MODELING THE WATER BALANCE, RESERVOIR OPERATION AND SIMULATION ANALYSIS FOR CASCADED HYDROPOWER PLANTS.

(A CASE STUDY OF UPPER GENALE-DAWA RIVER BASIN)

By

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A Thesis Submitted to The School of Graduate Studies of Addis Ababa University in Partial Fulfillment of The Requirements for The Degree of Master of Science in Hydraulic Engineering

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I, the undersigned that I have read and here by recommended for acceptance by the Addis Ababa University a dissertation entitled **“Modeling The Water Balance, Reservoir Operation and Simulation Analysis for Cascaded Hydropower Plants: A Case Study of Upper Genale-Dawa River Basin”,** and here by recommend for acceptance by Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Hydraulic Engineering.

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ABSTRACT

This research is intended to assure the equilibrium between energy production and consumption from hydroelectric energy. Hydroelectric power plant development on Genale-Dawa River basin is, a part of development plan for Ethiopian energy production. Modeling of Water balance and Reservoir Operation is frequently required in Hydraulic engineering for reservoir management and to control fluctuation of water. This study mainly focuses on water balance and reservoir operation analysis for cascaded hydropower plants in the Genale-Dawa river basin by using HEC-ResSim and HEC-HMS model. The stream flow generation were estimated by using HEC-HMS model to enhance the water balance components at Genale cascade reservoirs in the semi-ungauged parts of upper river basins. A Digital Elevation Model (DEM) with 30×30 *resolution of the study area was used to extract the physical characteristics of watersheds using Arc-Hydro and the Geospatial Hydrologic Model Extension HEC-GeoHMS. Then the HEC-HMS program was selected for this study, to attain the water balance components of the basin due to its versatility, capability for flow generation, automatic parameter optimization and its connection with GIS through HEC-GeoHMS.*

HEC-ResSim (Hydrologic Engineering Center-Reservoir System Simulation) was used to simulate the water allocation and operation of ongoing and planned reservoirs system in Genale-Dawa River basin. It is capable of modeling any reservoir system and designed to perform reservoir operation modeling at single or multi reservoir system. The performance of the model has been evaluated through calibration and validation process. The HEC-HMS model was calibrated and validated on a monthly time scale, with reference to Chena-Mansa gauging station to estimate the flow from Genale-Dawa river basin using a time series dataset of 16 years from 1990-2005. For calibration the model results in the performance criteria of $\boldsymbol{R^2 = 0.903}$*, and* ***NSE = 0.8926****, and* ***D = -0.0002%****, and for validation performance criteria of* $\boldsymbol{R^2 = 0.866}$*, and* ***NSE = 0.8447****. Thus, HEC-HMS model has the ability to predict the water potential of the basin.*

Following the configuration, and application of HEC-ResSim model, the position of guide curve was fixed at a minimum operative level for GD-3 and assigned at top of conservation zone for GD-5, and GD-6 along with explicit system storage balance which is used to force the upstream reservoir, GD-3, to fill first, allowing the downstream reservoirs, GD-5, and GD-6 *to stay empty as long as possible when operating for flood control. The results of annual average hydropower energy generated by the model from joint operation of the reservoirs system is* ***4,311.25 GWh/year****. The whole cascade power generation increment is* ***381.25 GWh/year*** *and it is a* ***9.701%*** *improvement over the current design which is* ***3,930 GWh/year****. Also, Combined reservoir system operation model is capable to store* ***517.13*** *million cubic meter flood water resources annually which shows* ***16.75%*** *total reduction of spill release over the current design.*

Keywords: Arc-GIS, Arc-Hydro, HEC-GeoHMS, HEC-HMS, HEC-ResSim, Optimal Water Release, Storage Balance, Genale-Dawa River Basin.

