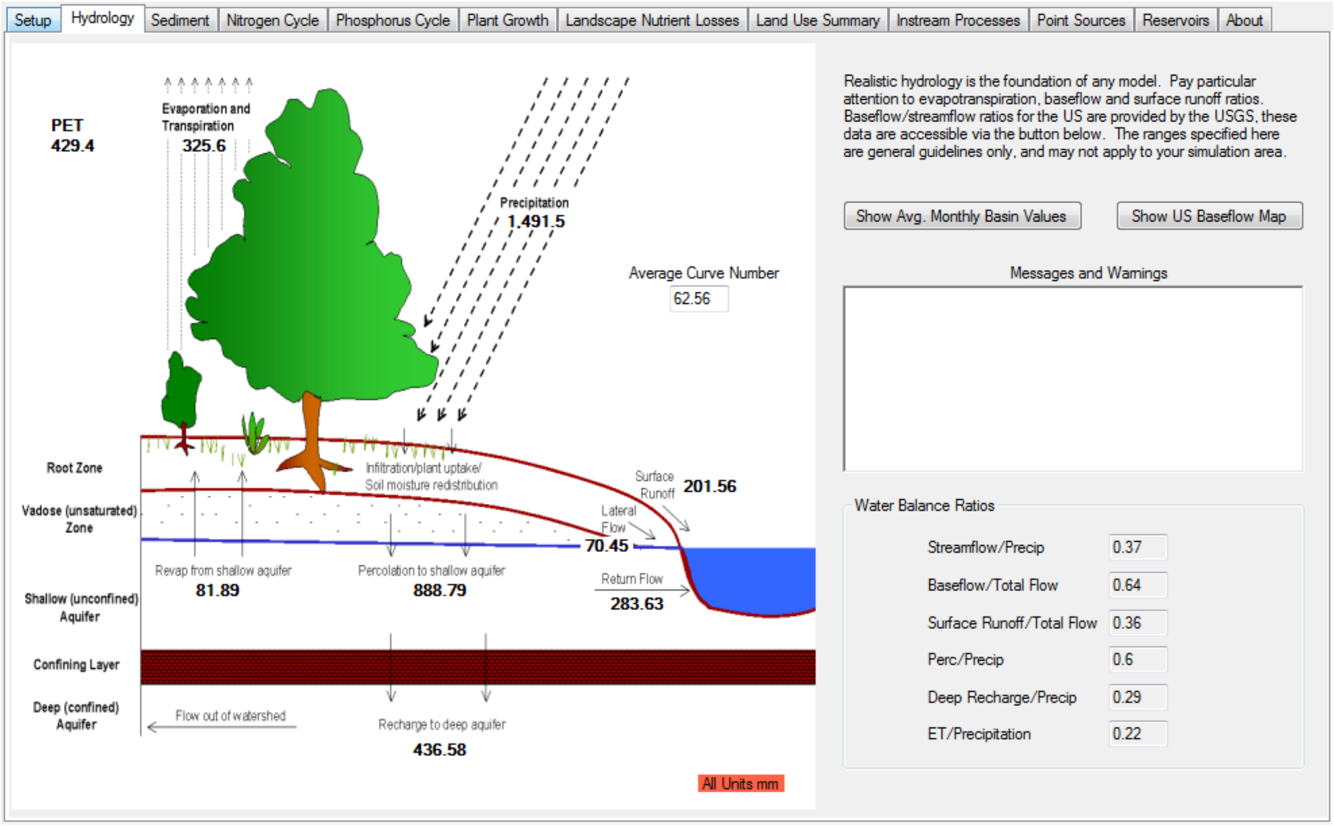
```
********** Starting Analysis **************
Reading output.std...
Finished reading output.std in 00h:00m:00.78s. Reading output.rch...
Finished reading output.rch in 00h:00m:02.98s. Reading output.rsv...
Finished reading output.rsv in 00h:00m:00.03s. Reading hyd.out...
Finished reading hyd.out in 00h:00m:00.13s. Computing SWAT_Check analysis...
Finished computing analysis in 00h:00m:00.57s.
********** Finished Analysis **************
Hydrology Warnings - Please Examine
Sediment Warnings - Please Examine
Nitrogen Cycle Warnings - Please Examine
Plant Growth Warnings - Please Examine
Nutrient Losses Warnings - Please Examine
Land Use Warnings - Please Examine
In-stream Processes Warnings - Please Examine
Point Source/Inlet Warnings - Please Examine
Reservoir Warnings - Please Examine
```

