JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING
HYDRAULIC ENGINEERING MASTERS PROGRAM

ESTIMATION OF POTENCIAL HYDROPOWER USING GIS AND SOIL & WATER ASSESSMENT TOOL ON DIDESSA SUB-BASIN, ETHIOPIA

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES
OF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN
HYDRAULIC ENGINEERING

BY
TUFA FUFA

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APPROVAL PAGE

This thesis entitled with Estimation of Potential Hydropower Using GIS and Soil & Water Assessment Tool on Didessa Sub-Basin has been approved by the following advisors, department head, and Coordinator and Director of Graduate studies in partial fulfillment of the requirement of the degree of Master of Science in Hydraulic Engineering.

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ABSTRACT

Hydropower development is the urgent need of the Ethiopia to mitigate the current power and energy crisis made due to industrial and technological development in the country. The basic things for the development of water resources in the country is the availability of accurate and reliable information about the resources. Ethiopia is rich in water resources but, lacks the reliable information about the hydro potential.

Water resource is the main important natural resource for the hydropower and other water based development and needs to managed and controlled carefully.

The main objective of the study was to estimate the river discharge in Didessa sub-basin using SWAT hydrologic model and use the calibrated and validated model to estimation of stream flow for the development of hydropower in the sub-basin.

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SWAT model set up was done, using readily available spatial and temporal data, after Projecting all spatial data like DEM, land use and soil digital map data and select catchment/watershed outlet location at *the Didessa-Abay confluence.*

The calibration and validation was done by SWAT-CUP SUFI2 program and the statistical parameters like RSR, NSE, PBIA and R^2 *were used for calibration and validation process.*

The calibrated and validated of SWAT simulate was then used as the discharge to estimate hydropower potential. For estimation of hydropower potential, available head was extracted from the longitudinal profile of the river by ArcGIS toolbox from the stream network using DEM data as a surface for selected sub-basin.

The power was estimated using discharge at each selected sub-basin outlet and estimated head from extracted longitudinal profile elevation drop. The total power was calculated by adding all power at each sub-basin and gives ***1773.5MW****.*

Key words: *ArcGIS, ArcSWAT, SWAT-CUP, SUFI-2, ROR, Hydropower.*

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LIST OF ACRONYM

CN	Curve Number
DEM	Digital Elevation Model
ESCO	Soil evaporation compensation factor
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographical Information System
GPS	Geographical Positioning System
GTZ	German Agency for Technical Support.
HEC-HMS	Hydraulic Engineering Centre- Hydrologic Modeling System
HRU	Hydrological Response Unit
HRUs	Hydrologic Response Units.
LULC	Land Use Land Cover.
MoWIE	Ministry of Water Irrigation and Energy
NMSA	National Metrological Service Agency
NSE	Nash Sutcliff Efficiency
pcpSTAT	Precipitation Statistics
PET	Potential Evapotranspiration
R2	Coefficient of Determination
ROR	Run-off River
SCS	Soil Conservation System
SPSS	Statistical Package for Social Science.
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool
USDA-ARS	United States Department of Agriculture-Agriculture Research Service
UTM	Universal Transverse Mercator
WGN	Weather generator station.

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CHAPTER ONE: INTRODUCTION

Historically, Ethiopia has been known the '*water tower of horn of Africa'* having enormous amount of water source. Water resource is the main important natural resource for the development of hydropower and other water based development like irrigation, domestic water supply, hydro-power development etc.

Hydropower development is the urgent need of the Ethiopia to mitigate the current power and energy crisis. Because of the increasing demand of electricity in all Ethiopia including big cities like Addis Ababa. The basic things for the development of hydropower in the country is the availability of accurate and reliable information about the water resources. Ethiopia is rich in water resources but, lacks the reliable information about the hydro potential

The government has large expansion plans for large hydropower plants to reduce energy shortages and to eventually become an energy exporter using potential water resource of the country (Awulachew & Yilma, 2009).

Different national and international agencies are very interested in hydropower development in Ethiopia because of the country has good surface and ground water resource to generate hydro-power, but until now there exist unreliable information about the surface and ground water resource in the country(Molla, 2015). For the development of hydropower, it is very important to know the true information about Water resource. Some studies suggest that the theoretical potential of hydropower in Ethiopia is estimated to be 30,000-45,000 MW which would enable an annual energy of 160,000 GWh. The economically exploitable hydropower potential is estimated to be between 15,000 and 30,000 MW. Large hydro power makes up 98% of Ethiopia's power production(Molla, 2015)

The Blue Nile contributes 62% of the total Nile flow reaching the Aswan Dam in Egypt. Flow in the Abay River averages approximately 48 billion cubic meters (Bm3) at the Sudan border, equivalent to average annual runoff from the catchment of 260 mm and a runoff coefficient of approximately 14%. The Abay River is perennial, but more than 80% of annual average runoff occurs in just four months (July-October) with less than 1% in April(Robyn et al., 2010).

Didessa River is one of the largest sub-basin of the Abay basin in terms of volume of water, contributing roughly a quarter of the total flow as measured at the Sudan border(BCEOM, 1998)

Despite the fact that the Didessa sub basin provides the largest amount of the Blue Nile River flows and is comparatively well equipped with lengthy hydrological and meteorological data series, most studies related to the Blue Nile River have focused on the northern part of the Blue Nile Basin which makes Didessa sub-basin less studied area(Sima and Bizuneh, 2011)

Hydrological Model was used for this thesis study to estimate the catchment discharge for the feasibility of hydropower development to change previous condition in Didessa sub-basin.

Hydrological models are nowadays become the vital tool to study and understand hydrologic processes on very large and complex catchments even for ungauged catchment(Srinivasan et al., 1998).

SWAT is a physically based, continuous time and a river basin or watershed scale model for long term simulation. Water balance is the driving force behind everything that happens in a watershed to accurately predict the hydrological cycle, sediment or nutrient movement through the catchment(Arnold et al., 2011).

All-important data are collected using secondary data collection techniques like online data and data from organization. DEM/SRTM are collected from internet, land use/land cover, soil digital map and stream flow data from Ministry of Water, Irrigation and Energy and weather data (i.e. precipitation/rainfall, temperature, humidity, wind speed and solar radiation) from National Metrologic Agency.

All-important procedures or methodologies were undergone starting from raw data processing up to the hydropower potential estimation. Raw spatial data process was done by ArcGIS and Global mapper. Tabular data were processed using statistical software's like excel sheet, origin pro, pcpSTAT, DewPoint, automated base flow separator.

SWAT hydrologic model were used for hydrologic simulation of all hydrologic using semi-processed special and temporal data. SWAT model set up was done after selecting catchment/watershed outlet at River gauge station location.

The sensitivity analysis was done to identify the most controlling parameter of flow simulation process. The simulated value then was compared with observed value to Calibrate and validate the model using manual SWAT calibration and Uncertainty Program (SWAT-CUP). The statistical parameter like Observations Standard Deviation, Nash-Sutcliffe Efficiency, Percent bias and Co-efficient of Determination were used to calibrate and validate the simulated value of flow to use simulated flow data for hydropower development.

For estimation of hydropower potential of the site, available head was extracted from the longitudinal profile of the river ArcGIS using DEM data.

1.1 Statement of the Problem

Electrification is the major problems on the Ethiopian, because of the increasing demand of electricity in all country including rural areas for domestic use as well big cities like Ababa; although the country has good theoretical surface and ground water resource.

The demand for electric energy increase from time to time due to natural degradation in rural areas and increase of modernization in urban areas(Ministry, 1997).

Only having enormous amount of water resource is meaningless without using it in the proper manner for the development of the country. For the use of water resource, the study of catchment characteristic like catchment geomorphology, topology and hydrology are the important things that every individual and organization would have to done.

Catchment Discharge highly affects the hydropower development in that hydropower is the function of stream flow and available height. Thus, the study of catchment hydrology is one of the most crucial for hydropower development.

1.3 Significance of the Study

- On-site monitoring can be time-consuming, labor-intensive, and expensive. Therefore, the use of simulation models has become viable and cost-effective, although the model should be capable and reliable to describe hydrologic processes in various hydrologic conditions
- Hydrological models have become vital tools for understanding hydrologic processes at the catchment level and are used extensively for hydrologic predictions complex watershed.
- SWAT Model is physical based hydrologic model, in performing surface runoff and sub-surface flow including deep percolation, not only small watershed, but also for large and complex catchments.
- Use of SWAT model will be efficient and effective economically and perform with limited time to estimate catchment discharge then on site measurement.

1.4 Scope of the study

- The scope of this research gone only up to the extent of estimating stream discharge using SWAT model as hydrologic model to estimate stream flow and then estimation of hydropower potential.
- The selection of hydropower plant was also based on availability of head and discharge in the river as well as time cost/ budget for detail study

1.5 Objectives

1.5.1 General objective

- ✓ Estimating stream flow using GIS and SWAT model for hydropower development in Didessa sub-basin.

1.5.2 Specific Objectives

- ✓ Estimating stream flow using Soil and Water Assessment Tool(SWAT).
- ✓ Estimation of potential head drop at specific sub-basin from the DEM of the area.
- ✓ Estimation of potential hydropower after selection of specified hydropower plant.

CHAPTER TWO: LITERATURE REVIEW

2.1 Previous studies

Tena et al., (2015) On the study of "Assessment of Spatio-Temporal Occurrence of Water Resources in Didessa Sub-Basin"; the monthly and annual stream flow of the main stem of Didessa River and its major tributaries has been predicted by a SWAT hydrologic model, a model which performed very well. Besides, the monthly and annual precipitation and evapotranspiration have been predicted. Although the values of the parameters which have been predicted by SWAT in this study are somewhat different from those reported by previous investigators, the values of the statistical parameters which are often employed to test the predicting efficiency of SWAT model clearly indicate that the results of the present study are quite acceptable.

The study also showed that in data scarce areas, the use of satellite data from Climate Forecast System Reanalysis (CFSR) grids in conjunction with datasets from a few conventional weather monitoring stations can give reliable results of monthly and annual stream flow and other weather parameters. Thus, even though dataset from conventional meteorological stations are still more desirable for greater accuracy and reliability, data scarcity may no longer hinder watershed hydrologic modeling exercises in such areas as Didessa Sub-basin(Tena Bekele et al., 2015)

Sintayehu et al., (2015) by their study on Assessment of the Impacts of Climate Change on Water Resources Availability and The Hydrology Regime of Didessa Catchment; assured that it is possible to use ECHAM 5 GCM output for climate projection for Blue Nile River basin future projection of temperature and evapotranspiration results showed an increase trend in both future periods. At 2030`s and 2090`s average seasonal and annual precipitation increases over the catchment as compared to the base period. Maximum precipitation percentage change projected during summer season(Sintayehu Legesse et al., 2015).

According to the study a change in temperature and precipitation due to climate change has significant impacts on the amount of runoff. Generally, average monthly and seasonal runoff projection showed that runoff increases in most of the months, especially during summer seasons. Average annual runoff may increase by +131% and by +124% at 2030`s and 2090`s respectively. The projected increase of runoff associated with the increase in precipitation over the catchment in both future periods. The results shown in this research were similar to the output presented using different GCM out puts including ECHAM GCM the only difference is they used at River basin scale where as we used at catchment scale.

This study concludes that the future water resources availability in the catchment will not be under stressed by the climate change in meeting the water resources development. Hence, the surrounding community in the future will be more secured under climate change.

Yohannes (2007) Assessed Water Resource Potential for Lake Tana Basin Based on Remote Sensing Data: on the aim of improving hydrological description of Lake Tana basin and thus contributes towards integrated water Resource management (IWRM). The study makes the use of remote sensing techniques for hydrologic components of water balance estimation.

Satellite derived parameters have been used for evaporation estimation, satellite based rainfall estimates have been validated with recorded data and land cover information has been obtained from moderate resolution optical images. Penman-Monteith method for evapotranspiration estimation, HEC-HMS for flood hydrograph (SCS and SWAT curve number) and soil water balance method for runoff estimation were used in the study. The authors presented that major impact of land use/land cover change on runoff estimation in Lake Tana basin need to be carefully identified. The authors concluded the goodness of soil water balance method for un-gauged catchment for runoff estimation in Lake Tana sub basin(Yohannes, 2007).

Gutema (2015) on his study of Morphometric Analysis to Identify Erosion Prone Areas On the Didessa and Jemma Sub-Basin; reveals that Geographic Information System (GIS) and Remote Sensing Data and techniques play a vital role for the preparation of updated drainage map and evaluation of morphometric parameters. GIS based approach facilitated analysis of different morphometric parameters, provides efficient way of handling spatial data and enhances the exploration of the relationship between drainage morphometry and several terrain attributes such as the nature of bedrock, infiltration capacity, runoff, etc.

The morphometric analysis carried out by classifying the basin in to four watersheds shows that there is slight difference in their morphology and morphometric aspects.

Finally, he recommends that similar studies in conjunction with high resolution elevation data should be carried out in better understanding the characteristics of river basins in the rest of Ethiopia for efficient planning and management(Gutema, 2015).

Tsedalu Ayele (2015) by His study on Hydrological Responses to Land Use and Land Cover Changes of Ribb River Watershed; He revealed that hydrologic simulation models are very essential way used to assess hydrological characteristics of watershed. They are efficient tools for evaluating effects and impacts that occur in hydrologic regime. They can be used to find out, predict and understand what happened and will happen throughout a basin in time and space. He concluded that SWAT2009 is an effective tool in analyzing the impacts of land use/cover changes on stream flow and sediment yield and the ability of SWAT to adequately predict stream flows and sediment yield was evaluated through sensitivity analysis, model calibration, and model validation.

The model was successfully calibrated and validated for both stream flow and sediment yield of Ribb watershed using SUFI2 algorithms. According to the author, SUFI-2 algorithm is an effective method but it requires additional iterations as well as the need for the adjustment of the parameter ranges. The model evaluation statistics for stream flows and sediment yield prediction gave good results that was verified by Nash Sutcliff efficiency NSE > 0.5 and coefficient of determination R^2 >0.60. The most sensitive parameter for stream flow in Ribb catchment was the initial SCS curve number II (Cn2) and for sediment yield generation was USLE equation support practice (USLE-P). The hydrological model, SWAT simulates the flow and sediment in a better way with satisfactory (R2, NSE) (0.79, 0.78), (0.7, 0.68) for flow calibration and validation and (R2, NSE) (0.77, 0.71), (0.72, 0.72) for sediment calibration and validation respectively.

Three land use/cover change scenarios are developed to analyze the impact of land use/cover changes to the hydrological regime. Base scenario: current land use practices, scenario1: shrub and bush lands completely changed to forest land and scenario2: Grass land changed to cultivated land. The base scenario or current land use practice has cultivated land, grass land, Hydrological Responses to land use/land cover changes of Ribb River watershed, upper Blue Nile, Ethiopia shrub and bush land, and forest land, built up area and water body.

The model result for different land use scenarios in the study are showed that the wet season flow increases for the study period, while the dry season flow decreases significantly. This is mainly attributed to land use scenario2 conversion of grass land, shrub land in to cultivated land areas which in turn increased surface runoff during wet seasons and reduced base flow during the dry seasons. It is also concluded that as the peak flow increases it is suspected of carrying more sediment which makes the increasing of Lake Tana level and water more turbid. The annual average simulated stream flow for base scenario, scenario1 and scenario2 was 40.11,40.48 and 41.13 m3/s respectively and also the annual average simulated sediment yield for base scenario, scenario1 and scenario2 was 14.49, 14.47 and 21.15 ton/ha respectively(Tsedalu, 2015).

Therefore, it can be deduced that LULC impact for the study area might be the most sensitive than the propagated uncertainty on catchment flow. The rapid expansion of agriculture, deforestation and high population growth in the area resulted in high rate of soil erosion in the catchment area. Degradation of the catchment has affected the flow characteristics in the catchment as observed from increase in surface runoff and decreasing base flow.

The continuation of the land use/land cover change is becoming a serious threat to the Ribb catchment. The land use/land cover change should be controlled in the catchment and some appropriate measures should be taken for the stabilization of the land cover change. The calibrated model can be used for further analysis of the effect of climate and land use change as well as to investigate the effect of different management scenarios on stream flows and sediment yields. The output of this study can help planners, decision makers and other different stakeholders to plan and implement appropriate soil and water conservation strategies.

2.2 Hydrologic Cycle

Water circulates in the hydrosphere through the network of paths forming the hydrologic cycle. The hydrologic cycle is the central focus of hydrology. The cycle has no beginning or end, and its continuous processes. Water evaporates from the oceans and the land surface to become part of the atmosphere; water vapor is transported and lifted in the atmosphere until it condenses and precipitates on the land or the oceans; precipitated water may be intercepted by vegetation, become overland flow over the ground surface, infiltrate into the ground, flow through the soil as subsurface flow, and discharge into streams as surface runoff. Much of the intercepted water and surface runoff returns to the atmosphere through evaporation. The infiltrated water may percolate deeper to recharge groundwater, later emerging in springs or seeping into streams to form surface runoff, and finally flowing out to the sea or evaporating into the atmosphere as the hydrologic cycle continues(Chow et al., 1988)

Estimating the total amount of water on the earth and in the various processes of the hydrologic cycle has been a topic of scientific exploration since the second half of the nineteenth century.

However, quantitative data are scarce, particularly over the oceans, and so the amounts of water in the various components of the global hydrologic cycle are still not known precisely(Han, 2010).

In estimation about 96.5 percent of all the earth's water is in the oceans. If the earth were a uniform sphere, this quantity would be sufficient to cover it to a depth of about
2.6 km (1.6 mi). Of the remainder, 1.7 percent is in the polar ice, 1.7 percent in groundwater and only 0.1 percent in the surface and atmospheric water systems.

The atmospheric water system, the driving force of surface water hydrology, contains only 12,900 km3 of water, or less than one part in 100,000 of all the earth's water(Williamson, 2001).
Of the earth's fresh water, about two-thirds is polar ice and most of the remainder is groundwater going down to a depth of 200 to 600 m. Most ground-water is saline below this depth. Only 0.006 percent of fresh water is contained in rivers. Biological water, fixed in the tissues of plants and animals, makes up about 0.003 percent of all fresh water, equivalent to half the volume contained in rivers.
Although the water content of the surface and atmospheric water systems is relatively small at any given moment, immense quantities of water annually pass through them. The global annual water balance shows the major components in units relative to an annual land precipitation volume of 100. It can be seen that evaporation from the land surface consumes 61 percent of this precipitation, the remaining 39 percent forming runoff to the oceans, mostly as surface water. Evaporation from the oceans contributes nearly 90 percent of atmospheric moisture. Analysis of the flow and storage of water in the global water balance provides some insight into the dynamics of the hydrologic

cycle.

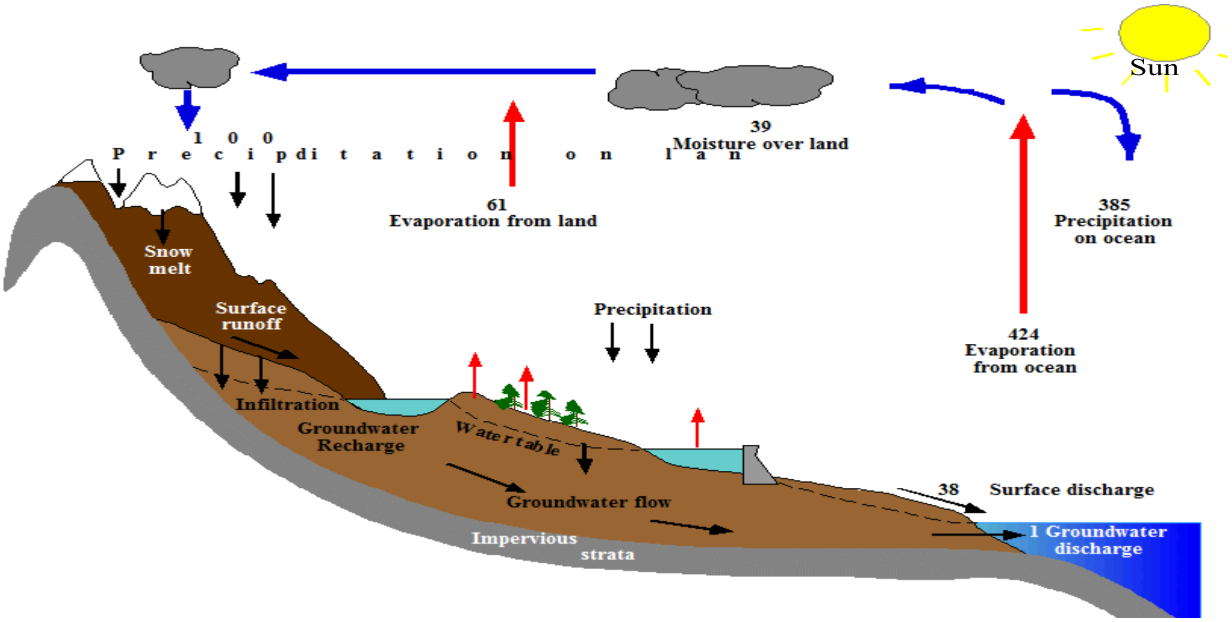


Figure 2.1: Hydrologic/Water cycle Source(Johansson,1994)

2.2 Catchment Discharge:

2.2.1 Definition and Concepts

A catchment is a basin shaped area of land, bounded by natural features such as hills or mountains from which surface and sub-surface runoff (due to a storm) water flows into streams, rivers and wetlands. Water flows into, and collects in, the lowest areas in the landscape. The system of streams which transport water, sediment and other material from a catchment is called a drainage network(Timo A. Räsänen and Kummu, 2013).

Catchment is the structure beyond the stream, and is the land areas surrounding the stream from where all the flows such as runoff and floods including sediment are coming from to join the stream or river.

Catchment discharge is the flows coming from all the area of the catchment in the form of surface and /sub-surface flows due to snow, ice melt and/or rain falling on the watershed area. A catchment catches water which falls to earth as precipitation (rainfall), and the drainage network channels the water from throughout the catchment to a common outlet. The outlet of a catchment is the mouth of the main stream or river. The mouth may be where it flows into another river or stream, or the place where it empties into a lake, estuary, wetland or ocean(Pieter van der Zaag and Kammer, 2005)

The single point or location at which all surface drainage from a basin comes together or concentrates as outflow from the basin in the stream channel is called *concentration point* or *measuring point*, since the stream outflow is usually measured at this point.