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ABBREVIATION

DEM	Digital Elevation Model
DSS	Decision Support System
EEP	Ethiopian Electric Power
EEPCO	Ethiopian Electric Power Corporation
ETo	Potential Evapotranspiration
FAO	Food and Agricultural Organization
FSL	Full Supply Level
GD	Genale-Dawa
GDMP	Genale-Dawa Master Plan
GIS	Geographic Information System
GWh	Giga Watt hour
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modeling System
HEC-GeoHMS	Hydrologic Engineering Center-Geospatial Hydrologic Modeling System
HEC-ResSim	Hydrologic Engineering Center-Reservoir Simulation
HEC-DSS	Hydrologic Engineering Center-Data Storage System
ICS	Inter Connected System
m.a.s.l	Meter Above Sea Level
MM^3	Million Cubic Meter
MOL	Minimum Operating Level
MoWIE	Ministry of Water, Irrigation and Energy
MoWR	Ministry of Water Resources
MW	Mega Watt
MWh	Mega Watt hour
NMSA	National Meteorological Service Agency
NSE	Nash and Sutcliffe Efficiency
OP	Operational Policy
RCC	Roller Compacted Concrete
SCS	Soil Conservation Service
SEI	Storage Effective Index

UH	Unit Hydrograph
UNDP	United Nations Development Program
USACE	United State Army Corps of Engineers
UTM	Universal Transverse Mercator
WAPCOS	Water and Power Consultancy Service
WRDA	Water Resources Development Association

1. INTRODUCTION

1.1 Background

Although Ethiopia is endowed with an abundant water resources having 12 major river basins, very little of it has been developed to achieve the national economic and social development goals due to lack of well-organized researches on integrated water resource management and finance (Tilahun, 2015). Competition for water consumption across sectors (Agriculture, Hydropower, Industries, and Domestic) become increased. To avert water scarcities particularly, in the Genale-Dawa River basin new strategies for effective use of water will be need for water development and management.

Water resources planners, engineers, and hydrologists have long recognized that the benefits from cooperative operation of a multi-reservoir system may exceed the sum of benefits attained for independently operated reservoirs. Reservoirs are built and operated to achieve multiple objectives such as water supply, flood control, hydropower, recreation, and environmental flow requirements. Their operation requires deciding how to apportion water storage and release. Decisions must consider apportionment among reservoirs, objectives, time periods, and method of release. It would be valuable to establish an analytic and more systematic approach to reservoir operation, based on the information and prediction of extreme hydrologic events and advanced computational technology in order to increase the reservoir's efficiency for balancing the demands from the different users.

Although various operation models based on optimization and simulation models are available, conventional simulation model is still widely used for deriving operation rules due to its concise and direct viewing. However, it is used in single reservoir operations, and cannot be used in combined operation of cascade reservoirs. Therefore, poor storage distribution can be seen among cascade reservoirs. Hence, much of flood water resources are wasted during flooding seasons. Several attempts have been made to solve this problem in the recent past. Due to the lack of such advanced reservoir operation system in the country the fluctuation and shortage of power production and improper operation of any one of the reservoirs technically inefficient operation that failed to meet the desired objective has been noticed. Hence, Genale-Dawa project will attempt to develop advanced reservoir operation for the combined operation of reservoirs using the HEC-ResSim model and HEC-HMS Model.

1.2 Problem statements

The water resources in the Genale-Dawa river basin which is one of the major twelve river basins of Ethiopia is not fully developed and optimally allocated yet. but there is a progress to use the source. Most of hydropower plants are still managed on fixed predefined operating rules. Although various operation models based on optimization and simulation models are available, conventional simulation model is still widely used for deriving operation rules due to its concise, and direct viewing. However, it is used in a single reservoir operation, and cannot be used in combined operation of cascade reservoirs. Therefore, poor storage distribution can be seen among cascade reservoirs. Hence, much of flood water resources are wasted during flooding seasons. Additionally, no great research effort has been put into evaluation of the developed master plan study under newly updated model for reservoir simulation and water allocation purpose.