Simulation Details

SWAT Sep 7 VER 2018/Rev 670

Simulation Length (yrs): 30
Warm up (yrs): 2
HRUs: 232
Subbasins: 25
Output Timestep: Monthly
Precip Method: Measured
Watershed Area km2: 4,021.8

General SWAT model result of Gilgel Gibe watershed hydrology



Realistic hydrology is the foundation of any model. Pay particular attention to evapotranspiration, baseflow and surface runoff ratios. Baseflow/streamflow ratios for the US are provided by the USGS, these data are accessible via the button below. The ranges specified here are general guidelines only, and may not apply to your simulation area.

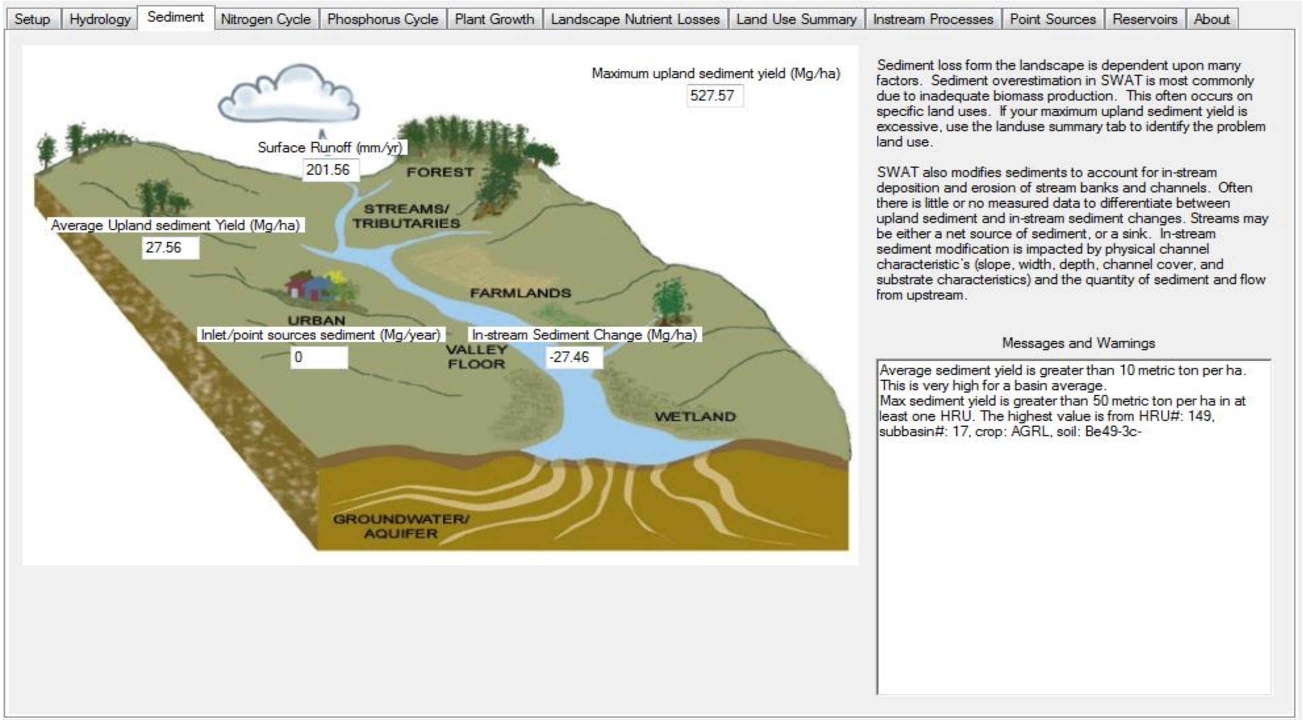
Average Curve Number: 62.56

Messages and Warnings

Water Balance Ratios

Streamflow/Precip	0.37
Baseflow/Total Flow	0.64
Surface Runoff/Total Flow	0.36
Perc/Precip	0.6
Deep Recharge/Precip	0.29
ET/Precipitation	0.22