The time required for the rain falling at the most distant point in the drainage area (i.e., on the fringe of the catchment) to reach the concentration point is called the concentration time.
This is a very significant variable since only such storms of duration greater than the time of concentration will be able to produce runoff from the entire catchment area and cause high intensity floods(H.M.Ranghunath, 2006).

2.2.2 Catchment characteristics

The characteristics of the drainage basin may be physically described by the followings(Johansson, 1994):

1. *The number of streams* or stream density of a drainage basin is expressed as the number of streams per square kilometer.

$$\mathrm{Ds} = \frac{\mathrm{Ns}}{\mathrm{A}} \qquad (1)$$

Where N_s = number of streams

A = area of the basin/catchment

2. *The length of streams*
3. *Stream density*
4. *Drainage density*(D_s) which is expressed as the total length of all stream channels (perennial and intermittent) per unit area of the basin and serves as an index of the areal channel development of the basin

$$D_s = \frac{L_S}{A} \qquad (2)$$

Where L_s – total length of all stream channels in the basin.

A - area of the basin/catchment

- ✓ Compactness coefficient $\mathrm{Cc} = \frac{Pb}{2\sqrt{\pi A}}$ where P_b is the perimeter of the basin; is circumference of circular area, which equals the area of the basin.

If R is the radius of an equivalent circular area, $A = \pi R^2$, or $R = \sqrt{\frac{A}{\pi}}$

The compactness coefficient is independent of the size of the catchment and is dependent only on the shape.

A fan- shaped catchment produces greater flood intensity since all the tributaries are nearly of the same length and hence the time of concentration is nearly the same and is less,

Where as in the fern (leaf*)*-shaped catchments, the time of concentration is more and the discharge is distributed over a long period(H.M.Ranghunath, 2006).

2.2.3 Importance of estimating Catchment discharge.

When rain starts falling, first of all it is intercepted by trees, buildings and other object which prevent rainfall to reach the ground these are very small but depends on land use and land cover of the catchment. All of the rainfall reaching the ground will also not be part of the runoff, some which are infiltrated into the soil and from infiltrated water some are percolated to the confined aquifer, others may be evaporated or transpired to the atmosphere and some collected to pond constructed by people for collecting roof and ditch or asphalt catchment for their domestic and agricultural uses(Guarg, 2006)

The importance of discharge estimation for specific catchment is more or less identifying the loss of water and uses water that are left for many purposes.

2.2.4 Catchment discharge estimating Models

A hydrologic model is an approximation of the actual system, with a structure that is a set of equations linking measured inputs and output variables(Chow et al., 1988). Hydrologic models can be categorized two broad classes.

1) Physically-based models that are based on solving governing equations such as conservation of mass and momentum equations.
2) Conceptual models that use simple mathematical equations to describe the main hydrologic processes such as evapotranspiration, surface storage, percolation, snowmelt, base flow, and runoff.

The next classification is deterministic and stochastic hydrological models.

2.2.4.1 Deterministic Models

Deterministic models permit only one outcome from a simulation with one set of inputs and parameter values. Deterministic models can be classified to whether the model gives a lumped or distributed description of the considered area, and whether the description of the hydrological processes is empirical, conceptual, or more physically-based. As most conceptual models are also lumped and as most physically based models are also distributed. The three main groups of deterministic models are.(Aghakouchak, 2010).

Empirical Models (black box):

Black box models are empirical, involving mathematical equations that have been assessed, not from the physical processes in the catchment, but from analysis of concurrent input and output time series. The model was a single simple equation often used for drainage design for small sub-urban and urban watersheds. The equation assumes the proportionality between peak discharge, (Qp,) and the maximum average rainfall intensity, (i_e)

$$Q_p = CR * I_e * AD \tag{3}$$

Where *AD* is drainage area and *CR* is the runoff coefficient, which depends on watershed land use The equation was derived from a simplified conceptual model of travel times on basins with negligible surface storage. The duration of the rainfall to be used in the equation is the mean intensity of precipitation for duration equal to the time of concentration and an exceedance probability of P. The model reflects the way in which discharges are expected to increase with area, land use and rainfall intensity in a rational way and hence its name *Rational Method.*

2.2.4.2 Lumped Conceptual Models (grey box):

Lumped models treat the catchment as a single unit, with state variables that represent average values over the catchment area, such as storage in the saturated zone. Due to the lumped description, the description of the hydrological processes cannot be based directly on the equations that are supposed to be valid for the individual soil columns. Hence, the equations are semi-empirical, but still with a physical basis. Therefore, the model parameters cannot usually be assessed from field data alone, but have to be obtained through the help of calibration.

2.2.4.3 Distributed Process (Physically) Description Based Models (white box)

Another approach to hydrological processes modelling was the attempt to produce models based on the governing equations describing all the surface and subsurface low processes in the catchment. A first attempt to outline the potentials and some of the elements in a distributed process description based model on a catchment scale was made by Freeze and Harlan (1969). The calculations require larger computers to solve the flow domain and points at the elements of the catchment.

Distributed models of this type have the possibility of defining parameter values for every element in the solution mesh. They give a detailed and potentially more correct description of the hydrological processes in the catchment than do the other model types. The process equations require many different parameters to be specified for each element and made the calibration difficult in comparison with the observed responses of the catchment.

In principle parameter adjustment of this type of model is not necessary if the process equations used are valid and if the parameters are strongly related to the physical characteristics of the surface, soil and rock. In practice the model requires effective values at the scale of the elements. Because of the heterogeneity of soil, surface vegetation establishing a link between measurements and element values is difficult. The Distributed Process Description Based Models can in principle be applied to almost any kind of hydrological problem. The development is increased over the recent years for the fact that the increase in computer power, programming tools and digital databases and the need to handle processes and predictions of runoff, sediment transport and/or contaminants.

Another reason is the need of the models for impact assessment. Changes in land use, such as deforestation or urbanization often affect only part of a catchment area.

With a distributed model it is possible to examine the effects of such land use changes in their correct spatial context by understanding the physical meaning between the parameter values and the land use changes.

2.2.4.4 Stochastic Time Series Models

Stochastic models allow for some randomness or uncertainty in the possible outcomes due to uncertainty in input variables, boundary conditions or model parameters. Traditionally, a stochastic model is derived from a time series analysis of the historical record. The stochastic model can then be used for the generation of long hypothetical sequences of events with the same statistical properties as the historical record. In this technique several synthetic series with identical statistical properties are generated. These generated sequences of data can then be used in the analysis of design variables and their uncertainties, for example, when estimating reservoir storage requirements.

Stochastic time series models are in reality composed of a simple deterministic core (the black box model) contained within a comprehensive stochastic methodology. So, these are the broad generic classes of rainfall-runoff models, lumped or distributed; deterministic or stochastic.

The vast majority of models used in rainfall-runoff modelling are deterministic. Simpler models still offer so wide applicability and flexibility. If the interest is in simulating and predicting a one-time series, for instance, run-off prediction, simple lumped parameter models can provide just as good simulation as complex process description based models

2.2.5 Catchment discharge estimating Methods

2.2.5.1 Rational Method

One of the most commonly used for the calculation of peak flow from small areas is the rational formula given as(S. Hajjam et al., 2005)

$$Q_p = \frac{1}{3.6} C\left(i_{tc,p}\right) A \tag{4}$$

Where, *Qp* = peak flow (m3/s)

C = dimensionless runoff coefficient

$$Weighted\ C = \frac{\sum(C_x A_x)}{A_{total}} \tag{5}$$

x = subscript designating values for incremental areas with consistent land cover

$i_{tc,p}$) = the mean intensity of precipitation (mm/h) for a duration equal to t_c and an exceedance probability p

A_{total} =A = Total drainage area in Km2

Rational method has many assumptions. Because of these inherent assumptions, the Rational Formula should only be applied to drainage areas smaller than 80 ha(J. V. Tyagi et al., 2014).

2.2.5.2 SCS Curve Number Method

The SCS (now known as NRCS) method calculates peak flow as the function of drainage basin area. Potential watershed storage and the time of concentration. This rainfall-runoff relationship separates total rainfall into direct runoff, retention and initial abstraction to yield the following equation for rainfall-runoff(Arnold et al., 2011)

$$QD = \frac{(P-0.2SR)^2}{(P+0.8SR)} \tag{6}$$

Where QD=Direct runoff depth in mm or inch

P=Depth of 24-hour precipitation

SR=Retention in mm or inch which is related to soil type, land cover antecedent moisture condition of the basin

$$SR = 25.4\left[\frac{100}{CN} - 10\right] \tag{7}$$

Where CN-curve number which depends on land use type for each hydrologic soil group.

2.2.5.3 Time-Area Method

The time – area method of obtaining runoff or discharge from rainfall can be considered as an extension and improvement of the rational method. The peak discharge *Qp* is the sum of flow – contributions from subdivisions of the catchment defined by time contours (called isochrones), which are lines of equal flow – time to the river section where Qp is required(Alemu, 2011)

2.2.5.4 Stream Flow Hydrograph

A hydrograph is a graphical plot of discharge of a natural stream or river versus time. The hydrograph is a result of a particular effective rainfall hyetograph as modified by basin flow characteristics. By definition, the volume of water under an effective rainfall hyetograph is equal to the volume of surface runoff.

The areas enclosed by the hyetograph and the hydrograph each represent the same volume, V, of water from the catchment. The maximum flow rate on the hydrograph is the peak flow, Q_p, while the time from the start of the hydrograph to Q_p is the time to peak, tp. The total duration of the hydrograph known as the base time, t_b.

The lag time, t_L is the time from the center of mass of effective rainfall to the peak of runoff hydrograph. It is apparent that tp = tL + D/2, using this definition.

Some define lag time as the time from center of mass of effective rainfall to the center of the runoff hydrograph.

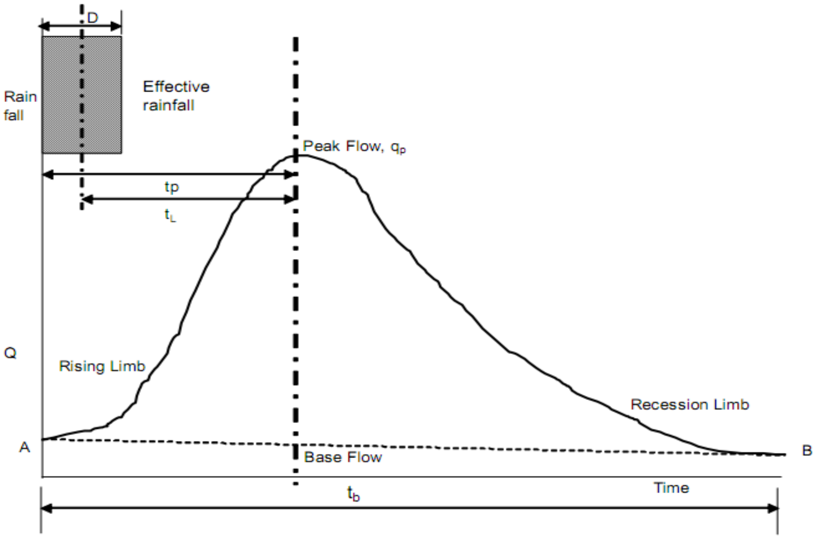


Figure 2.1: Stream hydrograph

2.2.5.5 The Unit Hydrograph (UH)

A major step forward in hydrological analysis was the concept of the unit hydrograph introduced by the American engineer Sherman in 1932.

The unit hydrograph (UH) of duration T is defined as the storm runoff due to unit depth (e.g. 1 mm rain depth) of effective rainfall, generated uniformly in space and time on the catchment in time T. The duration can be chosen arbitrarily so that we can have a 1h UH, a 6h UH, etc. in general a D-h hour unit hydrograph applicable to a given catchment.

2..2.6 SWAT Model

The SWAT (Soil and Water Assessment Tool) watershed model is one of the most recent models developed at the USDA-ARS (Arnold et al., 1998) during the early 1970s. SWAT is a potential distributed parameter and continuous time hydrological model capable of modeling watershed hydrology, irrigation and water transfer, lateral flow, ground water and detailed lake water quality components. It is semi-distributed physically based simulation model and can predict the impacts of land use change and management practices on hydrological regimes in watersheds with varying soils, land use and management conditions over long periods and primarily as a strategic planning tool(Neitsch et al., 2005).

The interface of ArcSWAT is compatible with ArcGIS that can integrate numerous available geospatial data to accurately represent the characteristics of the watershed.

In SWAT model, the impacts of spatial heterogeneity in topography, land use, soil and other watershed characteristics on hydrology are described in subdivisions. There are two scale levels of subdivisions; the first is that the watershed is divided into a number of sub-watersheds based upon drainage areas of the attributes, and the other one is that each sub-watershed is further divided in to a number of Hydrologic Response Units (HRUs) based on land use and land cover, soil and slope characteristics(Tewodros, 2012).

The SWAT model simulates eight major components: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides and agricultural management(Neitsch et al., 2005) Major hydrologic processes that can be simulated by the model include evapotranspiration, surface runoff, infiltration, percolation, shallow aquifer and deep aquifer flow, and channel routing(Arnold et al., 2011). Stream flow is determined by its components (surface runoff and ground water flow from shallow aquifer)

2.3 Hydropower Development

2.3.1 Definition and Concepts

The water of the oceans and water bodies on land are evaporated by the energy of the sun's heat and gets transported as clouds to different parts of the earth. The clouds travelling over land and falling as rain on earth produces flows in the rivers which returns back to the sea. The water of rivers and streams, while flowing down from places of higher elevations to those with lower elevations, loose their potential energy and gain kinetic energy(C. N. Emeribe et al., 2015).

The energy is quite high in many rivers which have caused them to etch their own path on the earth's surface through millions of years of continuous erosion. In almost every river, the energy still continues to deepen the channels and migrate by cutting the banks, though the extent of morphological changes varies from river to river. Much of the energy of a river's flowing water gets dissipated due to friction encountered with its banks or through loss of energy through internal turbulence. Nevertheless, the energy of water always gets replenished by the solar energy which is responsible for the eternal circulation of the Hydrologic Cycle(H.M.Ranghunath, 2006).

Hydropower engineering tries to tap this vast amount of energy available in the flowing water on the earth's surface and convert that to electricity. There is another form of water energy that is used for hydropower development: the variation of the ocean water with time due to the moon's pull, which is termed as the tide. Hence, hydropower engineering deals with mostly two forms of energy and suggest methods for converting the energy of water into electric energy. In nature, a flowing stream of water dissipates throughout the length of the watercourse and is of little use for power generation(Mosonyi, 1991).

To make the flowing water do work usefully for some purpose like power generation (it has been used to drive water wheels to grind grains at many hilly regions for years), it is necessary to create a head at a point of the stream and to convey the water through the head to the turbines which will transform the energy of the water into mechanical energy to be further converted to electrical energy by generators

Water at high pressure or flowing with a high velocity can be used to run turbines or water wheels coupled to generators, and therefore, for generation of electric power. This method of generating electric power is well established as one of the principal energy producing technologies around the world. It is widely acclaimed as the cleanest and cheapest of all energy forms. About 90% of total energy is generated from water(Emil, 1991).

The status of hydropower with respect to the total power generation varies considerably from country to country. Developing countries need affordable energy to: Increase agricultural productivity, deliver basic educational and medical services, establish adequate water supply and sanitation facilities, and Build and power new job-creating industries.

Worldwide, only 15.2% of the technically possible hydroelectric energy was developed by 1990. The following Table gives hydroelectric generation in 1990.

Table 1.1:Hydropower Status in the World According to UN estimates in 1981,

Country	Installed capacity of hydropower(mw)	Percentage of hydropower in the power system(%)
USA	90000	16
USSR	73000	19
Canada	59000	66
Brazil	57000	-
Japan	26000	27
Norway	25000	99.9
India	23000	34
France	21000	38
Italy	20000	-
Sweden	15000	-
Spain	15000	-
Switzerland	12000	-
Australia	7000	-
Ethiopia	200	88/2010

2.3.2 Hydropower Development in Ethiopia

Although there is no recorded history, the use of waterpower in Ethiopia in its non-electric form is estimated to exist since long period of time. It has been used in the water mills, and such practice is still under use in some rural areas of the country(Vorgelegt von and Saarbrücken, 2011). The water power use in its more effective form, i.e. electricity generation, came to existence in the beginning of 1930's, when *Abasamuel* hydropower scheme is commissioned in 1932. This station was capable of generating 6MW and operational up to 1970. In Ethiopia, by 1990, about 94% of the energy requirement satisfied through the traditional energy sources, and the remaining 6% through modern sources such as fuel oil, gas and electricity(Fikadu and Abdela, 2008/2009/).

According to Ministry of Mines and Energy, in 1990 the energy total requirement in Ethiopia was estimated at 177.6 TWh per year of which 76.1% from wood, 16.1% agricultural by-product, 5.3% from fuel oil and 1.1% from electricity, 0.8% from charcoal and 0.6% through others. The energy is used in the sectors of domestic in the town and rural areas, industry, service, agriculture and transport.

Ethiopia is naturally endowed with quite a substantial amount of water resource potential, even though its distribution and occurrence through time & space is erratic. Despite its abundant water resources, the section. In particular, the exploitation of the hydropower potential was not noticeably successful inspire of being given priority as a major filed of nation development.

The hydropower potential of Ethiopia is very considerable such an abundant potential is attributed to the high rainfall regimes & steep slopes of the meter's natural landscape. Most of the rivers generally drop hundreds of meters in relative short distances, especially at plateau escarpments, making them attractive to hydropower development
Hydropower development is the urgent need of the country to mitigate the current power and energy crisis. Because of the increasing demand of electricity in all Ethiopia including big cities like Addis Ababa and neighboring country,

The theoretical potential of hydropower in Ethiopia is estimated to be 30,000-45,000 MW which would enable an annual energy of 160,000 GWh. The economically exploitable hydropower potential is estimated to be between 15,000 and 30,000 MW. Large hydro power makes up 98% of Ethiopia's power production. Among Estimated energy potential of the country 85%of the total covered by the Blue Nile, Ome-Gibe & Baro basins

Table 2.2: Hydropower potential of Ethiopian river basins

River basin	**Estimated Potential GWh/year**	**%Share of the Total**
Awash	4500	2.8
Baro-Akobo	19,000	12
Blue-Nile	7900	49.5
Generale-Dawa	9,500	6
Omo-Gibe	3500	22
Riftvally lakes	1,000	0.6
Tekeze	6000	3.8
Wabi-Shebele	5500	3.4
Total	159000	100

Source: Hydropower Engineering-I Lecture Note(Fikadu and Abdela, 2008/2009/)

The government has large expansion plans for large hydropower plants to reduce energy shortages and to eventually become an energy exporter (Awulachew & Yilma, 2009)

The Blue Nile contributes 62% of the total Nile flow reaching the Aswan Dam in Egypt. Flow in the Abay River averages approximately 48 billion cubic meters (Bm3) at the Sudan border, equivalent to average annual runoff from the catchment of 260 mm and a runoff coefficient of approximately 14%. The Abay River is perennial, but more than 80% of annual average runoff occurs in just four months (July-October) with less than 1% in April.

Abay basin covers 180,000 km2 which accounts for 20% of Ethiopia's land area and is home of around 19 million (i.e., 28% of the country's) population (Awulachew & Yilma, 2009).

Flow in the Abay River averages approximately 48 billion cubic meters (Bm^3) at the Sudan border, with average annual runoff of 260 mm from the catchment and a runoff coefficient of 14% in approximation. The Abay River is perennial, but more than 80% of annual average runoff occurs in just four months (July-October) and less than 1% in April.

The Abay Basin receives on average rainfall of 1,535 mm. Rainfall varies considerably from year to year.

The mean annual temperature ranges from 5 to 30 °C depending on altitude, which makes the potential evaporation to exceeds rainfall mostly in the lowlands of the northwest ((Awulachew & Yilma, 2009)

The Didessa River is the largest tributary of the Blue Nile River in terms of volume of water, contributing roughly a quarter of the total flow as measured at the Sudan border (BCEOM, 1998)

Draining an area of nearly 34,000 square kilometers, the Didessa River originates in the

Mt. Vennio and Mt. Wache, flowing in an easterly direction for about 75 kilometers, and then turning rather sharply to the north until it reaches the Blue Nile River. The major tributaries of the Didessa River are the Wama entering from the east, the Dabana from the west, and the Anger from the east. Didessa catchment is situated in the south-west part of Blue Nile River Basin. The catchment area at a gauging station near Arjo town is 9,981 km2.

CHAPTER THREE:MATERIALS AND METHODS

3.1 Description of the study area

Didessa Sub-basin is one southwestern part of Abay basin found in Western Ethiopia. It is situated between 07^0 42’40” to 09^0 58’17” N latitude and $35^0$33’14” to $37^0$07’52” E longitude (Figure 3). Didessa is a great river of Abay basin that originates from the tropical rainforest mountains of Gomma and Guma area, where Gabba and Gojeb rivers come from, and drains big rivers of the Jimma, Illubabor and Wolega areas. The total area of the watershed is about 1, 9629.square kilometers.

The altitude in Didessa Sub-basin ranges between 618 m a.s.l at the Didessa-Abay confluence and 3,100 m.a.s.l at the source of Anger River, one of the major tributaries of Didessa River, in Abe Dongoro District of Horro Guduru Wollega Administrative Zone, Northeast of the Sub-basin. The highlands in the northeastern and southern parts of the sub-basin are higher in altitude than 2100 m.a.s.l. The lowlands, with altitudes less than 1,100 m.a.s.l are located at the eastern remote areas of Anger Sub-watershed and the northern end of the sub-basin, following the Valley of Didessa River(Tesfaye and Wondimu, 2014).