Power demand is getting increasing from time to time. The exploitation of hydropower has been recognized as a key issue in the economic development of the country. But Power interruption is common in years of severe drought over the country and shortages in water disrupts power plant operation in the basin. For example, the 2008-2009 droughts caused an interruption that was lasted for about four months with a one day per week complete interruption throughout the country; hampering all business and economic activities. The crisis has also reached a critical point that blacks out occurred every other day with the water level in the currently operating hydropower generations dams going down by an average of one to two centimeters every day (EEPCO, 2005). In order to prevent this Reservoir water fluctuation during dry season the water resources in the Genale-Dawa river basin which is one of the major basins of Ethiopia should be fully developed and optimally allocated which is not yet. As a result, this study is going to put an evaluation of the water balance and reservoir operation analysis on Genale-Dawa river basin by using HEC-ResSim and HEC-HMS model to provide appropriate water allocation and reservoir management.

The Genale-Dawa Basin energy demand depends on traditional energy, mainly wood energy, is the major contributor to the basin energy supply which accounts about 99.6% (woody biomass 91%, Agri-residue 0.54%, and charcoal 0.79%) whilst the remaining 0.36% comes from modern sources energy (electricity 0.05% and Gas oil, Kerosene 0.26%). Rapid population growth, which increases the consumption of fuelwood and is causing drastic reductions of vegetation cover, with subsequent deleterious effects on the environment (GDMP

Volume-I.1, July,2007). Since, the continued and increasing use of wood as a fuel for cooking and heating, which is causing widespread environmental damage such as deforestation, soil erosion, and the loss of soil fertility places even greater pressures on forest reserves. The human interference of land use land cover for agricultural expansion and excessive grazing have a great influence on water resources availability, distribution, and variability of the river basin. The inappropriate and unsustainable use of environmental resources and the consequences of this phenomena may directly result in the climate change and flood hazards in this basin. However, as sited in Master Plan study by the ministry of water resources the Basin offers good opportunities for hydropower generation, and the economic hydropower potential was estimated as 1,200 MW installed capacity with a corresponding annual generation of about 5,500 GWh. Thus, this study will have a profound importance on water resources development, and management of Genale-Dawa river basin which enhance and expand the appropriate technology, and utilization of hydrological resources for power generations.

Downstream Water demands; in the lower Genale river (downstream of Kole bridge) there is a wide plain on both banks of Genale with topography suitable for irrigation. Pumping from Genale at Kole to a canal at approximately the 220m contour, including part of lower Weyib valley, a total net area of some 30,000 ha can be served on both banks of Genale. The gross area is about 55,000 ha but some of this is made up of rocky hill and other land not suitable for irrigation. The static required pumping lift is estimated to be about 30-35 meters. The alternative to pumping at Kole is to construct a diversion dam at the site which would allow the irrigation of an additional small area along the Genale river. If the hydropower projects are constructed on the Genale the flow will be regulated to a greater extent. The perennial flow in the Genale river, particularly with regulation, would permit irrigation all the year round and the growing of perennial crops. In the lower Genale, there are reports of serious flooding leading to loss of life, livestock and livelihood (The FDRE; MoWR, GDRB-Integrated Resources Development Master Plan Study, V.II.3.H, July, 2007). The development and effective management of Genale-Dawa reservoirs system would have provide some of the regulation required by in between reservoirs and, downstream irrigation as well as used to reduce flooding hazards.

Hence, the HEC-ResSim model can support the decision-making process which will enables the government and policy makers to formulate and implement water resource management options and appropriate response strategies.

1.3 Project Objective

1.3.1 General Objective

The general objective of this research is to estimate the water balance components and, enhance the hydropower generation capacity of the country through developing cascaded hydropower reservoir systems along the Genale main river basin.

1.3.2 Specific Objectives

- To estimate the water balance components in the river basin by using HEC-HMS and HEC-ResSim models' application.
- To analyze reservoir operation of Genale-Dawa cascade reservoirs.
- To simulate optimal Power production for Genale-Dawa cascade hydropower plant.