General SWAT model result of Gilgel Gibe watershed sediment



Maximum upland sediment yield (Mg/ha): 527.57

Surface Runoff (mm/yr): 201.56

Average Upland sediment Yield (Mg/ha): 27.56

Inlet/point sources sediment (Mg/year): 0

In-stream Sediment Change (Mg/ha): -27.46

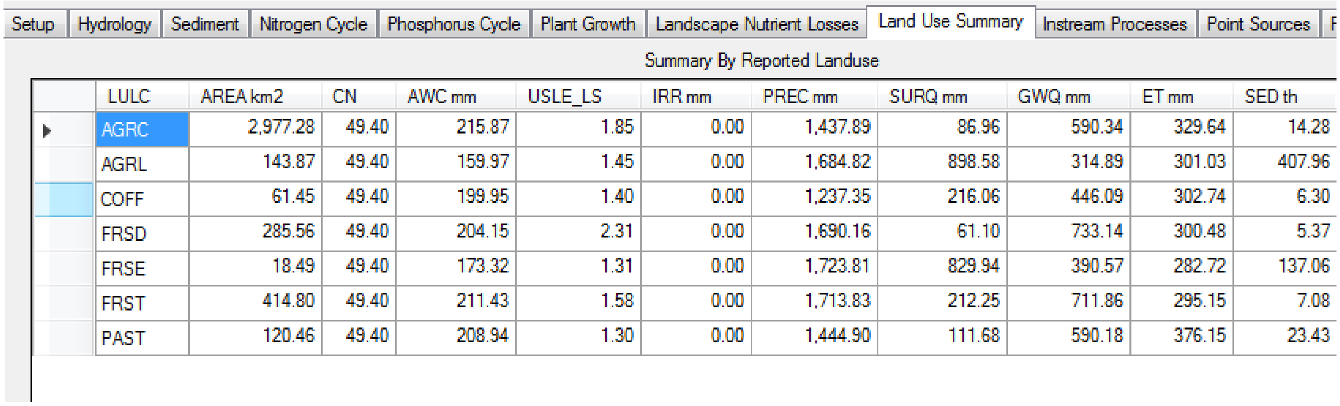
Sediment loss form the landscape is dependent upon many factors. Sediment overestimation in SWAT is most commonly due to inadequate biomass production. This often occurs on specific land uses. If your maximum upland sediment yield is excessive, use the landuse summary tab to identify the problem land use.

SWAT also modifies sediments to account for in-stream deposition and erosion of stream banks and channels. Often there is little or no measured data to differentiate between upland sediment and in-stream sediment changes. Streams may be either a net source of sediment, or a sink. In-stream sediment modification is impacted by physical channel characteristic's (slope, width, depth, channel cover, and substrate characteristics) and the quantity of sediment and flow from upstream.

Messages and Warnings

Average sediment yield is greater than 10 metric ton per ha. This is very high for a basin average.
Max sediment yield is greater than 50 metric ton per ha in at least one HRU. The highest value is from HRU#: 149, subbasin#: 17, crop: AGRL, soil: Be49-3c-

General SWAT model result of Gilgel Gibe watershed land use summery



Summary By Reported Landuse

LULC	AREA km2	CN	AWC mm	USLE_LS	IRR mm	PREC mm	SURQ mm	GWQ mm	ET mm	SED th
AGRC	2,977.28	49.40	215.87	1.85	0.00	1,437.89	86.96	590.34	329.64	14.28
AGRL	143.87	49.40	159.97	1.45	0.00	1,684.82	898.58	314.89	301.03	407.96
COFF	61.45	49.40	199.95	1.40	0.00	1,237.35	216.06	446.09	302.74	6.30
FRSD	285.56	49.40	204.15	2.31	0.00	1,690.16	61.10	733.14	300.48	5.37
FRSE	18.49	49.40	173.32	1.31	0.00	1,723.81	829.94	390.57	282.72	137.06
FRST	414.80	49.40	211.43	1.58	0.00	1,713.83	212.25	711.86	295.15	7.08
PAST	120.46	49.40	208.94	1.30	0.00	1,444.90	111.68	590.18	376.15	23.43