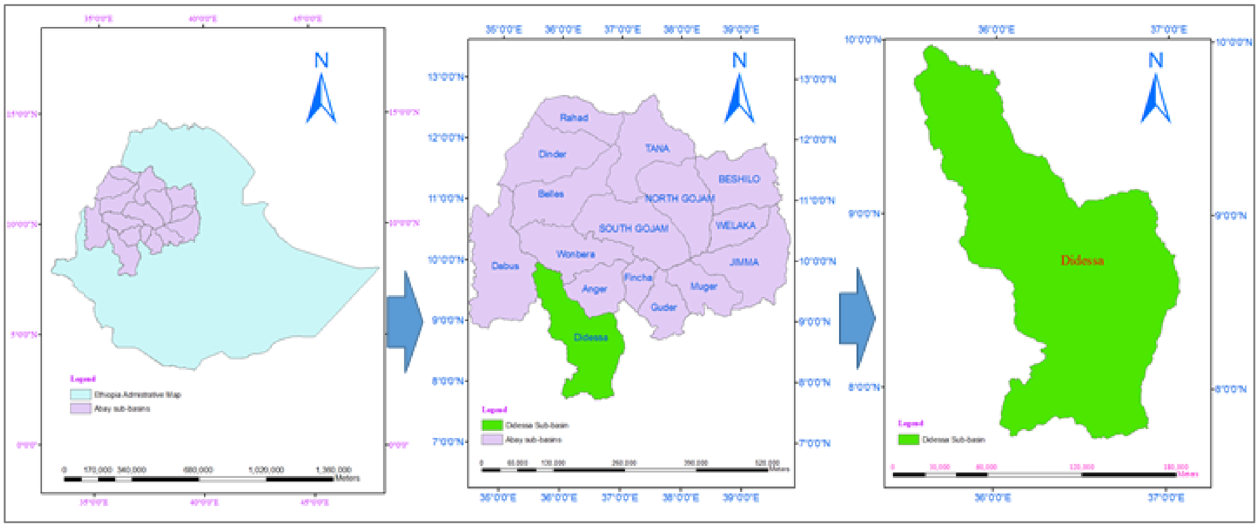


Figure 3.1: Relative location of the Didessa sub-basin

3.2 Materials

For implementation of Stream flow estimation of Didessa sub- basin to prioritize and locate Dams in the watershed for hydropower development, some equipment, materials and software are required for data collection, processing and evaluation. Some of the software and materials required for this study include the following.

A) Software Used:

1. Arc-GIS 9.3 to digitalize, and analyze some spatial and non-spatial information of the catchments of the study area.
2. Soil and Water Assessment Tool (SWAT2009) software for stream flow or catchment discharge of the sub-basin.
3. Global mapper for process of SRTM data for creation of longitudinal and cross-sectional profile of the river used for creation of power duration curve of the specified location in the river and process it for further use in ArcGIS.
4. SWAT-CUP for calibration and uncertainty analyze of ArcSWAT simulation /output data.
5. SWATPlot/ SWATGraph for graphing and comparing simulated value and observed value from the graph plot.
6. PcpSTAT and DewPoint program for processing of precipitation data and temperature for calculation of weather generator parameter of specific area of the study.
7. Map window for processing FAO soil and use as SWAT user soil database.
8. SPAW for processing soil, water, plant and air relationship and estimate some parameter for SWAT user soil database.
9. Automated base flow separator for separation of base flow from observed stream flow data collected.
10. Google Earth for visualization of extracted shape file to see the basin structure in 3D view.
11. Origin Pro, Sigma Plot, Excel sheet and SPSS for input and output data processing and management.

B) Equipment and Data

1) GPS for collection of special data like location of river gauge, outlet of the watershed.
2) SRTM 90m resolution DEM data is used as an input data for Arc-GIS software for catchment delineation and estimation of catchment characteristic
3) Hydrological data (Daily Discharge) for calibration and validation of SWAT model.
4) Meteorological data (Precipitation, Maximum & Minimum Temperature, Solar Radiation, Wind Speed and solar radiation) for ArcSWAT input Tables.
5) Digital Land use/land cover and Soil data map of the sub-basin for the analysis of HRUs.

3.3 Data collection

Two major categories of data collection methods are used for collecting necessary data and information which is primary and secondary data collection type. Most of the data for the thesis were collected by secondary data collection type and data like reservoir location. Stream flow gauge and some outlet of the watershed were collected by primary data collection type. The detail of data collection are as follows.

A) Boundary Shape File

The sub-basin boundary shape file is important to GIS spatial processing of land use/land cover, soil and digital elevation model such as clipping and masking. The Abay sub-basin boundary was obtained from Ministry of Water, Irrigation and Energy. The shape file then was projected to projected coordinate system and clipped to specific area of study using ArcGIS toolbox (Figure-6A)

B) Digital Elevation Model (DEM)

Digital Elevation Model is one of the essential spatial input data required by SWAT to delineate the watershed in to number of sub watershed or sub basins. The DEM is used to analyze the drainage pattern or stream network of the watershed, stream lengths, and widths of channel within the watershed. The raw DEM was obtained from Ministry of Water, Irrigation and Energy which was projected and masked to specific area of study using ArcGIS toolbox.

C) Land Use/Land Cover Map

The land use is one of the most important factors that affect hydrologic response unit of catchment such as runoff, evapotranspiration and surface erosion. The land use/land cover map gives the spatial extent and classification of the various land use/land cover classes of the study area(Bewket and Sterk, 2005). The land use land cover data combined with the soil cover data generates the hydrologic characteristics of the basin or the study area, which in turn determines the excess precipitation, recharge to the ground water system and the storage in the soil layers. The Land use data were obtained from ministry of water, irrigation and energy of Ethiopia. Major land use of the study area is: Agriculture, Agro-pastoral, Agro-sylvicultural, Pastoral, State Farm, Sylvicultural, Sylvo-pastoral, Traditional and Urban as shown on (Figure _6C).

Table 3.1: land use type and coverage of the study area

ID	Land Use	Area (km^2)	Area(%)
0	Agriculture	8835.903727	6
10	Agro-pastoral	20333.53862	15
20	Agro-sylvicultural	9821.224112	7
30	Pastoral	8771.118238	6
40	State Farm	5874.349694	4
50	Sylvicultural	17831.91434	13
60	Sylvo-pastoral	15590.52044	11
70	Tradition	43240.03	31
80	Urban	9348.267874	7

D) Soil Digital Map Data

The soil data as required by ArcSWAT to predict the stream flow. Since hydrologic response unit of catchment also affected by soil physical and chemical properties; The shape file format of soil type distribution through the catchment was obtained from Ministry of Water, Irrigation and Energy (MoWIE,2016). Major soil of study area includes Dystric Leptosols, Eutric Vertisols, Eutric Fluvisols, Eutric Leptosols, Eutric Regosols and Haplic Acrisols. Using this shape file, soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type were extracted from major Soils of the world database(FAO, 1995) and Digital soil map of the world database Figure_6D). The major soil types of the study area are listed in Table below.

Table 3.2: Soil type and coverage of the study area

ID	Soil Name	Area in km2	Area in %
10	Dystric Leptosols	362.356	1.17
20	Eutric Vertisols	1429.718	4.62
30	Eutric Fluvisols	100.779	0.33
40	Eutric Leptisols	172.796	0.56
50	Eutric Regosols	8.499	0.03
60	Haplic Acrisols	4871.382	15.74
70	Haplic Alisols	19607.542	63.36
90	Haplic Nitosols	1298.797	4.20
100	Rhodic Nitosols	3092.820	9.99

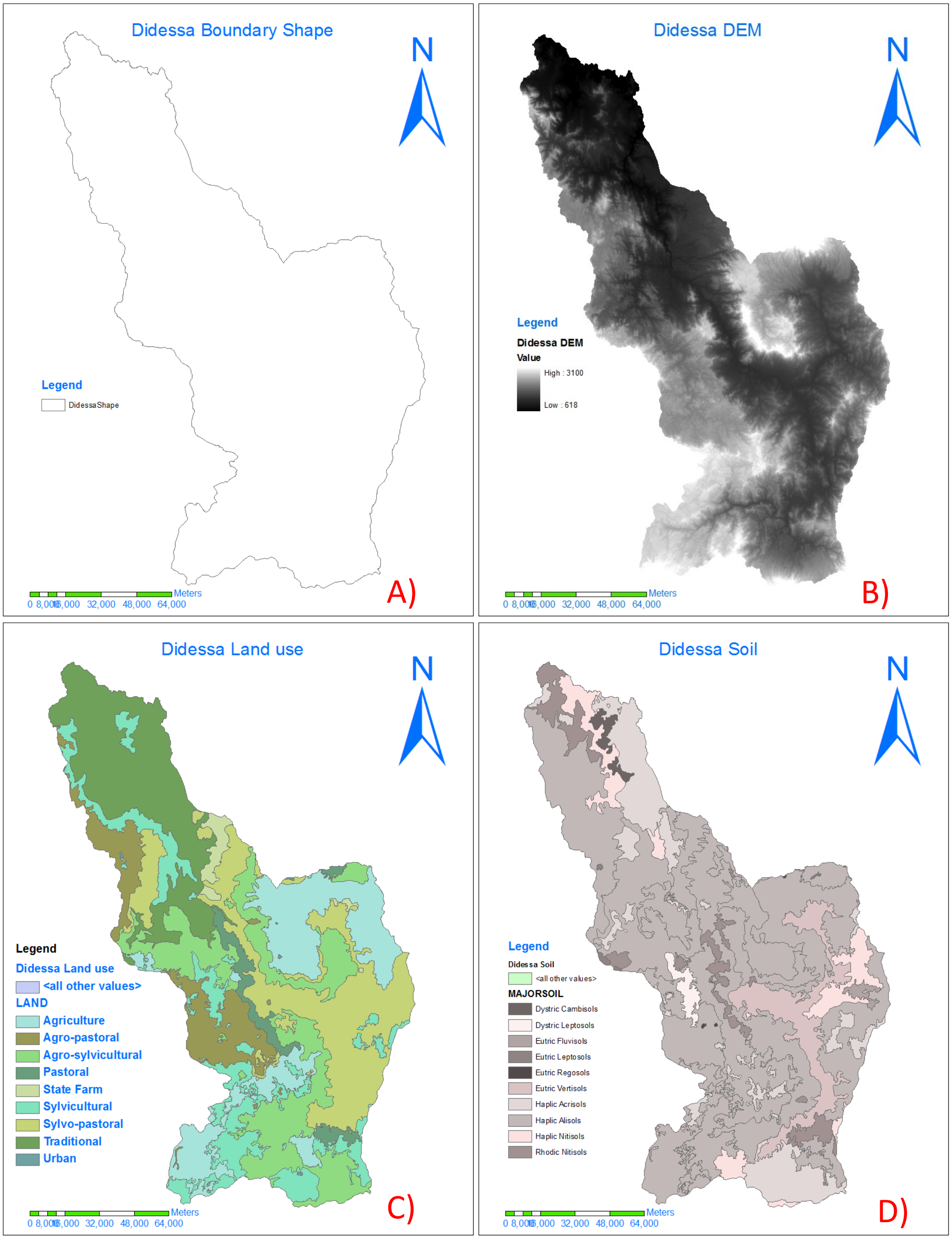


Figure 3.2: Spatial data collected from (MoWIR, 2016).

E) Weather Data

Weather data is very important SWAT input Tables for the simulation of hydrological processes like stream flow, sediment transport and other agricultural processes(Arnold et al., 2011). The available climatic data for the study area and nearby station were obtained from the National Meteorological Services Agency (NMSA).

Although there are many metrological station in and near Didessa sub basin some of them are incomplete and has only short period data records. The number of meteorological variables collected varies from station to station depending on the class of the stations. Some stations contain only rainfall data. The other group includes maximum and minimum temperature in addition to rainfall data. There are also stations which contain variables like humidity, sunshine hours, and wind speed in addition to rainfall, maximum and minimum temperature.

The first class station Jima which have all components of climatic variables mentioned above were used as weather generator station. Four meteorological stations (Abyssinia-Jogger, Agaro, Arjo, Didessa, Jimma and Nekemte). Data of precipitation, maximum and minimum temperatures, sunshine hours, relative humidity, and wind speed were collected within and around the catchment. Though, there were quite a number of missing data; the collected data ranges are in time between (1980- 2014) from station shown in Table below including their class and location.

Table 3.3: station class and location

Station Name	**Latitude**	**Longitude**	**Elevation**	**Metrological Variables**	**Station class**
Abyssinia Jogger	187464.482	996114.40	1420	PCP,TMP	III
Agaro	235351.160	868472.54	1666	PCP,TMP,WND	II
Arjo	230119.862	959071.57	1515	PCP,TMP	III
Didessa	181462.410	1038548.03	1310	PCP, TMP,WND	III
Nekemte	221123.170	999506.80	2080	PCP,TMP,HMD,WND	II
Jimma	**265578.940**	**846140.88**	**1733**	**PCP,TMP,HMD,SLR,WND**	**I**

F) River Discharge Data.

Daily river flow values of Didessa River were obtained from the hydrology department of the Ministry of Water, Irrigation and Energy (MoWIE) of Ethiopia.

These daily river discharges of Didessa River were used for model calibration and validation. River discharge data was available for one Station in Didessa near Arjo. The station have discharge data from 1980 to 2010, though they have missing data.

Table 3.4: Spatial location of Didessa River gauge and Catchment area under Station

Station Name	Latitude	Longitude	Catchment area under Station.
Didessa near Arjo	238372.503	944929.892	9799.188 km^2

3.4 Data Quality Analysis (Control)

3.4.1 Spatial Data Analysis

The elevation, land use/land cover and soil digital map are the spatial information of the study area for the watershed-modeling process. Both land use and soil maps obtained from Ministry of Water, Irrigation and Energy (MoWIE) of Ethiopia were used for extracting and clipping large dataset of land use/cover and soil map after importing them into ArcGIS interface to the specific study area for simplification of data processing, management and controlling.

Similar attribute classes of the land use/cover and soil map extracted maps that has different names either because of spatial variability or have no distinct difference in terms of hydrological prospect that had been reclassified and renamed before they have been used for further task. By doing this, the same classes have been assigned in the same name and the comparable classes have also been combined in to one name. To arrange all the layers geometrically so as fit to the study area, they were geo-referenced to the same coordinate projection which is WGS_1984_UTM_Zone_37N. The data shape file was visualized using Google Earth for the validation of the spatial data with respect to the actual visibility of the streams.

3.4.2 Weather Data Analysis

The measurement of periodic weather data used for hydrologic analysis and design obtained from National Meteorological Services Agency (NMSA) were not all in all complete and needs methods and procedures for its viability. There is a missing of data for periodic record of weather or climatic data which make failure to observer.

Damage of recording gauges is another problem that results in incomplete data records, and instrument failure because of mechanical or electrical malfunctioning can result in missing data. Any such causes of instrument failure reduce the length and information content of the weather data record.

Therefore, to validate the records filling missing data was done. There are number of methods for estimating missing data such as, Arithmetic average method, normal ratio method, quadrant method, and inverse distance, weighting method and regression methods. For this case Regression method was used for filling missing data.

Weather Data Consistency analysis

Data obtained from any organization who supply the data is not always consistent because of many problems. The first problem occurs when missing data exist during data collection or management and the second problem occurs when the catchment rainfall at rain gages is inconsistent over a period of time. Therefore, adjustment of the measured data is necessarily the problem that hydrologists need to address first before data use for any purposes to provide a consistent record.

To overcome the problem of inconsistency; a technique most widely applied called double mass curve was used. The double mass curve is used to check the consistency of many kinds of hydrologic data by comparing data for a single station with that of a pattern composed of the data from several other stations in the area(H.M.Ranghunath, 2006).

The curve is a plot on arithmetic graph paper of cumulative rainfall collected at a gauge where measurement condition may have changed significantly against the average of the cumulative rainfall for the same period of record collected at several gauges in the same region. The double mass curve can be used to adjust inconsistent precipitation data. Consistency of precipitation data from individual stations used in this study was checked using a double mass analysis and any of the stations used in this study have not undergone a significance change during the base line period (1980-2014) of the study and therefore no need of data adjustment other than filling missed data(H.M.Ranghunath, 2006) Figure.7.

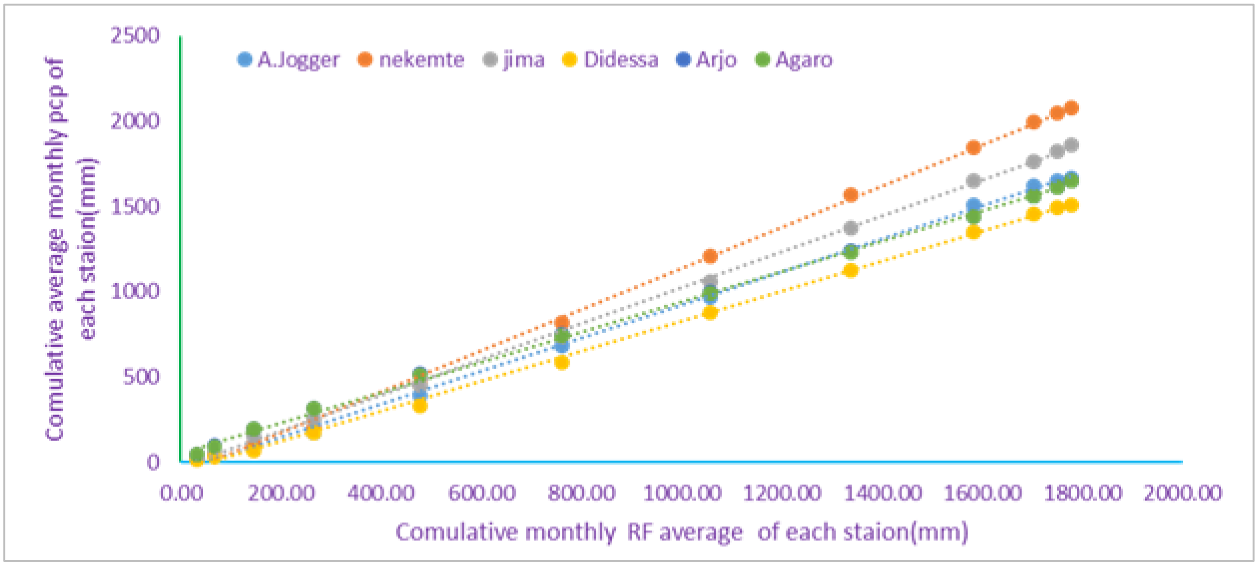


Figure 3.3: Double Mass Curve plots for consistency check of rainfall average

Estimation of Average Precipitation/Rainfall Depth.

Estimation of rainfall depth all over the catchment is important; since rain gauge measurement represent only point data specific to the location of the gauge only. Many methods can be used to convert the point rainfall values of these stations into an average value over the whole catchment such as (i) Arithmetic Mean, (ii) Thiessen Polygon, (iii) Isohyetal, etc. (H.M.Ranghunath, 2006)
Arithmetic Mean is simply averaging arithmetically the amounts of rainfall at the individual rain-gauge stations in the area. This method is fast and simple and yields good estimates in flat country if the gauges are uniformly distributed and the rainfall at different stations do not vary very widely from the mean. These limitations can be partially overcome if topographic influences and aerial representatively are considered in the selection of gauge sites.

In isohyetal method the average rainfall between the successive isohyets taken as the average of the two isohyet values are weighted with the area between the isohyets, added up and divided by the total area which gives the average depth of rainfall over the entire basin. This method if analyzed properly gives the best results(H.M.Ranghunath, 2006).
Thiessen polygon method attempts to allow for non-uniform distribution of gauges by providing a weighting factor for each gauge. The results obtained are usually more accurate than those obtained by simple arithmetic averaging.
Thiessen Polygon was selected for this study based on simplicity and accuracy of method with respect to data availability.

To determine mean areal rainfall using Thiessen polygon, amount of rainfall at each station was multiplied by area of its polygon and the sum of those products is divided by total area of the catchment.

The Thiessen was created using selected rain fall station by GIS arc toolbox proximity (Figure_8). The created Thiessen polygon shape was projected to metric unit (WGS_1984_UTM_Zone_37N) to calculate the area of each polygon

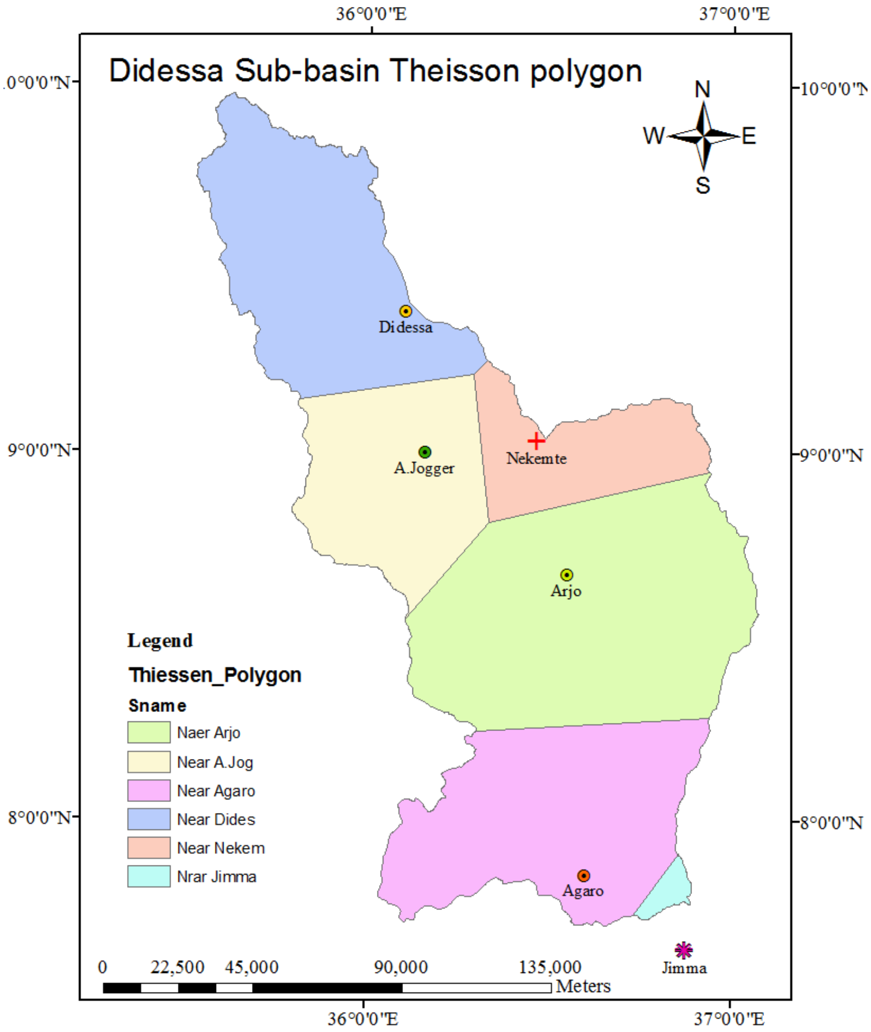


Figure 3.4: Didessa sub-basin Thiessen Polygon

Each polygon area is assumed to be influenced by the rain gauge station inside it, i.e., if P_1, P_2, P_3 ... Pn are the rainfalls at the individual stations, and A_1, A_2, A_3 ... An are the areas of the polygon surrounding these stations, (influence areas) respectively, the average depth of rainfall for the entire basin is given by

$$Pav = \frac{\sum_{i=1}^{n} AiPi}{At} \qquad (8)$$

Where

- P_{av}-Average rain fall
- P_i-Total precipitation at each area
- *Ai*- area of each Thiessen polygon

The rainfall stations included in the Thiessen were *Agaro, A. Jogger, Arjo, Didessa, Jimma* and *Nekemte* stations for the calculation of average areal rainfall.