1.4 Project Scope

This project focuses on designing, networking, and water balance and simulation reservoir of Genale-Dawa hydropower plant. Design, simulation & networking of the reservoir involve making the reservoir fulfillment of the design flood discharge. After the analysis, the reservoir using HEC-ResSim and HEC-HMS model the designing process is completed for each reservoir element.

1.5 Research Questions

The main research questions are presented as follows;

1. What are the potential water resources of the river basin?
2. What are the proposed multi-purpose water resources development projects in the Genale-Dawa river basin?
3. What are the impacts of the river basin storage water on downstream and upstream interaction with the reservoir operation?

2. LITERATURE REVIEW

2.1 Reservoir operation

The HEC-ResSim model which was most recently introduced by U.S. Army corps of Engineers is an interesting tool for hydropower plant simulation. Most of the hydropower plants are still managed on fixed predefined operating rules. This is mainly institutional, rather than technological and mathematical limitations. this predefined rule is usually presented in the form of graphs and tables and called reservoir operation charts. It represents all the regular functions of operating rules and provides guidance to system operators. Although, various operation models are available, conventional simulation model is still widely used for deriving operation rules due to its concise and direct viewing. However, it is used in single reservoir and cannot be used in combined operation of cascade reservoirs. Therefore, poor storage distribution can be seen among cascade reservoirs. Hence, much of flood water resources are wasted during flooding seasons. Several attempts have been made to solve this problem in the recent past. The Storage Effectiveness Index (SEI) which has been introduced by U.S Army Corps of Engineers is one of the decision-making rules in the cascade reservoirs operation for maximizing firm hydropower production. This combined reservoir operation model consists of three components;

- Combined guide curves,
- Storage distribution,
- Optimization

During the release process, it is required that combined reservoir operation model can synthesize reflecting hydrological characteristics of the river basin and unique features of reservoirs. it should also satisfy with the guide rules of reservoirs in different inflow scenarios and different water level condition **(Shenglian Guo Xiang li pan liu Fuqiang Guo, March 2009)**. Reservoir operation is the method used to allocate water stored in the reservoir among different upstream and downstream users. It is an important element in water resources planning and management. Reservoir operation consists of several control variables that defines the operation strategies for guiding a sequence of releases to meet a large number of demands from stakeholders with different objectives, such as flood control, hydropower generation and allocation of water to different users. A major difficulty in the operation of reservoirs is the often conflicting and unequal objectives that require optimal operation rule and strong decision support system. Reservoir operating policies are based on dividing the total storage capacity into designated pools or vertical zones (USACE, 2007)

2.1.1 Reservoir System Operation Policy

An operating plan or release policy is a set of guidelines for determining the quantities of water to be stored and to release or withdraw from a reservoir or system of several reservoirs under various conditions. Operating decisions involve allocation of storage capacity and water releases between multiple reservoirs, between project purposes, between water uses, and between time periods. Optimization models automatically search for an optimal set of decision variable values **(Labadie, J., 2004).**

Reservoir Pools Zones

Reservoir operating policies are based on dividing the total storage capacity into designated pools or vertical zones (USACE, 2007).

A typical reservoir consists of one or more of the zones, or pools, illustrated by figure 2.1.

Inactive Pool: Water releases or withdrawals are normally not made from the inactive pool, except through the natural processes of evaporation and seepage. The top of inactive pool elevation may be fixed by the invert of the lowest outlet. The inactive zone is sometimes called dead storage. It may provide a portion of the sediment reserve, head for hydroelectric power, and water for recreation and fish habitat.

Conservation Pool: Conservation storage provides purposes, such as municipal and industrial water supply, irrigation, navigation, hydroelectric power generation. Conservation storage also provides opportunities for recreation. The reservoir water surface is maintained at or as near the designated top of conservation pool elevation as stream inflows and water demands allow. Drawdowns are made as required to meet the various needs for water

Flood Control Zones: The flood control zone remains empty except during and immediately following a flood event. The crest of an uncontrolled emergency spillway often sets the top of flood control pool elevation, with releases being made through other outlet structures. Gated spillways allow the flood control pool to exceed the spillway crest elevation.