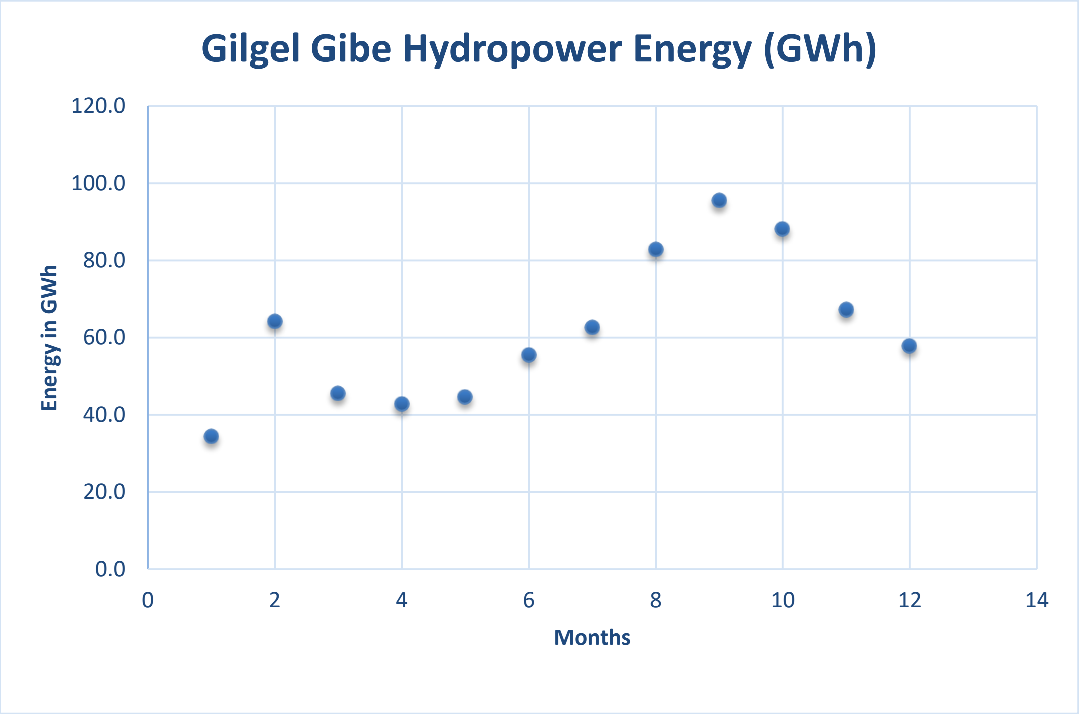
Appendix V

Average Monthly Basin Values of Gilgel Gibe I Catchment

MON	RAIN	SURF Q	LAT Q	Water Yield	ET	SED Yield	PET
mm	mm	mm	mm	mm	mm	T/HA	mm
1	29.43	1.56	2.03	45.95	21.17	0.82	39.66
2	36.96	2.30	2.59	34.50	21.41	1.53	38.46
3	96.48	6.43	7.56	45.05	37.37	2.11	42.54
4	137.58	10.88	13.19	63.39	36.63	2.15	38.46
5	169.01	14.86	17.67	89.99	35.31	2.40	38.63
6	214.82	19.66	24.21	119.88	26.91	2.89	31.41
7	224.76	20.56	27.92	151.58	20.99	3.05	23.85
8	226.29	22.31	28.56	170.76	23.05	4.04	25.61
9	181.42	18.13	22.82	161.24	27.38	3.97	31.20
10	97.58	9.92	12.06	128.92	29.12	2.61	39.93
11	47.12	4.61	5.06	87.38	23.16	1.48	39.15
12	29.71	1.96	2.50	62.02	21.09	0.64	40.18

Appendix VX

Energy Generation for Gilgel Gibe I in GWh for power plant



Appendix VII

Landslide causing damage to cropland and source of sedimentation in the catchment(PHE,2010)

Domestic Animal Grazing and Agricultural Plough in the Buffer Zone