Therefore, the average rainfall was calculated using only these station.

Table 3.5: Thiessen polygon area and average yearly rainfall of study sub basin

ID	St.Name	Polygon Area(km2)	Polygon Area (%)	Average Yearly Rain-fall(mm)
1	Arjo	615916.66	31	1647.57
2	Nekemte	186996.15	10	2077.14
3	Agaro	425481.85	22	1647.68
4	Jimma	15522.05	1	2108.54
5	A.Jogger	297579.26	15	1667.88
6	Didessa	421487.55	21	1511.65
	Total	1962983.53	100	10660.46

$$Pave = \frac{(A1 * Parjo + A2 * Pnekemt + A3 * Pagaro + A4 * Pjima + A5 * Pa.jogger + A6 * Pdidessa)}{Atotal}$$

$$Pave = \frac{\begin{pmatrix} 615916.66 * 1647.57 + 186996.15 * 2077.14 + 425481.83 * 1647.68 + 15522.05 * 2108.54 \\ + 297579.26 * 1667.88 + 421487.55 * 1511.65 \end{pmatrix} km2 * mm}{1962983.53 km2}$$

$$Pave = \frac{3244010711.64}{1962983.53} = 1652.592 mm$$

3.4.3 Flow Data Filling and Consistence Analysis.

Didessa stream flow data of thirty years (1980 - 2010) was obtained and from the long- term average monthly discharge of Didessa river the flow was realized as the maximum flow was in the month of August whereas lowest flow was usually in the month of March and April(Figure_9).

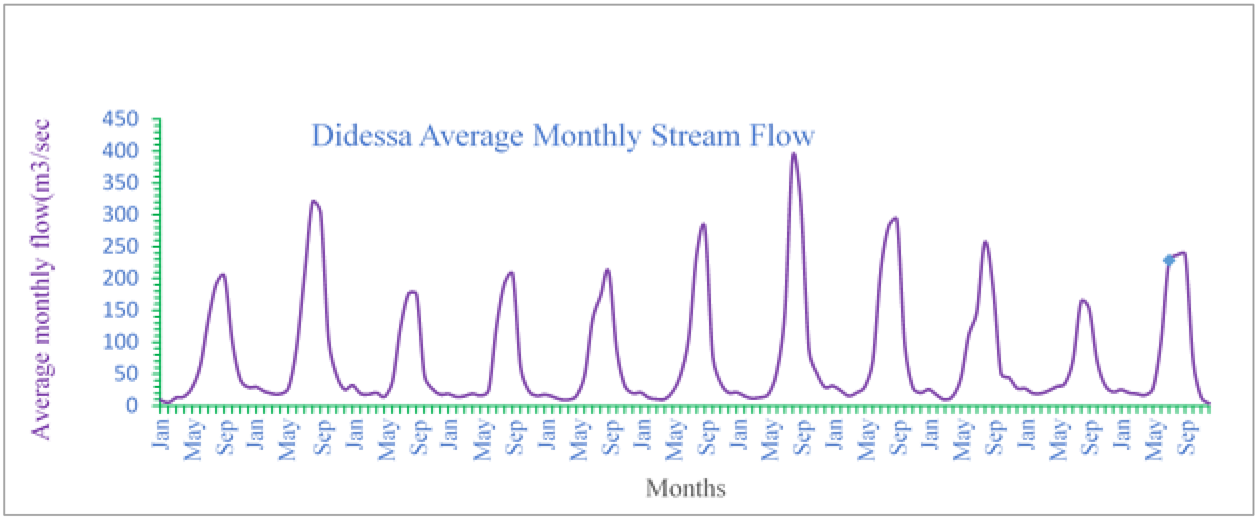


Figure 3.5: Didessa Average Monthly Stream Flow (source MoWIE)

Like that of daily meteorological data, the daily discharge data has limited data composition for the considered stations to represent the study area so that filling of missing data should be important for data consistence.

Regression analysis was used to fill the missing flow data and to extend those short lengths recorded data by using satisfactory correlation Coefficient for the common data period of neighboring station and use linear interpolation between the last value before the gap and the first value after it or same day average method was used to fill the gap of data for which hydrometric stations that have not satisfactory correlation from any of the neighboring stations(Chap T. Le, 2003). Consistency and homogeneity test of flow data is analyzed by DMC using excel sheet

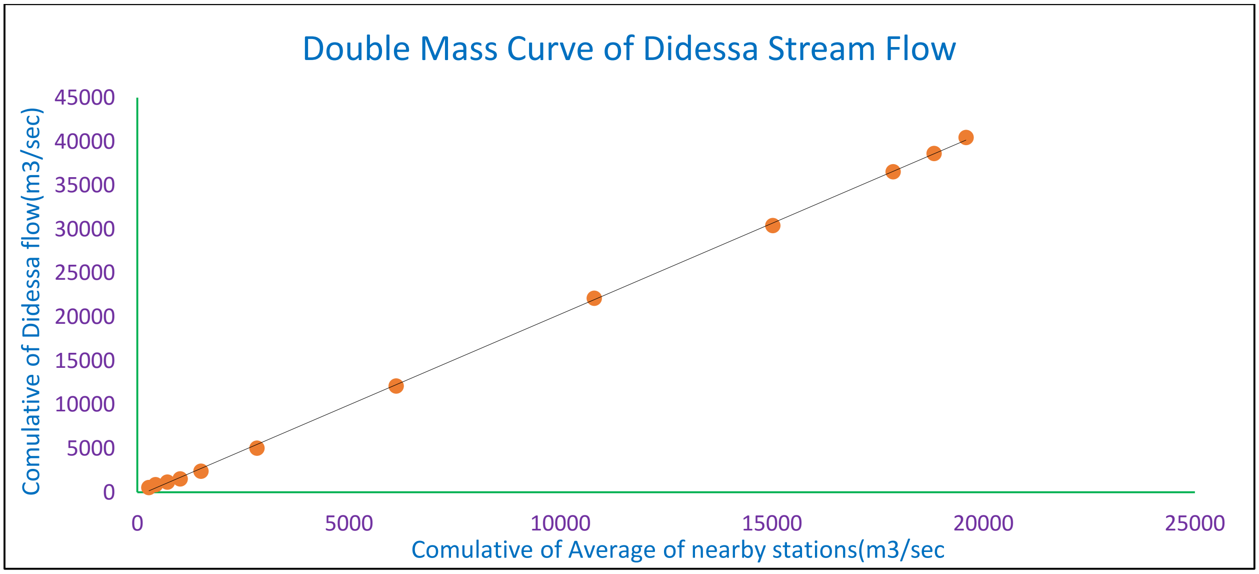


Figure 3.6: Double mass-curve of Didessa stream flow

3.5 Hydrological Models and Model Selection.

Hydrological models are nowadays become the vital tool to study and understand hydrologic processes in the catchment or watershed level; though hydrologic models are approximations of reality in which the output of the model depends on hydrologic phenomena(Setegn et al., 2008). Hydrologic phenomena vary in all three sources of variation (space, dimensions, and in time). A practical model usually considers only one or two sources of variation

Selection of hydrologic models needs multiple selection criteria which can be used for choosing the “right” hydrologic model.

The selection criteria are always project-dependent, since every project has its own specific requirements. Among the various selection criteria four common and fundamental ones are (Cunderlik M. Juraj, 2003).

- The outputs estimated by the model and importance of the output for the project objectives (Does the model estimate/simulate the variables required by the project such as long-term Sequence of flow?),
- Hydrologic processes that need to be modeled to estimate the desired outputs adequately (Is the model capable of simulating single-event or continuous processes?),
- Availability of input data (Can all the inputs required by the model be provided within the time and cost constraints of the project?),
- Cost (Does the investment appear to be valuable for the objectives of the project?)

Generally, SWAT model was selected for this study because of the following reasons:

- ✓ SWAT model is physical based model: It is based on readily observed and measured information and it attempts to simulate many hydrological components at ones for large and complex catchments.
- ✓ Simulate on a very large basins or a variety of management strategies can be performed without excessive investment of time or money
- ✓ Enables users to study long-term impacts users and involve the gradual buildup of pollutants and the impact on downstream water bodies.
- ✓ It is a continuous time model, i.e. a long-term yield model. The model is not designed to simulate detailed, single-event flood routing
- ✓ It is public domain with free and online access.

- ✓ It is compatible with ArcGIS interface: for ease of data base management.
- ✓ It has easy linkage to sensitivity, calibration and uncertainty analysis tools.
- ✓ It has smart and harmonized user groups.

3.5.1 SWAT Model and Its Description.

SWAT is a physically based, continuous time and a river basin or watershed scale model developed to predict the impact of land management techniques on water, sediment and agricultural chemical yields in large and complex watershed or basin with varying soil, land use and management condition over a long period of time.

No matter what type of problem studied with SWAT; water balance is the driving force behind everything that happens in a watershed to accurately predict the hydrological cycle, sediment or nutrient movement through the catchment(Arnold et al., 2011).

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

Water balance equation

SWAT model estimates related hydrologic components such as evapotranspiration, surface runoff, groundwater flow and sediment yield for each HRUs unit.

The hydrologic cycle simulated by SWAT is based on the water balance equation(Neitsch et al., 2005)

$$SWt = SWo + \sum_{n=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \qquad (9)$$

Where, SW_t -the final soil water content (mm),

SW_o - the initial soil water content (mm water),

t - the time (days),

R_{day} - the amount of precipitation in day *i* (mm),

Q_{surf} - the amount of surface runoff in day *i* (mm),

E_a - the amount of evapotranspiration in day *i* (mm),

W_{seep} - the amount of water percolating to bottom the soil profile in day i (mm, water)

Q_{gw} is the amount of return flow in day i (mm water)

3.5.1 Surface runoff

Surface runoff is the flow of water over the land surface occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration to the soil or the portion of rainwater that is not lost to interception, infiltration, and evapotranspiration(Hecht and Lacombe, 2014).

When initially applying water to a dry soil, the infiltration rate is usually very high. But it will decrease as the soil becomes wetter. Then, when the application rate is higher than the infiltration rate, surface depressions begin to fill and as application of water continues all surface depressions have filled and then the flow of water over the land begins which is known as surface runoff.

SWAT provides two methods for estimating surface runoff: the SCS curve number procedure and the Green & Ampt infiltration method to determine the respective amounts of infiltration and surface runoff.

A curve number is an index that represents the combination of a hydrologic soil group and a land use and land management. Empirically CN is a function of three factors: soil group (A, B, C and D soils have high, moderate, slow, and very low infiltration rates with low, moderate, high, and very high runoff potential) respectively, the land cover complex, and antecedent moisture conditions. For each specific land use and soil combination in the watershed, then calculates upper and lower limits for each CN following a probability function described by the NRCS to account for varying antecedent moisture conditions (AMC). Curve number can be equated as(Shivhare et al., 2014):

$$Q_{surf} = \frac{\left(R_{day}-I_a\right)^2}{\left(R_{day}-I_a+S\right)} \; Or \; Q_{surf} = \frac{\left(R_{day}-0.2S\right)^2}{\left(R_{day}-0.8S\right)} \qquad (10)$$

Where where

- ✓ Q_{surf} - accumulated surface runoff or rainfall excess (mm)
- ✓ R_{day} - rainfall depth for the day (mm H O)
- ✓ Ia - initial loss which includes surface storage, interception and infiltration before runoff (H_2O),
- ✓ S - Retention parameter (mm). The retention parameter varies spatially due to changes in soils (soil water content), land use management and slope.

The retention parameter is defined as:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \qquad (11)$$

Where CN-curve number of the day Runoff will only occur when $R_{day} > I_a$

3.6 SWAT Model Set-up and Simulation Procedure.

The entire database required by the SWAT model was developed for the study area (Didessa sub-basin) and the model setup was done for the area. The main procedure and various steps followed in model application in simplified shortly as.

- SWAT projectsetup → Watersheddelineation → HRU Analysis → Writeinput table → Edit SWAT Input → SWAT Simulation → SWAT run → SWAT output . → Sensitivity Anaysis → Calibration → Validation

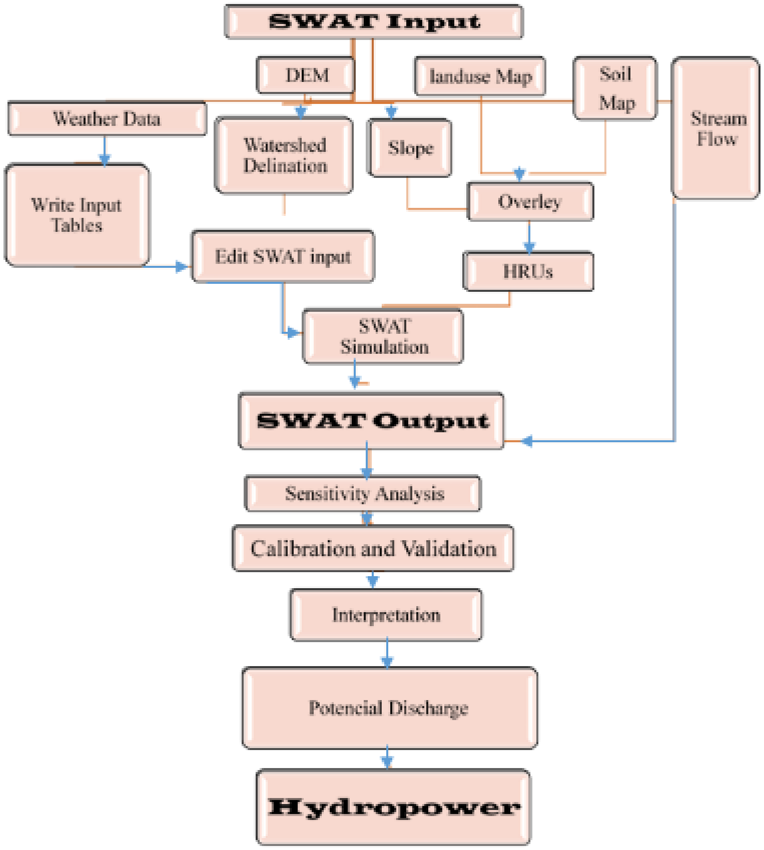


Figure 3.7: SWAT Model Set-up and Simulation Procedure Graph

3.6.1 Watershed Delineation

The watershed delineation for the Didessa catchment was performed using ArcSWAT2009. A 30 m by 30 m resolution DEM was used to delineate the watershed of the study area. The DEM was projected to UTM or metric unit system; since the measurement in ArcSWAT are metric unit; The stream definition, stream network and the sub basin outlets were defined as well as sub-basin parameters are calculated.

Didessa river gauge station inside the basin, was manually added and defined as an outlet for watershed delineation. A watershed is subdivided into sub basins based on the number of tributaries. The sizes of watershed and number of sub basins in the watershed vary from place to place. The sizes of sub basins also vary based on the nature of the topographic and the stream network system of an area. So, the watershed whose outlet is at Didessa river gauge was delineated and subdivided into 23 sub basin Figure (12) subsequently; the geomorphic parameters for each sub basin were calculated.

3.6.2 Hydrologic Response Unit Analysis

Hydrologic response units (HRUs) are lumped land areas within the sub-basin which represents homogeneous land cover/land use, soil and management conditions. The HRU in SWAT are spatially implicit, their exact position on the surface cannot be identified, and the same HRU may cover different locations in a sub basin(Di Luzio et al., 2002). HRUs enable the model to respond differently in deferent hydrologic conditions for different land covers/use, soils and land slope. The runoff is estimated separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy in flow prediction and provides a much better physical description of the water balance.

The land use and the soil shape file format data; which were obtained from MoWIE was projected to the same projection with DEM and were loaded into the SWAT interface to determine the area and hydrologic parameters of each land-soil category simulated within each sub-watershed.

Though, there are the same land cover classes at different location; this land cover was defined using the look up Table. A look-up Table was prepared after giving grid code to spatial land use and soil data using GIS to relate the grid values to SWAT land cover/land user data bases. After the land use SWAT code is assigned to all map categories, calculation of the area covered by each land use and reclassification were done.

As for the land use, the soil layer in the map was linked to the user soil database information by loading the soil look-up Table and reclassification applied. Slope classification was done using the DEM data used during the watershed delineation. After the reclassification of the land use, soil and slope, overlay operation was performed.

The second step in the HRU analysis was the HRU definition. During HRU definition; HRU distribution was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definition, a threshold level in percent was used to eliminate minor land uses, soils or slope classes in each sub-basin.

Land uses, soils and slope which cover less than the threshold level of 5%, 20%, 20% respectively are eliminated. The reason for taking these threshold values was in order to keep the HRUs to a reasonable and manageable number and also considering computer processing time required.

After the elimination process, the area of the remaining land use, or soil was reallocated so that 100% of the land area in the sub-basin is modeled. The threshold levels set is a function of the project goal and amount of detail required.

In selection of slope classification option for this study multiple slope option (an option for considering different slope classes for HRU definition) was selected and the slope class was classified depending up on the FAO slope classification to five and the range was 0-2%, 2-10%, 10 – 15%, 15 – 30% and above 30%. (FAO, 2001)

Table 3.6: Slope classification and its percentage area coverage in the watershed

Slope Class (%)	Area km2	Area(%)
0-2	324.85	4
3-10	1748.2	24
11-15	2492.21	34
16-30	2187.05	30
>30	488.77	7
Total	7241.08	100

Finally, a total of 421 HRUs for 23 sub-basins was created; even though, application of these thresholds eliminates the land uses and soils that covered relatively small areas in the sub-basins. The created HRUs was spatially viewed after processing it using ArcGIS.

3.6.3 Weather Data Preparation and Writing to ArcSWAT.

Weather data obtained from National Meteorological Services Agency (NMSA), which includes precipitation and maximum and minimum temperature data, relative humidity, solar radiation and wind speed for the SWAT modeling are not arranged for SWAT simulation. There are also missing data throughout the time series and periods of the measured weather data was differ from station to station.

Most of the station has many missing data which are not manageable these station was excluded from SWAT weather inputs. The weather stations which were used in the study are Jimma, Nekemte, Agaro, Didessa, Arjo and Abyssinia Jogger. The periods of the measurement of weather data from January 1st 1980 to December 31st 2014. From all these climatic stations; even though, they are more preferable; there are still missing periodical data and absence of data records for some climatic data parameters as shown on (Table-6).

Depending on the availability of climatic data and representativeness to study area climatic condition, Jimma station was selected as the 1st station class and used for weather generator station. All the parameter values needed for SWAT weather generator are calculated using statistical software like pcpSTAT. Dew02 and excel sheet. The weather generator then imported as *wgnjimma* to the SWAT2009 weather station database in order to make the SWAT to use specified weather generator. All available data are arranged and prepared to the file format of ArcSWAT for each and every station selected and saved in DBF format which is read by ArcSWAT interface. The geographical coordinate of the weather stations of the study area were prepared and saved in DBF format to import into ArcSWAT database (Figure-13).

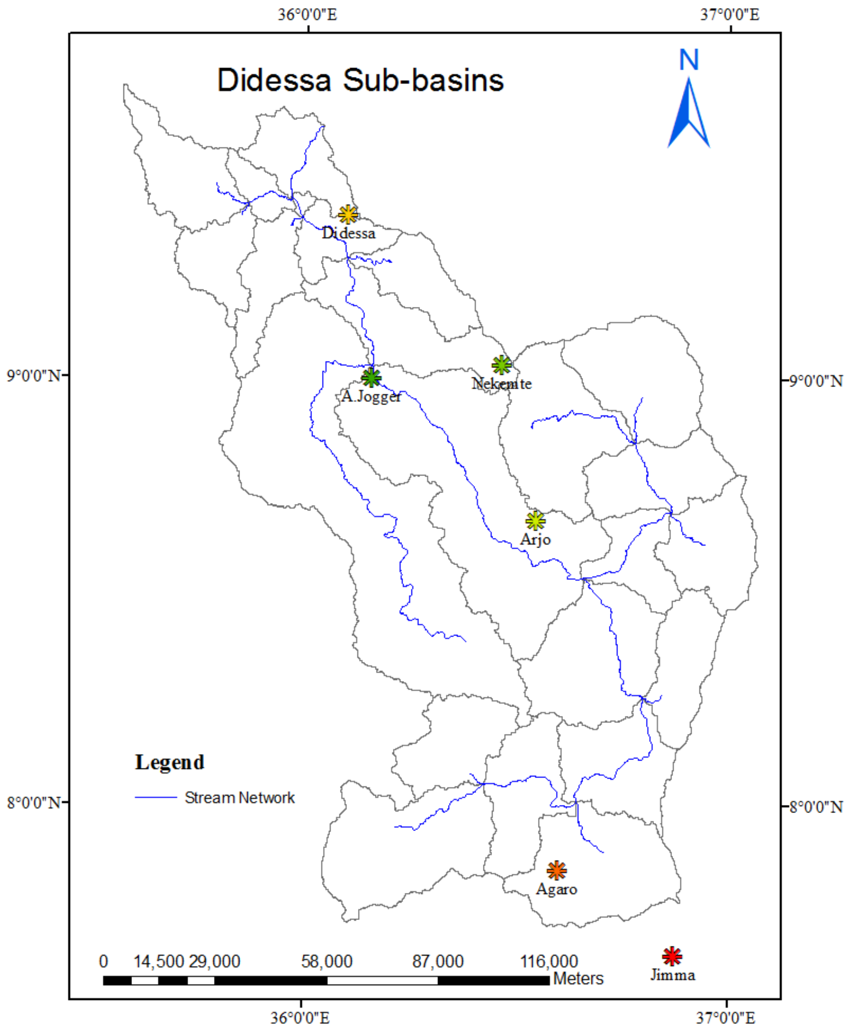


Figure 3.8: Distribution of rainfall station in the watershed sub-basins.

3.6.4 SWAT Simulation Setup

After editing and importing all important database files containing the information needed to generate default input for SWAT model; the simulation was done. In SWAT, once the default input database files are built, the necessary parameter values can be entered and edited manually. The HRU distribution was also modified whenever it was needed. The soil parameters values of each type of soil were entered. The land use land cover parameters were edited where it was necessary. SWAT simulation run was carried out on the period of 1980-2014. Two-year data was kept as warm up period. The warm-up period is important to make sure that there are no effects from the initial conditions in the model. The lengths of warm-up period differ from catchment to catchment. It is mainly depending on the objective of the study. The run output data imported to database and the simulation results were saved in different files of SWAT output. It is used for SWAT model calibration since most of the observations of the watershed’s behavior are obtained by measuring these parameters.

3.6.5 Sensitivity Analysis

Sensitivity analysis is a method of identifying the most sensitive parameters that significantly effect on model calibration or on model prediction by comparing the output variance due to input variability. The objective of sensitivity analysis is to estimate the rate of change of the model with respect to change in model input or to identify the most controlling parameter for the change in the output and determining parameter for which it is important to have more accurate values. It facilitates selecting important and influential parameters for a model calibration by indicating the parameters that shows higher sensitivity to the output due to the input variability.

The analysis was carried out to identify the models hydrologic sensitive parameters by comparing their relative sensitiveness. It was performed on Twenty-seven different SWAT parameters. Then the model parameters used in the sensitivity analysis of stream flow were selected and the method algorithm for analysis was defined.

During sensitivity analysis important (highly sensitive) parameters are selected and less important parameters (low to negligible sensitive) parameters are rejected for optimization of the parameters so that the calibration process can be easily performed.

There is sensitivity class parameter to select or reject some parameter from the whole parameter. According to Lenhert, 2002 for model development, model validation and reduction of uncertainty the following value is given(Lenhart et al., 2002).

Sensitivity analysis can be categorized into four categories

- ✓ Small to negligible sensitivity: mean relative sensitivity<0.05
- ✓ Medium sensitivity: 0.05≤mean relative sensitivity≤0.2
- ✓ High sensitivity: 0.2≤mean relative sensitivity≤1
- ✓ Very high sensitive: mean relative sensitivity>1

Table 3.7:Parameters for sensitivity class(Lenhart et al., 2002)

Sensitivity Class	Index(I)	Sensitivity
I	I > 1	Very High
II	0.2 = < I < =1	High
III	0.05 = < I<0.2	Medium
IV	I<0.05	low to negligible

Sensitivity analysis was performed on study sub-basin and four highly sensitive flow parameters like Cn^2, Canmx, Esco and Alpha_Bf are selected for optimization process according to sensitivity class and the parameters, which resulted from the analysis, were ranked according to the sensitivity index as shown below.

Table 2:Selected parameter based on sensitivity analysis

Parameter	Index(I)	Sensitivity	Range of value	
			min	max
Cn2	0.34	High	35	98
Canmx	0.13	Mideum	0	10
Esco	0.10	Mideum	0	100
Alpha_Bf	0.06	low	0.5	10

3.6.6 Model Calibration

Model calibration is the method of adjusting model parameters values by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions(Shawul et al., 2013)

During sensitivity analysis, sensitive parameters which govern the watershed were obtained and ranked according to their sensitivity index and then parameters were optimized by adjusting parameters until the simulated and observed value showed good agreement(Moriasi, 2007).

The calibration/validation process consists of three steps(Arnold et al., 2011)

- ✓ Selecting some portion of observed data
- ✓ Running the model at different values for unknown parameters until fit to observations is good

- ✓ Applying model with calibrated parameters to remaining observations.

Periodic discharge (measured stream flow data from 2005 to 2010) making the outlet of the watershed at River gauging station for calibration. The optimization procedure and values was done depending the stream flow gauge record and flow out at the gauging station until the total the statistical data comparison become acceptable value.

Model Calibration and Validation Using SUFI2 Algorithm:

The calibration of the model was done by SWAT-CUP (SUFI2) using statistical measures to determine the quality and reliability of predictions when compared to observed values.

Calibrated model predictive performance for Didessa River catchment was done using semi-automated calibration technique by converging the parameter values in to very narrow range and use as model constraints, the default R^2 was the objective function for this calibration and also the number of simulations was 500(Abbaspour, 2015).

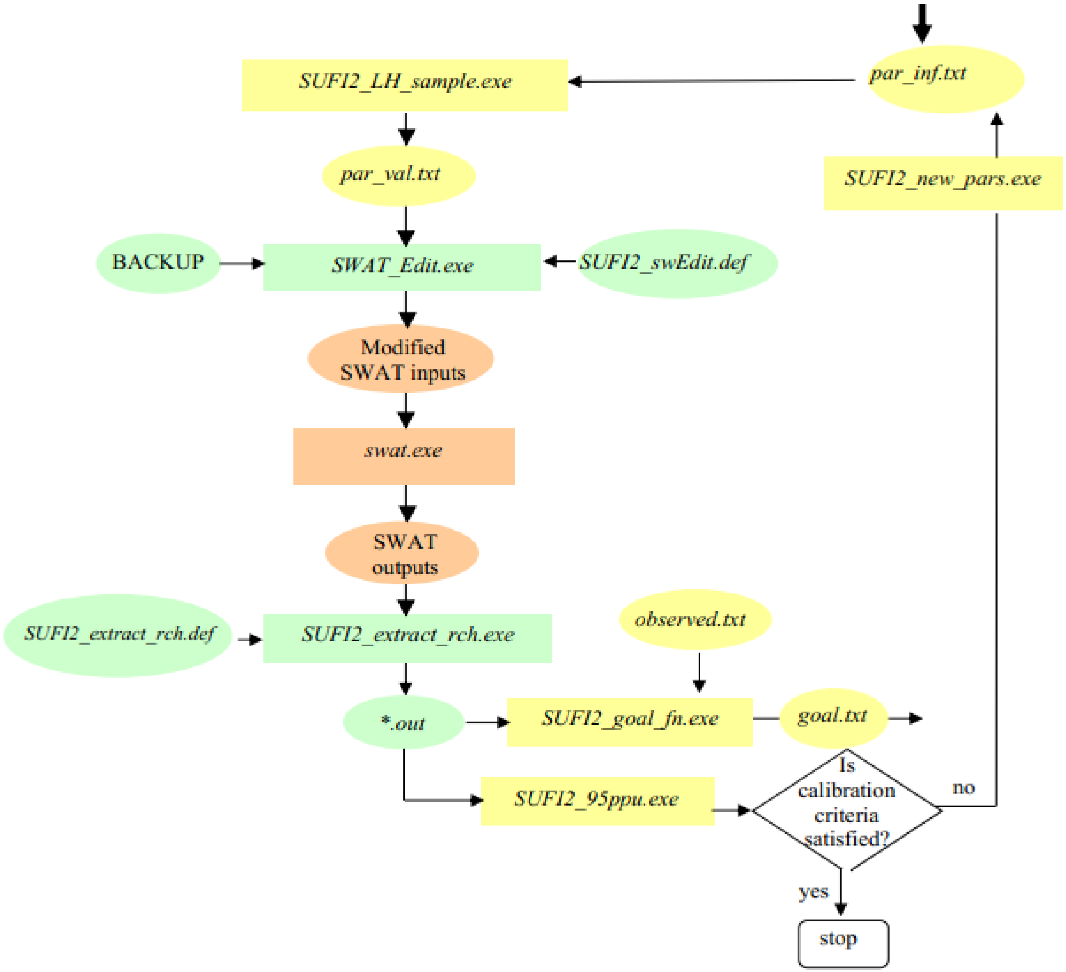


Figure 3.9:Calibration Procedure in SUFI2:Source(Abbaspour, 2015)

3.6.7 Model Validation and Model Performance Evaluation.

Model validation is a justification or confirmation of the model by comparing the model outputs with an independent data set after the calibration of the model. There are many statistical parameters to calibrate and validate the model by comparing simulated data with observed data(J. G. Arnold et al., 2012).

The four statistical model performance evaluation criteria were used for validation of the SWAT model are: Observations Standard Deviation Ratio (RSR), Nash-Sutcliffe Efficiency (NSE), Percent bias (PBIAS) and Coefficient of Determination (R^2) (Moriasi, 2007)which were described as follows:

A. Observations Standard Deviation Ratio (RSR). RSR is calculated as the ratio of the root mean square error and standard deviation of measured data, as shown in the following equation.

$$RSR = \frac{RMSE}{STDEVobs} = \left[\frac{\sqrt{\sum_{t=1}^{n}(Y_t^{obs} - Y_t^{simu})^2}}{\sqrt{\sum_{t=1}^{n}(Y_t^{obs} - Y^{mean})^2}}\right] \qquad (12)$$

Where

- ✓ $\boldsymbol{STDEVobs}$ is standard deviation of observed data of the constituent being evaluated,
- ✓ $\boldsymbol{Y_t^{sim}}$ is the $\boldsymbol{i^{th}}$ simulated value for the constituent being evaluated,
- ✓ $\boldsymbol{Y_t^{obs}}$is the $\boldsymbol{i^{th}}$ observation for the constituent being evaluated
- ✓ $\boldsymbol{Y^{mean}}$ is the mean of observed data for the constituent being evaluated,
- ✓ $\boldsymbol{n}$ is the total number of observation,

RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value

B. Nash-Sutcliffe Efficiency (NSE): The Nash-Sutcliffe Efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance (“noise”) compared to the measured data variance (“information”). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as shown in the following

$$NSE = 1 - RSM = 1 - \left[\frac{\sqrt{\sum_{t=1}^{n}(Y_t^{obs} - Y_t^{simu})^2}}{\sqrt{\sum_{t=1}^{n}(Y_t^{obs} - Y^{mean})^2}}\right] \qquad (13)$$

NSE ranges between $-\infty$ and 1.0 (1 inclusive), with NSE =1being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

C. Percent bias ($PBIAS$): Percent bias ($PBIAS$) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of $PBIAS$ is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model
overestimation bias. $PBIAS$ is calculated with the following equation

$$PBIAS = \left[\frac{\sqrt{\sum_{t=1}^{n}(Y_t^{obs} - Y_t^{simu}) * (100)}}{\sqrt{\sum_{t=1}^{n}(Y_t^{obs})}}\right] \qquad (14)$$

where $PBIAS$ is the deviation of data being evaluated, expressed as percentage.

D. Coefficient of Determination (R^2) . R^2 is the index of correlation of measured and simulated R^2values, has been used to evaluate the accuracy of the overall model calibration and validation.

$$R^2 = \left[\frac{\sum_{t=1}^{n}(Y^{obs} - Y^{obs\ mean})(Y^{simu} - Y^{simu\ mean})}{(\sum_{t=1}^{n}(Y^{obs} - Y^{obs\ mean})^2 * (\sum_{t=1}^{n}(Y^{simu} - Y^{simu})^2}\right]^2 \qquad (15)$$

The value of R^2 ranges between 0 and 1. The more the value approaches 1, the better is the performance of the model and the values of less than 0.5 indicates poor performance of the model.

Table 3.9:General performance ratings for recommended statistics (Moriasi, 2007)

Rating	**RSR**	**NSE**	**PBIAS**	**R^2**
Very good	0.00≤ RSR ≤0.50	0.75 ≤ NSE ≤ 1.00	PBIAS < ±10	0.7 ≤ NSE ≤ 1
Good	0.50≤RSR≤0.60	0.65 ≤ NSE ≤ 0.75	±10 ≤ PBIAS ≤ ±15	0.6 <R^2 ≤ 0.7
Satisfactory	0.60≤RSR≤0.70	0.50≤NSE≤0.65	±15≤PBIAS≤±25	0.50≤R^2≤0.6
Unsatisfactory	RSR > 0.70	NSE≤0.50	PBIAS ≥ ±25	R^2<0.50

3.6.8 Uncertainty Analysis of Model.

The degree to which all uncertainties are accounted for is quantified by a measure of the p-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU) and the r-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data.

Theoretically, the value for p-factor ranges between 0 and 100%, while that of r-factor ranges between 0 and infinity. A p-factor of 1 and r-factor of zero is a simulation that exactly corresponds to measured data.

A larger p-factor can be achieved at the expense of a larger r- factor. Hence, often a balance must be reached between the two. When acceptable values of r-factor and p-factor are reached, then the parameter uncertainties are the desired parameter ranges. As the p-factor approach to unity (1) and r-factor approaches zero (0), the simulated value has a good relation and the model is accepted.

3.7 Hydropower development

3.7.1 Hydropower Potential Estimation.

Traditionally hydropower potential is estimated for a particular site by using historical data of discharge in which very limited tools were available to estimate the stream flow at ungauged locations. Due to the complexity involved in hydrological phenomena, the estimation of discharge at ungauged location based on the observed data of some specific sites using the traditional estimation method poses doubts regarding the accuracy and reliability of the assessment. Furthermore, the assessment based on the location specific recorded data does not cover the entire potential basin, thus leaving the more potential sites at other locations. The collection of observed data from a large number of gauging stations is costly as well.

Most of rivers in Ethiopia are ungauged or very poorly gauged and therefore, the observed discharge data are not sufficient for the assessment of hydro potential(Fikadu and Abdela, 2008/2009/). Therefore, GIS-based hydrological model like SWAT were developed to simulate the discharge and is used to estimate the hydro potential of the rivers in Didessa sub-basin.

With the creation of modern computation tools such as GIS, remote sensing (RS) and hydrological models, the constraints mentioned above have been addressed comprehensively. The realistic representation of: (i) terrain, (ii) complex hydrological phenomena and (iii) varying climate are now possible through the spatial tools and modeling techniques(B. Feizizadeh and E. Haslauer, 2012).

The power water or hydropower can be calculated by the following formula

$$P = \eta \rho g Q H \tag{16}$$

Where

- P-the power in watt
- Q-Discharge in m^3/sec
- H-Available head in m
- η-Turbine efficiency
- ρ-Mass density of water kg/m^3 at specified temperature.
- g- Acceleration due to gravity in m/sec^2

The mass density of water is taken as 1000 kg/m3 and acceleration due to gravity as 9.81 m/s2. The gross head is the elevation difference between headrace and tailrace. By estimating the head drop, H and discharge, Q of any basin, the theoretical hydro potential can be calculated.

A) Selection Hydropower Plant

Hydropower technology utilizes the potential energy possessed by water body between two elevation levels, which is proportional to the rate of flow of water and elevation difference, referred to as the head. Therefore, hydropower planning and design are focused towards increasing these two parameters by selecting proper plant and construction measures. Two types of hydropower plants have been developed depending upon the availability of head and control of discharge as Storage hydropower plants and Run-of-river (ROR) / Peak Run-of-river (PROR) hydropower plants.

Run-of-river (ROR) / Peak Run-of-river (PROR) hydropower plants

ROR projects are dramatically different in design and appearance from conventional hydroelectric projects. Traditional hydro dams store enormous quantities of water in reservoirs, sometimes flooding large tracts of land. In contrast, run-of-river projects do not have most of the disadvantages associated with dams and reservoirs, which is why they are often considered environmentally friendly.

The use of the term "run-of-the-river" for power projects varies around the world. Some may consider a project ROR if power is produced with no water storage while limited storage is considered ROR by others. Developers may mislabel a project ROR to soothe public perception about its environmental or social effects. The Bureau of Indian Standards describes run-of-the-river hydroelectricity as:

A power station utilizing the run of the river flows for generation of power with sufficient pondage for supplying water for meeting diurnal or weekly fluctuations of demand. In such stations, the normal course of the river is not materially altered.

When developed with care to footprint size and location, ROR hydro projects can create sustainable energy minimizing impacts to the surrounding environment and nearby communities.

Like all hydro-electric power, run-of-the-river hydro harnesses the natural potential energy of water, eliminating the need to burn coal or natural gas to generate the electricity needed by consumers and industry.

Although, Run-of-the-River power is considered an "unfirm" source of power, substantial flooding of the upper part of the river is not required for run-of-river projects as a large reservoir is not required. As a result, people living at or near the river don't need to be relocated and natural habitats and productive farmlands are not wiped out.

Small, well-sited ROR projects can be developed with minimal environmental impacts(Douglas T, 2007). Larger projects have more environmental concerns. For example, Plutonic Power Corp.'s canceled Bute Inlet Hydroelectric Project in BC would have seen three clusters of run-of-river projects with 17 river diversions(Plutonic Power, 2008) as proposed, this run-of-river project would divert over 90 kilometers of streams and rivers into tunnels and pipelines, requiring 443 km of new transmission line, 267 km of permanent roads, and 142 bridges to be built in wilderness areas

B) Turbine Selection for Plant Capacity Determination

Turbine selection and plant capacity determination require that rather detailed information has been determined on head and possible plant discharge. In practice, different selection procedures are used. Engineering firms or agency engineering staff do the selection using experience curves based on data from units that have already been built and installed or tested in laboratories. Another approach that is preferred by manufacturers is that they be provided with the basic data on head, water discharge, turbine setting possibilities, and load characteristics. The selection is then based on hill curves from model performance data that are proprietary in nature. Normally, the manufacturers provide a checklist which is the basis for making the selection. The manufacturer furnishes preliminary estimates of the cost of the turbines and necessary mechanical equipment and controls, together with basic characteristics and dimensions of the hydropower units(C. C. WARNICK et al., 1984).

Limits of Use of Turbine Types

For practical purposes there are some definite limits of use that need to be under-stood in the selection of turbines for specific situations. Impulse turbines normally have most economical application at heads above 1000 ft, but for small units and cases where surge protection is important, impulse turbines are used with lower heads. For Francis turbines the units can be operated over a range of flows from approximately 50 to 11 5% best-efficiency discharge. Below 40%, low efficiency, instability, and rough operation may make extended operation unwise. The upper range of flow may be limited by instability or the generator rating and temperature rise. The approximate limits of head range from 60 to 125% of design head. Propeller turbines have been developed for heads from 5 to 200 ft but are normally used for heads less than 100 ft. For fixed blade propeller turbines the limits of flow operation should be between.75 and 100% of best-efficiency flow. Kaplan units may be operated between 25 and 125% of the best-efficiency discharge. The head range for satisfactory operation is from 20 to 140% of design head.

For a run-off river high-head schemes, the head variation is greatly very little or even negligible when comparing with the total head and therefore if the relative head is smaller than 5 to 10 percent, the Pelton wheel is competitive with the Frances turbine over their common field of applications, when, beside the head, also taken in account the power for achieving reasonable values of the rated speed(Mosonyi, 1991).

C) Estimation of discharge.

To estimate the discharge along the river or stream, the SWAT model was used as simulating model. As discussed in model setup, the SWAT model was calibrated and validated by comparing the flow out at the stream gauge location and observed/or gauged stream flow. After calibration and validation of model, simulated discharge or stream flow at each selected watershed sub-basin was extracted using SWATPlot program. Flow duration curve and power duration was plotted using excel to calculate hydropower potential.

D) Estimation of potential head.

In estimating potential head drop the slope created using Digital elevation model for extracting longitudinal and cross-sectional profile by ArcGIS tool and Global mapper. During watershed delineation, the stream network was developed for each and every sub-basin. Using the stream network created, river longitudinal profiles were created for each sub-basin. The theoretical potential head is the elevation difference or drop which is the difference between maximum and minimum elevation along the stream line in specified watersheds sub-basins.

Flow Duration Curve

The flow-duration curve (FDC) is a cumulative frequency curve that shows the percent of time that flow in a stream is likely to equal or exceed some specified value of interest(K. Subramanya, 2008)

Applications of FDC are of interest for many hydrological problems related to hydropower generation, river and reservoir sedimentation, water quality assessment, water-use assessment etc. Hydropower design and hydro potential calculation require stream flow data which can be obtained from the flow duration curve(Rechard M.Vogel and Neil M.Fennessey, 1995).

The shape of FDC is determined by the hydrologic and geologic characteristics of the watershed and the curve may be used to study the hydrologic response of a watershed to various types of inputs such as snowmelt, rainstorms etc(James K. Searcy, 1999).

Power Duration Curve

The flow duration curve can be converted into a power duration curve, if the available head and efficiency of the power plant are known, by changing the ordinate to the available power.

The power which is available for 95% to 97% of the time on the reservoir regulated schemes is usually considered to be the primary or firm power, and the area of the power duration curve under the minimum amount of flow available for 95% to 97% of the time thus gives the total amount of the primary power. Primary power is not necessarily produced continuously. If poundage and interconnection facilities are available, the plant may be operated on the peak load only. The surplus or secondary power is all the available power in excess of the primary power, and is given by the area under the power duration curve between the firm power line and the total installed capacity of the power plant(Castellarin et al., 2004)

CHAPTER FOUR: RESULTS AND DISCUSSIONS

Not only result, but discussion on the result obtained is very important part of the thesis. The result obtained from the HRUs analysis up to the end result of best simulation and estimation of potential hydropower are discussed as follows.

4.1 Land Use, Soil and Slope.

Land Use, Soil and Slope are the important factors that affect runoff, evapotranspiration and surface erosion in a watershed. According to the land use, soil and elevation digital map of the area, which are obtained from Ministry of Water, Irrigation and Energy(MoWIE), the area was mainly fall under traditional agriculture land use and management practice (Table 4) and the soil type of the area is mostly Haplic Alisols and Haplic Acrisols (Table 5) which encompasses strongly acid soils that have accumulation of high activity clays in the subsoil. The crust allows insufficient penetration of water during rain showers with devastating surface erosion (low structure stability!) as an inevitable consequence. Many Acrisols and Alisols in low landscape positions show signs of periodic water saturation; their surface horizons are almost black whereas matrix colors are close to white in the eluvial albic horizon(FAO, 2006).

Slope is another very important catchment characteristic which affect runoff in terms of volume and time to reach the outlet of the watershed. When slope percentage increase the rainfall or precipitation reaching the land surface will immediately form runoff and moves without keeping soil saturation detaching soil particle from the surface as soil erosion and move it as sediment load to the reservoir. The slope of the area was reclassified based on FAO slope classification (FAO, 2001)in which most of the area is classified under gentle to moderately steep slope(Table_10).

Table 4.1: Slope class and area under the slope for study sub-basin

Slope class	Slope % range	Slope Description	Area(km2)	Area(%)
I	0-2	flat	324.85	4
II	3-10	Slightly gentle	1734.44	22
III	11-15	gentle	2487.62	32
IV	16-30	Slightly steep	2187.05	28
V	>30	Steep	977.54	13

4.2 Catchment discharge Estimation

Flow simulation was performed Didessa River or sub-basin using SWAT model as hydrologic model making Didessa near Arjo river gauge station as watershed outlet for the calibration and validation simulated flow by comparing with observed stream flow to estimate the hydropower potential in the sub-basin. The SWAT model calibration was done using SWAT-CUP SUFI2 program after identifying most sensitive parameter through sensitivity analysis to validate the model. The flow sensitivity analysis, calibration and validation was discussed as follow.

4.2.1 Flow Sensitivity Analysis.

Flow sensitivity analysis was carried out using SWAT interface for a period of 35 years (1980-2014) including two year warm up period, to identify the influential parameters on the modeled stream flow. During sensitivity analysis, 200 iterations have been done and 27 parameters were tested for flow sensitivity analysis, but 4 parameters ($CN^{2,}$ Canmx, ESCO and Alpha_Bf) were found to be the most sensitive with their effect on the simulated result when their value is changed and selected for calibration.

4.2.2 Stream Flow Calibration Analysis

The calibration of the model was executed, after sensitive parameters are identified, to evaluate the performance of the model simulation using SWAT-CUP (SUFI2) calibration technique in, since SWAT-CUP calibration gives a better result on fitting the parameters of simulated and observed flow value(Abbaspour, 2015).

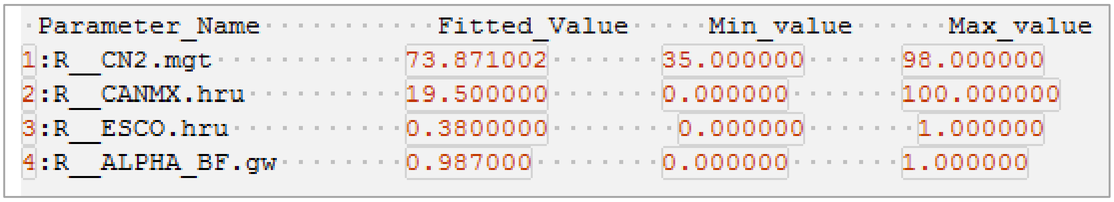
It was carried out using the most sensitive parameters to optimize the most sensitive parameter value which were resulted from sensitivity analysis.

From the result of sensitivity analysis were SCS curve number (CN2), Maximum Canopy Storage(Canmx), Soil Evaporation Compensation Factor (ESCO), and Base flow alpha factor(Apha_Bf) were found to be the most influential parameters (Table 11).

Most models are provided with default parameters values. However, these value may not provide the simulation that fit with observed value. Therefore, it is important to change the values of sensitive parameter to validate the model to specific area for further simulation.

The minimum and maximum acceptable values were provided based on related previous works and literatures. The automated calibration was made by SWAT-CUP SUFI2 to change the values of the sensitive parameters to get the acceptable values at which observed and simulated flow are the same or nearly similar (Table 11).

Table 4.2: Max, min and accepted Values of sensitive flow parameter after calibration



```
 Parameter_Name            Fitted_Value     Min_value       Max_value
1:R__CN2.mgt              73.871002       35.000000       98.000000
2:R__CANMX.hru            19.500000       0.000000        100.000000
3:R__ESCO.hru             0.3800000        0.000000       1.000000
4:R__ALPHA_BF.gw          0.987000        0.000000        1.000000
```

The calibrated parameters are within the range of the suggested values of SWAT in SWAT database. After the calibration result, the model was run and the simulated flow was compared with the observed flow. On Figure 14 below showed the hydrographs of the observed and simulated flows from 01 January, 2005 to 31 December 2010 for the calibration phase.

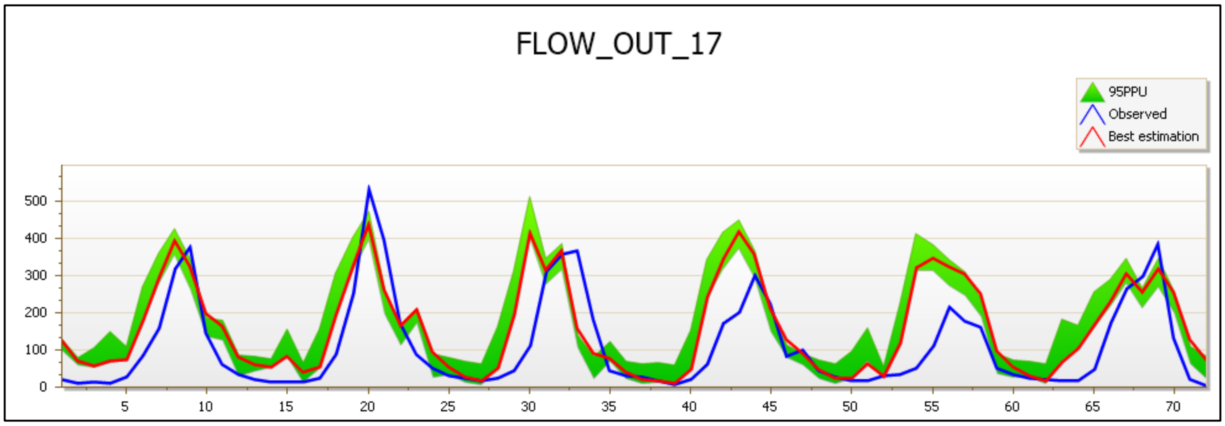
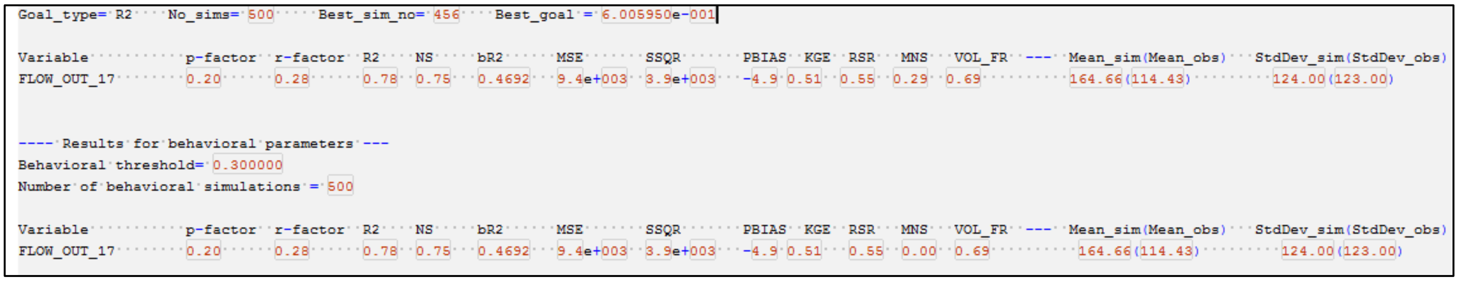


Figure 4.1: Calibrated Vs Observed flow hydrograph 95PPU_plot



```
Goal_type= R2    No_sims= 500     Best_sim_no= 456    Best_goal = 6.005950e-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_17       0.20      0.28      0.78  0.75  0.4692  9.4e+003  3.9e+003   -4.9   0.51 0.55  0.29  0.69         164.66(114.43)        124.00(123.00)


---- Results for behavioral parameters ---
Behavioral threshold= 0.300000
Number of behavioral simulations = 500

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_17       0.20      0.28      0.78  0.75  0.4692  9.4e+003  3.9e+003   -4.9   0.51  0.55  0.00  0.69         164.66(114.43)        124.00(123.00)
```

Figure 4.2: Statistic summary of simulated value for Calibration

The calibration period has shown a good agreement between monthly measured and simulated flows at simulation (Figure16).

The graphical *95PPU* plot of the values of the measured and the simulated monthly stream flow data have also shown a fair linear correlation between the two data sets (observed and simulated).

4.2.3 Stream Flow Validation Analysis

Once the model is built, it is calibrated by tuning the model parameters within recommended ranges to match the simulated output with the observed data. This involves the comparison of model results with the recorded flow data at selected outlets. After the calibration of the model, the validation was done.

The validation was carried out using the calibrated parameters.

For model validation, observed stream flow data of Didessa River from 2011 to 2012 were used. In the validation process, the model was run with input parameters set during the calibration process without any change(Abbaspour, 2015).

The validation period depends on an agreement between monthly measured and individual simulated flows and select the best simulate based on the statistical parameter.

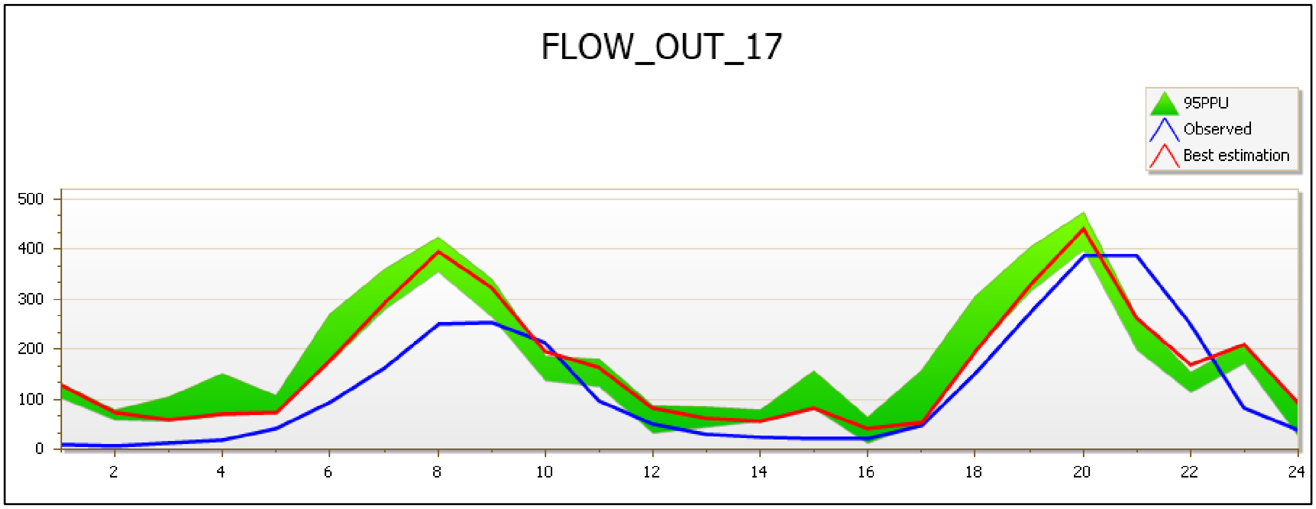


Figure 4.3: Validated Vs Observed flow hydrograph 95PPU_plot

The validation result showed that the coefficient of determinations (R2), the Nash-Sutcliffe Efficiency (NS), Percent bias(PBIAS) and Standard Deviation Ratio (RSR) are 0.76, 0.60, -13.4 and 0.43 respectively for validation (figure 18).

Based on the performance ratings for recommended statistics for a monthly time step, the model performance assessment indicated a very good correlation and agreement (Table 9) between the monthly measured and simulated flows. The scatters plot of the values of the measured and the simulated monthly stream flows data has also shown a fair linear correlation between the two datasets.

After the calibration and validation of model, it is used to get the monthly discharge data for the other sub-basin.

Flow Duration Curve

The result of average monthly discharge of best simulate then used to calculate the flow duration curve of the stream flow.

FDC was prepared for the monthly stream flow data. The following steps are followed to prepare the flow-duration curve(Oregon State University (OSU), 2002).

- ✓ Sort out or rank the average monthly (or daily) discharges for the period of record from the largest value to the smallest value involving a total '*ne*' number of values.
- ✓ Assign each discharge value a rank M, starting with 1 for the largest monthly discharge value.
- ✓ Calculate the exceedance probability as follows:

$$P_{rb} = 100\ x \left[\frac{M}{(n_e+1)}\right] \qquad (17)$$

Where,

P_{rb} = The probability that a given flow will be equaled or exceeded (% of time)

M = The ranked position on the list (dimensionless)

n_e = The number of events for a period of record (dimensionless)

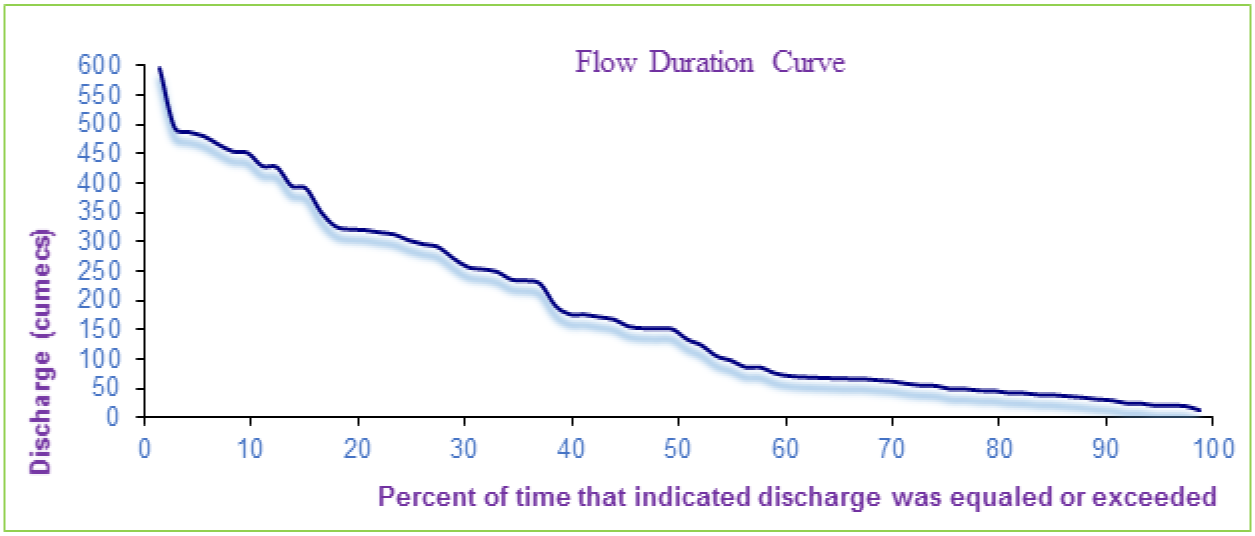


Figure 4.4: Monthly Flow Duration Curve for Didessa River at River gauge outlet (2005-2010)

The flow duration curve was converted into a power duration curve, using the available head and efficiency of the power plant, by changing the ordinate to the available power.
The graph of power duration curve is simply plotted by multiplying the discharge ordinate with effective head, gravity and coefficients(P. Novak et al., 2007).

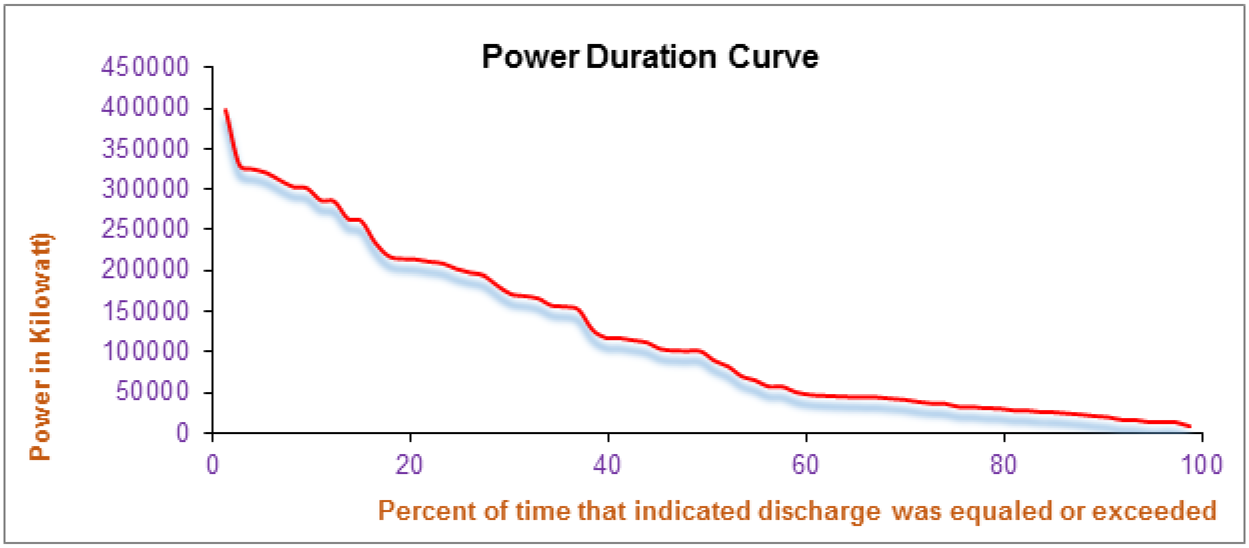


Figure 4.5: Power Duration Curve to the specified flow in Figure19

4.3.1) Hydropower Potential

Run-of-river hydro projects use the natural downward flow of rivers and micro turbine generators to capture the kinetic energy carried by water(Raja and Srivastava, 2006). Typically, water is taken from the river at a high point and diverted to a channel, pipeline, or pressurized pipeline (or penstock). The technology is applied best where there is a considerably fast moving river with steady seasonal water. How much electrical energy can be generated by a hydroelectric turbine depends on the flow/quantity of water, and the height from which it has fallen (the head). The higher the head, and the larger the flow, the more electricity can be generated.

Selection of dam site involves many variables, including physical feasibility related to available head, flow, geological and topographical characteristics; energy factors related to potential capacity, potential energy, local electricity market, energy demand, and grid integration; and other related issues such as opportunity costs of hydro development that might include reduced water availability to meet non power demands and environmental and social impacts.

In addition to dam site selection, reservoir area, volume and geomorphological characteristics was other issues as it needs detail study and is very costy and need long period of time. In contrast runoff river more or less needs only physical feasibility like available head, flows and topographical characteristics.

4.3.1.1 Discharge Estimation

River flow estimation is one of the most important things for run-off river hydropower potential estimation in the development of hydropower. For the estimation of stream flow, SWAT model was used and then calibrated and validated for the simulation.

The monthly simulated values at each sub-basin outlet in the watershed was used for the estimation of average flow out from the sub-basin outlet. As discussed above, Didessa watershed was subdivided into 23 sub-basins and the selected sub-basin through which Didessa stream flow line paths were selected.

The selected sub-basin for estimation of average flow out were: sub-basin 17. 15, 9, and 1. Average daily flow out in a month from each sub-basin was calculated after running the model with optimized parameter value.

The value of simulated flow out from each sub-basin in cubic meters per seconds was as shown in the table

Table 4.3: average monthly flow out from each sub-basin in m^3/sec

Month	Average of Flowout-20	Average of Flowout-17	Average of Flowout-15	Average of Flowout-9
Jan.	18.98	29.37	65.71	91.79
Feb	10.62	17.09	40.00	49.80
Mar	11.95	18.64	43.05	51.59
Apr	17.23	26.73	56.62	72.16
May	56.85	84.33	187.62	255.10
Jun	147.29	208.42	503.62	755.58
Jul	227.04	318.89	758.06	1075.55
Aug	242.93	341.11	783.06	1092.61
Sep	208.58	294.81	655.88	951.79
Oct	132.40	188.01	402.66	538.69
Nov	61.26	89.05	189.35	237.95
Dec	28.68	42.95	92.90	116.84
Total	**96.98**	**138.28**	**314.88**	**440.79**

Since there was no significant difference in flow out at sub-basin 9, 7 and 5, sub-basins 5 and 7 were excluded for the estimation of run-off-river potential hydropower (Figure 27).

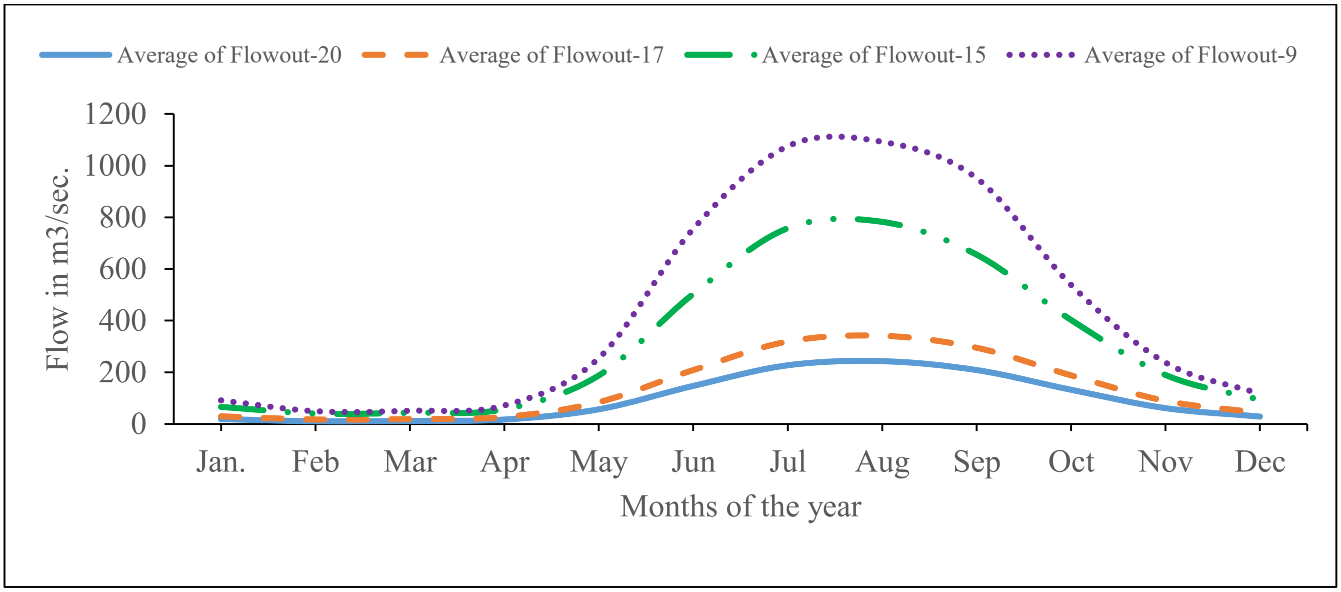


Figure 4.6: Average daily Flow hydrograph in a month of mostly selected sub-basin.

4.3.1.2 Estimation of Head Drop

Potential head was calculated based on the topographic characteristics of the sub-basin. To calculate head drop, DEM data were used to extract longitudinal profile by ArcGIS tool by following river stream created during watershed delineation specified to the individual sub-basin selected for estimation of flow out. From the longitudinal profile extracted, the head drop is the difference between maximum and minimum elevation along the stream line.

Head drop for sub-basin 14 was extracted using river profile created by GIS 9.3 with the maximum elevation of 1351 meter and minimum elevation of 1321 meter (Figure 4.7). Therefore, the head drop of the sub-basin 14 was calculated by subtracting minimum elevation from maximum elevation.

$$H_{20}=1351m-1321m$$

$$H_{20}=30m$$

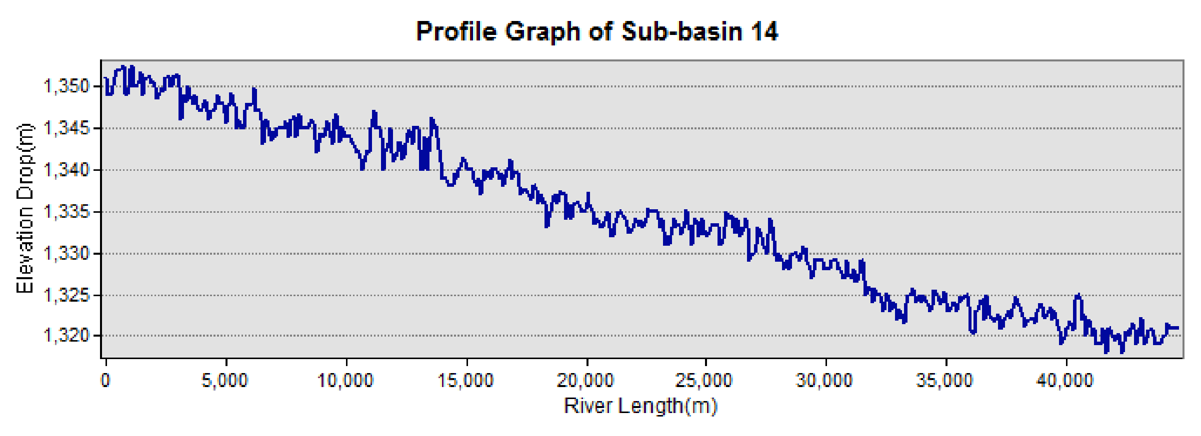


Figure 4.7: River Longitudinal Profile in Sub-basin 14

Head drop for sub-basin was extracted using river profile created by GIS 9.3 with the maximum elevation of 1321 meter and minimum elevation of 1132 meter (Figure 28). Therefore, the head drop of the sub-basin 15 was calculated by subtracting minimum elevation from maximum elevation.

H_{17}=1321m-1132m

H_{17}=189m

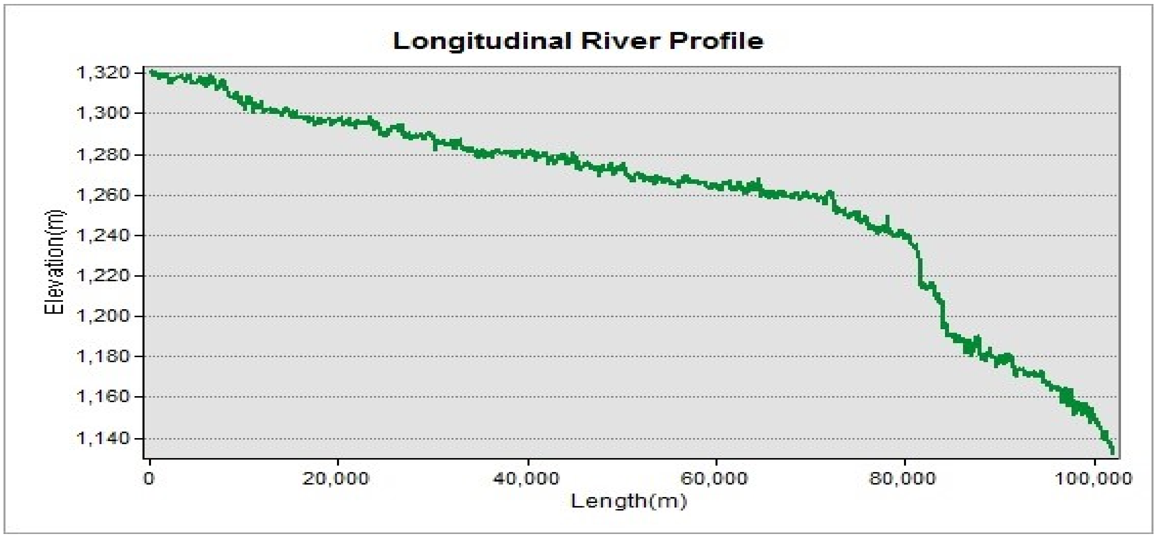


Figure 4.8: River Longitudinal Profile in Sub-basin 15

The river longitudinal profile for the next sub-basin (sub-basin 9) was also extracted as in the sub-basin 15 and the maximum and minimum elevation for the river profile is 1132meter and 936meter respectively. The head drop of the sub-basin 9 was calculated by subtracting minimum elevation from maximum elevation.

H_{15}=1132m-936m

H_{15}=196m

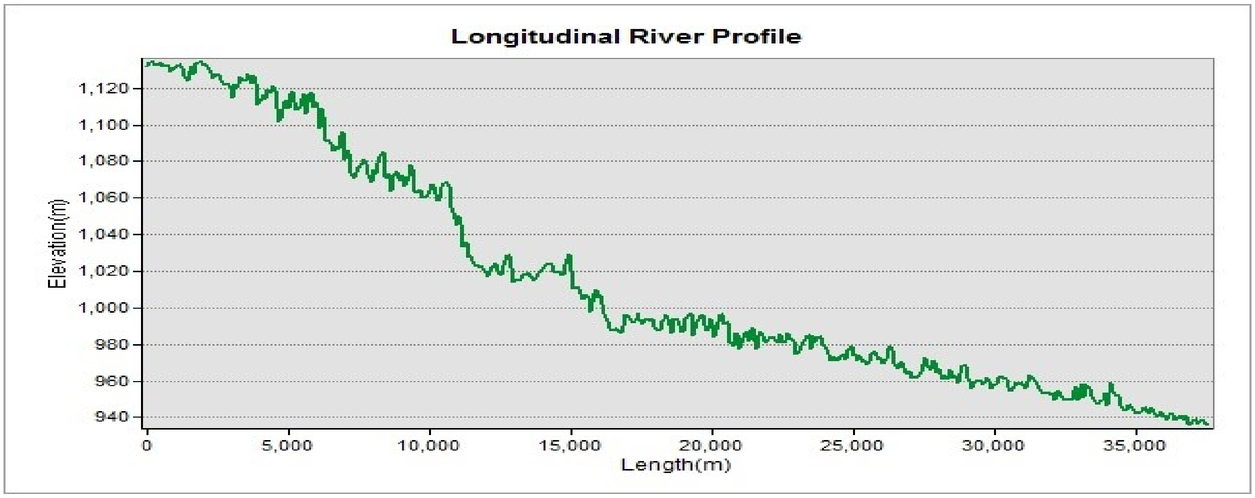


Figure 4.9: River Longitudinal Profile in Sub-basin 9

As discussed in section ‘A’ above there were no significant difference in flow out from sub-basin 5, 7 and 9 and the flow out from sub-basin 5 and 7 were transferred to sub-basin 1. Therefore, the river profile of sub-basin 1,5 and 7 were dissolved by GIS data management tool to make one stream profile (Figure 30). The maximum and minimum elevation from the stream profile were 936meter and 834meter respectively and the head drop of the sub-basin 1 was calculated by subtracting minimum elevation from maximum elevation like that of the others.

H_9=936m-834m

H_9=82m

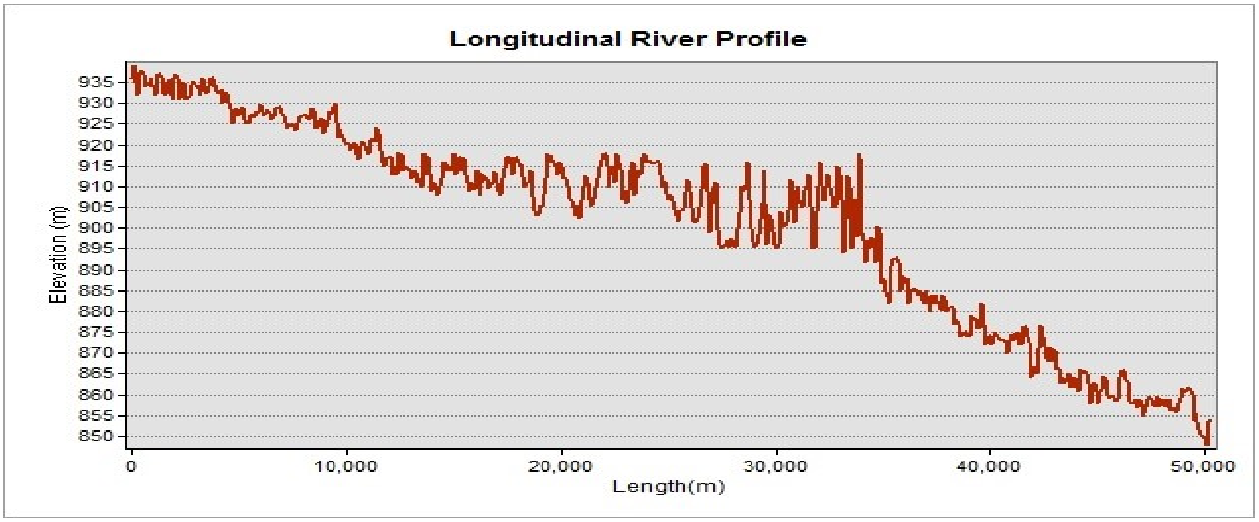


Figure 4.10: River Longitudinal Profile in Sub-basin 1

4.3.1.3 Potential Power Estimation for Run-Off-River Hydropower

The potential run-off-river hydropower was estimated by calculating the power at each sub-basin selected for flow out and river profile extraction. The power for each sub-basin was then calculated by multiplying average discharge and potential head drop at each selected sub-basin with efficiency and other ordinates as follow using equation 16.

Power at sub-basin 14(P_{14})

$$P_{14} = \left[\frac{\eta \rho g Q_{14} H_{14}}{1000000}\right] MW$$

$$P_{14} = \left[\frac{0.90 * 1000 * 9.81 * 96.98 * 30}{1000000}\right] MW$$

$$P_{14} = \left[\frac{186870921.6}{1000000}\right] MW$$

$$\boldsymbol{P_{14} = 186.87. MW}$$

Power at sub-basin 17(P_{17})

$$P_{17} = \left[\frac{\eta \rho g Q_{17} H_{17}}{1000000}\right] MW$$

$$P_{17} = \left[\frac{0.90 * 1000 * 9.81 * 138.63 * 189}{1000000}\right] MW$$

$$P_{17} = \left[\frac{227657354}{1000000}\right] MW$$

$$\boldsymbol{P_{17} = 227.66\ MW}$$

Power at sub-basin 15(P_{15})

$$P_{15} = \left[\frac{\eta \rho g Q_{15} H_{15}}{1000000}\right] MW$$

$$P_{15} = \left[\frac{0.95 * 1000 * 9.81 * 316.56 * 196}{1000000}\right] MW$$

$$P_{15} = \left[\frac{5487336651}{1000000}\right] MW$$

$$\boldsymbol{P_{15} = 548.73 MW}$$

Power at sub-basin 9(P_9)

$$P_9 = \left[\frac{\eta \rho g Q_9 H_9}{1000000}\right] MW$$

$$P_9 = \left[\frac{0.95 * 1000 * 9.81 * 443.043 * 82}{1000000}\right] MW$$

$$P_9 = \left[\frac{809272090.7}{1000000}\right] MW$$

$$\boldsymbol{P_9 = 809.27MW}$$

4.3.1.4 Total Hydropower Estimation of the Catchment

The total hydropower for the Didessa sub-basin was calculated by adding all hydropower potential at each selected watershed sub-basin

$$P_T = P_{20} + P_{17} + P_{15} + P_9$$

$$P_T = \mathbf{186.87} + \mathbf{227.66} + 549.73 + 809.27$$

$$\boldsymbol{P_T = 1773.5\ MW}$$

Table 4.4: Estimated Hydropower Potential at selected sub-basin outlet

	Sub-basin_20	Sub-basin_17	Sub-basin_15	Sub-basin_9	Units
Height(H)	30	186	196	82	meter
Average Q	96.86	138.63	443.04	525.22	m3/s
Power(P)	186.87	227.66	549.7336511	809.273006	MW
Total Power				1773.53	MW

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Electrification is the major problems on the Ethiopian, because of the increasing demand of electricity in all country including rural areas for domestic use as well big cities like Ababa; although the country has good theoretical surface and ground water resource.

Hydrologic simulation models are very essential way used to assess hydrological characteristics of watershed. They are efficient tools for evaluating effects and impacts that occur in hydrologic regime. They can be used to find out, predict and understand what happened and will happen throughout a basin in time and space.

SWAT2009 is an effective tool in estimating stream flow. The ability of SWAT to adequately predict stream flows was assessed through sensitivity analysis, model calibration, and model validation. The model was successfully calibrated and validated for stream flow estimation of the watershed by semi-automatic calibration. Calibration was done by SWAT-CUP SUFI2 for the adjustment of same flow parameter. The model evaluation statistics for stream flows prediction gave very good relation for validation and the results was verified by Nash Sutcliff efficiency NSE = 0.6, coefficient of determination R^2 =0.76. Percent Bias =-13.4 and Observations Standard Deviation Ratio RSR =0.43

Although the values of the parameters which have been predicted by SWAT in this study are somewhat different from those reported by previous investigators, the values of the statistical parameters which are often employed to test the predicting efficiency of SWAT model clearly portray that the results of the present study are quite reliable.

After calibration and validation of the model simulation by changing the parameter values of sensitive parameter average monthly flow was calculated to construct flow duration curve so, that power duration curve could easily be constructed for hydropower generation.

Didessa sub-basin potential hydropower was estimated based on potential head drop and estimated discharge. potential head was calculated from longitudinal river profile.

5.2 Recommendation

The idea of discharge estimation is useful in the power generation to meet the present and future electricity demand of the country. It will not only increase the development of future power requirement, but also, improves the water supply for irrigation, and other domestic use.

Therefore, for the development of the country, economically and environmentally sound power development has to be undertaken and priority should be given towards the development hydropower and other sources of renewable energy that are available in the country such as solar and wind, have to be developed sufficiently to meet the future electricity demand.

Although, hydrology is the core for hydropower development; studding only the hydrologic and topologic characteristic of the catchment is not sufficient for hydropower development. So, the following work should have to be recommended:

In this thesis, only theoretical hydropower potential has been estimated. The information about the technical and economic potential is very important in the development of hydropower in the country. So, the present work can be extended to estimate the technical and economic potential of hydropower in the future.

The effective head from the river profile is calculated after subtracting head loss throughout the profile. Therefore, the study of geological and morphological characteristics of the should have to be done for actual hydropower potential of the sub-basin.

The study has been done using only the power supply simulation. This study can be further extended to find the least cost electricity mix using least cost optimization.

This study covers only the power supply side. The effect of demand side management on power supply could not be studied. The present work can be extended to cover the demand side as well, so that the effect of policy intervention on the demand side can be studied on power generation and expansion planning.

REFERENCES

Abbaspour, K. C. (2015) Swat-Cup; Swat Calibration And Uncertainity Programme User Manual. Eawag.

Aghakouchak, A. (2010) *Application Of A Conceptual Hydrologic Model In Teaching Hydrologic Processes,* University Of Louisiana At Lafayette Arnold, J. G.

Alemu, E. (2011):Effects Of Watershed Characteristics On River Flow For The Case Of Rib And Gumara Catchments, . *Msc. Thesis.* Addis Ababa, University, Addis Ababa.

Arnold, J., Kiniry, J., Srinivasan, R., Williams, J., Haney, E. & Neitsch, S. (Eds.) (2011) *Soil And Water Assessment Tool Input/Output File Documentation Version 2009,* Texas, Texas A&M University System.

Awulachew & Yilma, A. D. (2009) Water Resources And Irrigation Development In Ethiopia. Colombo, Sri Lanka.

B. Feizizadeh & E. Haslauer (2012) Gis-Based Procedures Of Hydropower Potential For Tabriz Basin, Iran

Bceom (1998) Abbay River Basin Integrated Development Master Plan Project Phase 2,Data Collection And – Site Investigation Survey And Analysis, Section Ii. Addis Abeba.

Bewket, W. & Sterk, G. (2005):Dynamics In Land Cover And Its Effect On Stream Flow In The Chemoga Watershed, Blue Nile Basin, . Ethiopia.

C. C. Warnick , Howard A. Mayo, J., P.E,, James L. Carson & Lee H. Sheldon, P. E. (1984) *Hydropower Engineering*, Coul.Tesy Of Bureau Of Reclamation, U.S. Department Of The Interior.

C. N. Emeribe, E. T. Ogbomida, O.A Fasipe, O. Biose, I. Aganmwonyi, M. Isiekwe & I. P. Fasipe (2015)*:Hydrological Assessments Of Some Rivers In Edo State, Nigeria For Small-Scale Hydropower Development,. Nigerian Journal Of Technology (Nijotech):,* Vol. 35,**,** 656 - 668.

Castellarin, A., Galeati, G. & Brandimarte, L. (2004) Regional Flow-Duration Curves: Reliability For Ungauged Basins. Advances In Water Resource

Chap T. Le (2003) *Introductory Biostatistics,* Canada, Printed In The United States Of America, John Wiley & Sons, Inc., Hoboken, New Jersey.

Chow, V. T., Maidment, D. R. & Mays, L. W. (1988) *Applied Hydrology,* United States Of America.

Cunderlik M. Juraj (2003) Hydrologic Model Selection Fort The Cfcas Project: Assessment Of Water Resources Risk And Vulnerability To Changing Climatic Conditions, Project Report I, 40pp.

Di Luzio, M. D., R. Srinivasan, J.G. Arnold & S.L. Neitsch (2002) Arcview Interface For Swat2000 (Avswat2000), User's Guide, Grassland Soil And Water Research Laboratory, Black Land Research Center, Texas Agricultural Experiment Station, Texas Water Resources Institute, College Station, Texas Twri

Douglas T, B. P., Orr C, (2007) *Run-Of-The-River Hydropower In Bc: A Citizen's Guide To Understanding Approvals, Impacts And Sustainability Of Independent Power Projects* <Http://Www.Rivershed.Com/Documents/Guide_To_Runriver.Pdf>. *Watershed Watch.* .

Emil, M. (1991) *Water Power Development Volume Two/A, High-Head Power Plants*, Academiai Kido.Budepest.

Fao (1995) Digital Soil Map Of The World And Derived Soil Properties (Cdrom) Food And Agriculture Organization Of The United Nations, Fao. .

Fao (2001) Preparation Of Land Cover Database Of Bulgaria Through Remote Sensing And Gis, Vershion 6. Bulgaria, Europe.

Fao, U. S. D. O. F. A. O. (2006) *Natural Resources Conservation Service Irrigation National Engineering Handbook Part 623*

Fikadu & Abdela (2008/2009/) Hydropower Engineering-I Lecture Note/. Arbaminch Arbaminch University Department Of Hydraulic Eng'g.

Guarg, K. (2006) *Irriagtion Engineering & Hydraulic Structures*, Sh.Romesh Chander Khanna.

Gutema, D. (2015) *Morphometric Analysis To Identify Erosion Prone Areas On The Didessa And Jema Sub-Basin*. *Hydraulic Engineering.* Jimma, Jimma University.

H.M.Ranghunath (2006) *Hydrology Principles, Analysis And Design,* Mumbai, New Age International (P) Ltd.,.

Han, D. (Ed.) (2010) *Concise Hydrology*, Dawei Han And Ventus Publishing Aps.

Hecht, J. & Lacombe, G. (2014) The Effects Of Hydropower Dams On The Hydrology Of The Mekong Basin.

J. G. Arnold, D. N. Moriasi, P. W. Gassman, M. J. White, K. C. Abbaspour, R. Srinivasan, C. Santhi, R. D. Harmel, A. Van Griensven, M. W. Van Liew & N. Kannan, M. K. J. (2012) Swat: Model Use, Calibration, And Validation

J. V. Tyagi, S. P. Rai, Nuzhat Qazi & Singh, M. P. (2014) Assessment Of Discharge And Sediment Transport From Different Forest Cover Types In Lower Himalaya Using Soil And Water Assessment Tool (Swat) Jal Vigyan Bhawan, National Institute Of Hydrology.

James K. Searcy (1999) Flow-Duration Curves; Manual Of Hydrology: Part 2. Low-Flow Techniques. United States Government Printing Office, Washington Geological Survey Water-Supply.

Johansson, B. (1994) The Relationship Between Catchment Characteristics And The Parameters Of A Conceptual Runoff Model

Norrkôping,Sweden, The Swedish Meteorological And Hydrological Institute.

K. Subramanya (2008) *Engineering Hydrology,* New Delhi, Tata Mcgraw-Hill Publishing Company Limited.

Lenhart, T., Eckhardt, K., Fohrer, N. & Frede, H. G. (2002) Comparison Of Two Different Approaches Of Sensitivity Analysis. Physics And Chemistry Of The Earth.

Ministry, O. W. A. E. (1997) *Power Generation Projects Open For Private Sector Participation*. Addis Abeba.

Molla, M., Ayenew (2015) *Hydropower Development Indispensable To Ethiopian Economic Transformation. Addis Abeba.*

Moriasi, D. N. (2007) Model Evaluation Guidlines For Systematic Quantification Of

Accuracy In Watershed Simulations.

Mosonyi, E. (1991) *Water Power Development Volume Two/B, High-Head Power Plants*, Academiai Kido.Budepest.

Neitsch, S. L., J. G. Arnold, J. R. Kiniry & Williams, J. R. (2005) *Soil And Water Assessment Tool Theoretical Documentation-Version2005,* Texas, *Soil And Water Research Laboratory, Agricultural Research Service, And Black Land Agricultural Research Station,Temple*.

Oregon State University (Osu) (2002) Analysis Techniques: Flow Duration Analysis. Streamflow Evaluations For Watershed Restoration Planning And Design.

P. Novak, A.I.B. Moffat & C. Nallur (2007) *Hydraulic Structures,* Usa And Canad, Taylor & Francis.

Pieter Van Der Zaag & Kammer, D. (2005) *Handbook For The Assessment Of Catchment Water Demand And Use*

University Of Zimbabwe.

Plutonic Power (2008) Revised Project Description For Bute Inlet Hydroelectric Project Requirements. P1 <Http://Www.Ceaa.Gc.Ca/050/Documents/33401/33401e.Pdf>. . Plutonic Power.

Raja, A. K. & Srivastava, A. P. (2006) *Power Plant Engineering*, New Age International.

Rechard M.Vogel & Neil M.Fennessey (1995) *Flow Duration Curve Ii:A Review Of Application In Water Resources Planning*, American Water Resource Association.

Robyn, Johnston & Mccartney, M. (2010) *Inventory Of Water Storage Types In The Blue Nile And Volta River Basins*. *Colombo, Sri Lanka*.

S. Hajjam, N. Yusefi & P.Irannejad (2005) *A Blended Model For Estimating Of Missing Precipitation Data*

Setegn, S. G., Srinivasan, R. & Dargahi, B. (2008) Hydrological Modelling In The Lake Tana Basin, Ethiopia Using Swat Model.

Shawul, A. A., Alamirew, T. & Dinka, M. O. (2013) Calibration And Validation Of Swat Model And Estimation Of Water Balance Components Of Shaya Mountainous Watershed, Southeastern Ethiopia. Addis Abeba, Madawalabu,Addis Abeba & Haromaya University Respectivily.

Shivhare, V., Goel, M. K. & Singh, C. K. (2014) Simulation Of Surface Runoff For Upper Tapi Subcatchment Area (Burhanpur Watershed) Using Swat

Sima & Bizuneh, A. (2011) *Flow Regime And Land Cover Changes In The Didessa Sub-Basin Of The Blue Nile River, South - Western Ethiopia*. *Urban And Rural Development. Uppsala, Swedish University Of Agricultural Sciences*

Sintayehu Legesse, Kassa Tadele & Mariam, B. G. (2015) *Assessment Of The Impacts Of Climate Change On Water Resources Availability And The Hydrology Regime Of Didessa Catchment*. *Water Resources And Hydraulic Engineering, . Arbaminch Universit,Jimma University*.

Srinivasan, P., Arnold, J. G., Muttiah, R. S. & Williams, J. R. (1998) *Large Area Hydrologic Modelling And Assessment Part I., Model Development. J. Am. Water Resour. Assoc. 34, 73–89*.

Tena Bekele, Srinivasa Rao & Yerremsetty Abbulu (2015) Assessment Of Spatio-Temporal Occurrence Of Water Resources In Didessa Sub-Basin. *Department Of Civil Engineering, College Of Enginering.* Andhra Pradesh, University, Visakhapatnam.

Tesfaye, M. & Wondimu, M. (2014) Morphometric Analysis Of Didessa River Catchment In Blue Nile Basin,Western Ethiopia *Department Of Geography And Environmental Studies*. Gimbi, Ethiopia, Wollega University.

Tewodros, T. (2012):Physically Based Rainfall Runoff Modeling In The Northern Ethiopia Highlinds:-The Case Of Mizewa Watershed,. Bahirdar University.

Timo A. Räsänen & Kummu, M. (2013) *Catchment Hydrology And Its Modeling In Nam Theun-Nam Kading And Sesan River Catchments*

Tsedalu, A. (2015) *Hydrological Responses To Land Use And Land Cover Changes Of Ribb River Watershed. Hydraulic Engineering. Jimma University*.

Vorgelegt Von & Saarbrücken (2011) An Interdisciplinary Approach To The Dissemination Of Mini And Micro Hydropower -The Case Of Ethiopia. Darmstadt University Of Technology &Technology Of Addis Ababa University (Aau).

Williamson, R. (2001) *Surface Water Hydrology,* California; Davis.

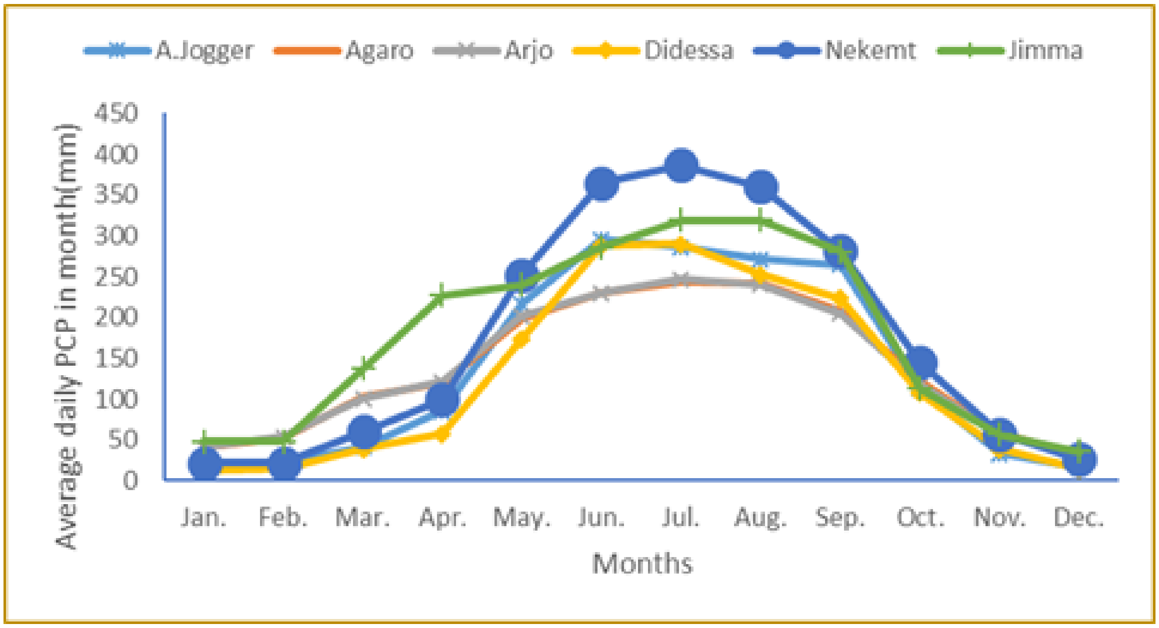
Yohannes, E. (2007) *"Assessed Water Resource Potential For Lake Tana Basin Based On Remote Sensing Data*". *Civil And Environmental Engineering*. Addis Abeba, Addis Abeba University.

APPENDIXES

Appendix 1:Average Daily Precipitation of selected station in Didessa sub-basin

Month	A.Jogger	Agaro	Arjo	Didessa	Nekemt	Jimma
Jan.	22.03	41.2	40.97	12.46	21.74	47.77
Feb.	21.83	51.54	53.71	15.51	21.77	48
Mar.	41.31	103.14	100.89	38.37	60.46	136.89
Apr.	85.46	119.69	121.43	57.77	99.74	227.49
May.	217.2	197.66	202.03	173.74	252.74	239.8
Jun.	295.89	230.06	229.86	288.29	365.03	285.77
Jul.	286.49	244.34	246.57	289.63	386.09	318.65
Aug.	271.49	241.83	240.17	252.77	359.77	318.57
Sep.	264.71	208.26	204.89	223.11	281.37	280.57
Oct.	112.51	121.34	117.97	107.03	144.46	112.97
Nov.	33.23	57.11	56.26	38.46	57.29	56.29
Dec.	15.73	31.51	32.82	14.51	26.68	35.77

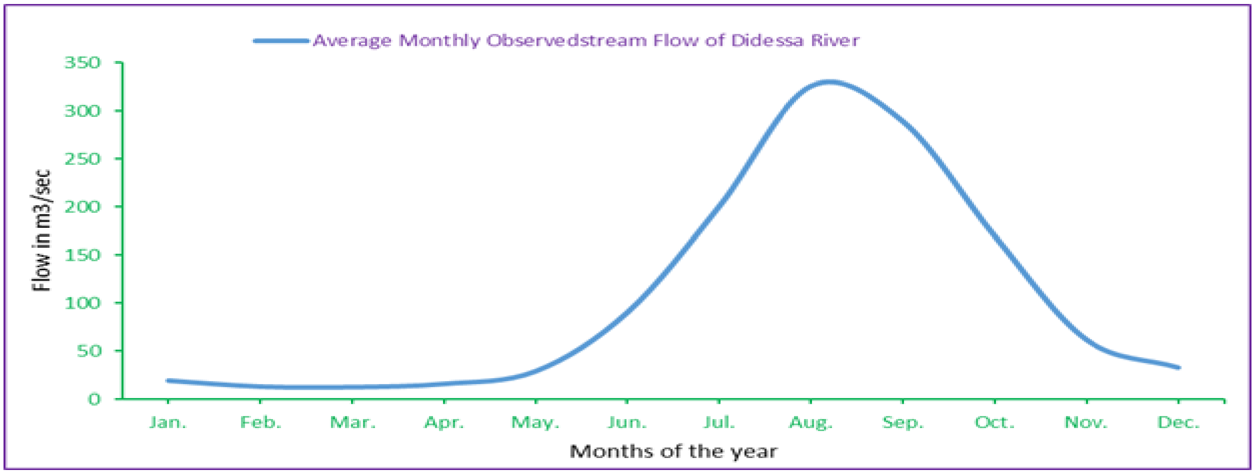
Appendix 2:Consistency graph of average precipitation of Didessa sub-basin



Appendix 3:Average Monthly Observed Daily Stream Flow of Didessa River

Average Stream flow of Didessa River												
Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1980	6.71	6.11	3.72	26.45	71.27	194.26	341.41	481.07	479.81	146.78	39.79	34.53
1981	29.86	17.92	16.18	13.65	20.04	20.54	187.71	443.68	3.21	15.34	21.61	21.69
1982	22.33	12.48	10.68	7.44	17.06	95.71	263.85	353.67	267.00	283.97	68.16	35.29
1983	16.20	13.09	12.73	9.01	19.58	59.15	211.14	425.39	430.38	459.61	102.08	45.29
1984	14.39	6.66	4.43	3.66	10.67	71.46	262.45	248.39	200.83	48.84	87.51	45.29
1985	4.47	2.25	0.97	4.56	23.28	65.32	163.61	346.14	324.68	97.07	30.66	16.82
1986	6.56	3.93	6.00	5.33	4.77	45.82	168.81	183.37	282.35	82.83	24.32	11.04
1987	4.85	2.45	4.63	6.71	15.76	55.78	168.81	245.84	259.51	144.26	61.85	25.31
1988	15.11	10.98	8.05	2.96	13.81	108.05	207.19	444.47	259.51	172.39	72.91	26.42
1989	15.10	9.65	7.60	12.93	10.12	46.51	101.83	186.46	419.48	147.86	41.34	45.98
1990	19.97	12.42	12.62	23.50	15.70	60.72	128.25	360.94	460.80	117.93	34.15	45.98
1991	19.97	12.42	12.62	23.50	15.70	57.74	202.87	426.67	236.52	117.93	23.92	14.23
1992	9.14	9.55	5.14	7.99	21.08	61.98	137.37	307.83	217.78	300.97	63.31	27.40
1993	15.88	11.52	9.11	21.11	39.28	120.43	223.87	432.62	243.33	148.57	64.48	23.65
1994	14.58	8.09	5.78	6.05	22.29	84.95	199.44	455.86	331.03	58.38	26.26	13.79
1995	7.60	5.06	5.53	7.50	14.28	32.02	84.00	212.42	187.46	58.32	23.12	13.36
1996	7.60	5.05	9.58	11.72	52.95	143.96	270.04	319.01	230.58	105.46	38.66	32.54
1997	15.46	7.87	5.61	20.19	51.15	151.53	216.20	318.73	236.59	264.15	205.71	88.52
1998	49.51	30.45	32.11	24.35	39.43	91.70	218.93	443.07	344.89	405.72	116.22	31.42
1999	7.00	1.84	0.39	0.16	27.41	116.53	189.36	268.86	234.56	380.91	70.13	21.67
2000	10.91	8.93	15.45	19.87	43.60	98.80	167.87	256.73	256.44	211.46	93.37	50.65
2001	31.77	24.61	24.66	22.65	47.89	154.65	276.40	390.27	387.87	251.66	82.80	41.71
2002	36.96	23.64	20.63	24.47	17.27	67.40	170.70	220.65	222.87	78.66	44.45	31.31
2003	21.05	14.98	20.97	28.68	17.91	46.38	181.53	243.49	273.07	112.69	41.25	27.53
2004	19.51	16.03	11.30	11.06	24.34	77.90	196.51	238.51	247.89	200.91	54.10	33.84
2005	23.15	14.43	16.55	13.77	31.10	87.70	159.50	320.71	382.96	147.71	62.79	35.20
2006	23.10	17.10	15.44	16.99	27.17	89.72	252.22	540.88	395.20	172.26	90.23	51.68
2007	34.07	26.30	19.13	25.09	45.01	113.37	313.01	357.57	369.17	181.91	47.95	33.97
2008	28.31	19.10	10.59	24.40	64.78	173.44	202.97	306.75	225.74	84.80	102.83	46.97
2009	30.22	21.53	21.45	31.87	35.06	52.22	111.88	219.24	177.91	163.97	53.95	37.21
2010	28.08	23.14	21.23	19.26	49.51	174.49	267.56	298.04	393.58	131.47	24.26	7.01
2011	10.91	8.62	15.58	19.34	42.32	97.09	166.26	252.81	255.96	215.20	97.57	51.46
2012	32.17	24.68	24.66	22.65	47.89	154.65	276.40	390.27	387.87	251.66	82.80	41.71
2013	36.96	23.64	20.63	24.47	17.27	67.40	170.70	220.65	222.87	78.66	44.45	31.31
2014	21.05	14.98	20.97	28.68	17.91	46.38	181.53	243.49	273.07	112.69	41.25	27.53

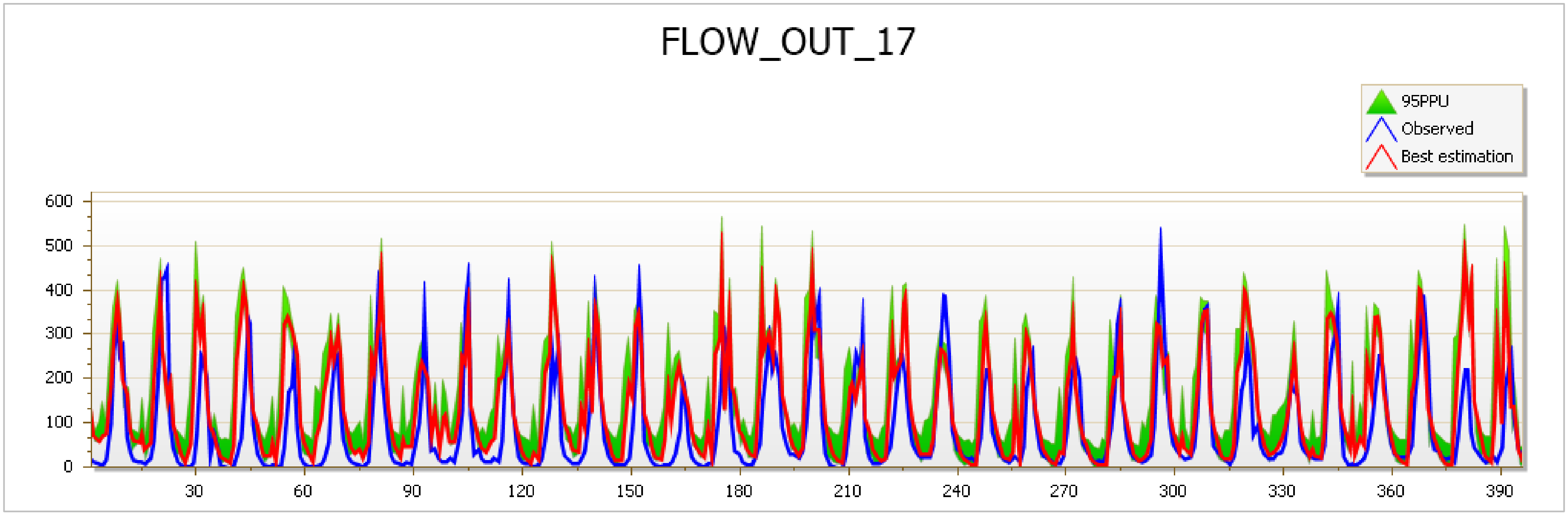
Appendix 4:Observed Stream Flow Hydrograph of Didessa River in five year interval



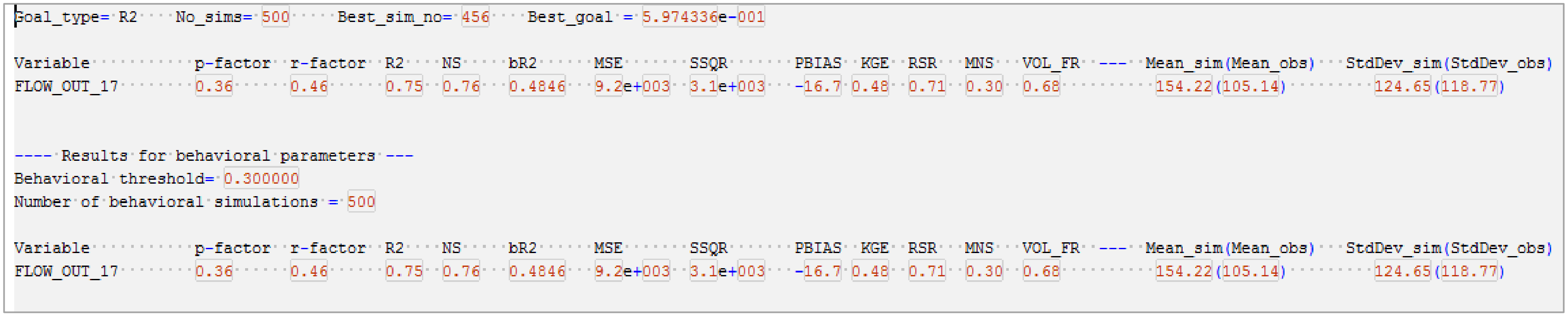
Appendix 5:Best simulated stream flow Data of study area from 1982-2014

Best simulated stream flow for Didessa												
Year	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1982	130.5	74	61.01	71.73	75.22	178.8	297	398	326.2	198.4	166.8	84.43
1983	62.74	57.49	85.03	43.95	56.23	197.5	329.9	444.4	263.8	170.6	212	95.99
1984	57.9	31.29	18.9	51.85	194.8	421.7	318	372.5	159	92.48	80.63	43.06
1985	24.27	19.53	13.19	48.7	243.9	346.3	421.6	358.4	211.9	129.3	92.49	51.48
1986	26.57	26.59	67.93	32.69	119.1	320.9	348.2	325.6	306.3	253.7	100.5	57.4
1987	34.07	21.53	70.33	106.7	169	233	308.1	258.3	322.9	256.7	128.1	76.4
1988	43.8	35.3	46.22	26.24	55.14	275.5	235.7	339.9	486.9	311.9	141.3	89.95
1989	50.83	30.51	73.02	47.88	46.95	115.9	214.3	247.6	228.4	200.6	96.27	141.5
1990	60.73	115.3	124.5	60.3	58.22	120.5	261.1	244.4	404.5	139.2	109.8	61.58
1991	43.38	37.29	57.77	64.72	202	203.9	235.6	336.5	218.7	116.8	69.35	36.99
1992	23.41	15.59	39.68	23.29	108.6	215.8	256.9	477	405.6	283.1	172.3	101.6
1993	73.5	41.83	37.16	150.2	115.5	292.5	192.2	379.6	321.7	159.9	104	60.48
1994	31.56	18.83	18.77	93.66	204.4	176.8	319.2	361.1	280.8	122.5	86.45	44.71
1995	25.08	22.33	61.5	207.8	132.8	192.5	243.7	205	178.3	134.9	81.7	52.64
1996	34.13	29.06	107.9	54.44	258.2	292.8	530.2	196.6	398.7	183.2	159.8	83.51
1997	72.56	42.1	30.54	26.88	197.1	454.6	281.8	312.2	272.1	413.6	335.9	163.1
1998	116.1	68.29	47.5	29.89	46.12	245.7	359.1	495.5	313.2	311.3	200.9	104.2
1999	57.12	29.95	18.26	14.49	79.71	181.6	198.1	165.3	221.8	276.8	112.4	78.99
2000	41.05	22.98	17.26	21.01	182.4	332.1	219.4	241.5	372.2	401.5	156.7	104.6
2001	56.93	29.9	30.74	29.54	65	150.7	269.1	267	255.6	186.4	105.1	66.13
2002	33.97	19.87	14.13	8.144	6.957	144.7	284.3	352.4	222.2	127.5	81.27	47.69
2003	23.34	20.23	34.85	188.2	57.51	222.5	314.1	277.9	190	131.5	77.55	43.05
2004	24.36	13.3	9.902	38.98	35.9	178.1	249.6	372.7	191.7	105.4	68.84	44.36
2005	22.38	12.76	7.773	7.482	6.43	159.9	203.4	207.3	359.4	150.8	96.85	61.24
2006	31.96	18.21	21.9	26.72	61.46	226.1	328.8	320.5	240.6	251.5	115.4	79.53
2007	45.91	83.56	43.85	33.1	90.08	167.1	326.4	353.6	357.2	146.2	97.96	55.81
2008	29.15	21.29	21.02	50.08	213.9	259.7	407.6	395	319.8	272.9	132.7	87.81
2009	51.25	30.57	35.9	43.07	61.83	81.71	116.5	206.8	283.8	151.1	93.67	55.88
2010	30.04	46.91	28.33	25.26	83.3	334.5	352.6	338.9	277.6	136.6	98.48	58.49
2011	164.4	40.26	73.1	58.8	266.1	198.9	338	343.8	299.1	177.9	107.8	68.74
2012	35	20.5	14.03	10.14	168.3	203.3	407.8	400.9	330.7	131.7	103.4	65.96
2013	36.73	20.01	12.12	7.837	115.6	224.1	357.7	513.4	373.3	458.7	149.7	98.39
2014	57.4	28.4	17.8	115.9	358.3	165.8	464.6	324.2	139.0	235.7	121.7	102.8

Appendix 6:Simulated Verses Observed Flow Hydrograph from 1982-2014 (95PPU_plot)



Appendix 7:Statistic summary simulated value for Calibration



```
Goal_type= R2   No_sims= 500    Best_sim_no= 456   Best_goal = 5.974336e-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_17       0.36      0.46      0.75  0.76  0.4846  9.2e+003 3.1e+003   -16.7 0.48  0.71  0.30  0.68          154.22(105.14)       124.65(118.77)


---- Results for behavioral parameters ---
Behavioral threshold= 0.300000
Number of behavioral simulations = 500

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_17       0.36      0.46      0.75  0.76  0.4846  9.2e+003 3.1e+003   -16.7 0.48  0.71  0.30  0.68          154.22(105.14)       124.65(118.77)
```

Appendix 8:Default and Best Simulated Verses Observed Flow Hydrograph