Surcharge Zone: is essentially uncontrolled storage capacity above the flood control pool (or conservation pool if there is no designated flood control storage capacity) and below the maximum design water surface. Major flood events exceeding the capacity of the flood control pool encroach into surcharge storage. Encroachments into the surcharge zone are accompanied by flows being passed through the spillway.

Maximum Design Water Surface Level: is an elevation established during project design from the perspective of dam safety. The top of dam elevation is set by adding a freeboard to the maximum design water surface.

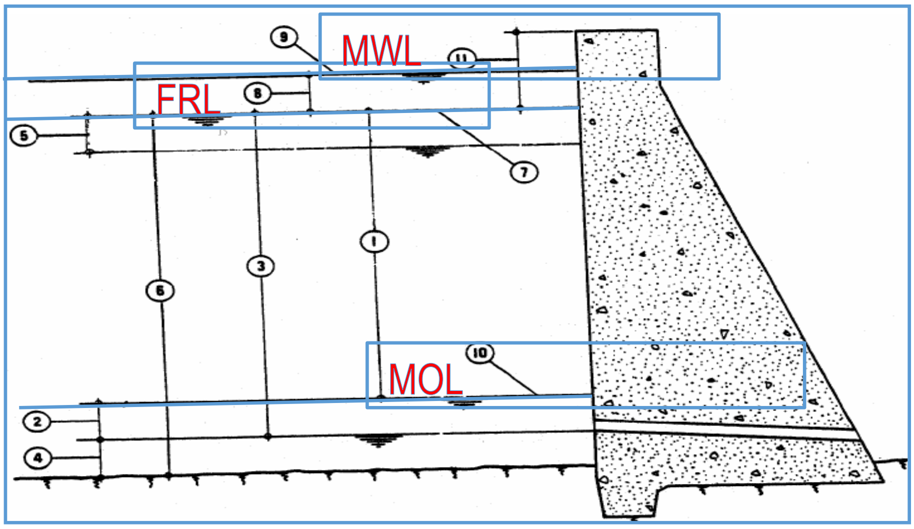


Fig.2.1. Typical Reservoir Pool Level

2.2 Reservoir Rule Curves

The terms rule curve or guide curve are typically used to denote operating rules which define ideal or target storage levels and provide a mechanism for release rules to be specified as a function of storage content (Wurbs et al,1985). Rule curves are usually expressed in as water surface elevation or storage volume versus time of the year. Although the term rule curve denotes various other types of storage volume designations as well, the top of conservation pool is a common form of rule curve designation. The top of conservation pool may be varied seasonally, particularly in regions with distinct flood seasons. The top of conservation pool could also be varied as a function of watershed moisture conditions, forecasted inflows, floodplain activities, storage in other system reservoirs, or other parameters as well as season of the year. A seasonally or otherwise varying top of conservation pool elevation defines a joint use pool which is treated as part of the flood control pool at certain times and part of the conservation pool at other times. An operating plan where upper and lower zones are used exclusively for flood control and conservation purposes, respectively, and the storage capacity in between is used for either purpose depending on season or other factors. Also, either the flood control or conservation pool can be subdivided into any number of vertical zones to facilitate specifying reservoir releases as a function of amount of water in storage.

2.3 Multi Reservoir System Analysis

Practical real-time operations also usually require the specification of reservoir operating rules. These rules determine the release and storage decisions for each reservoir at each time-step during the simulation and help guide reservoir operators (Bower et al. 1966; Hufschmidt, and Fiering, 1966). The most common rules used for reservoir operation are rules in series and parallel.

A. Rules for Reservoir in Series

Hydropower rules for reservoirs in series vary between refill and drawdown seasons or periods. During a refill period, the problem usually is to maximize the storage of energy at the end of the period. During a drawdown period, the objective is to maximize hydropower production for a given total storage amount. Different rules are employed for each period as shown in the figure 2.2 below diagrammatically.

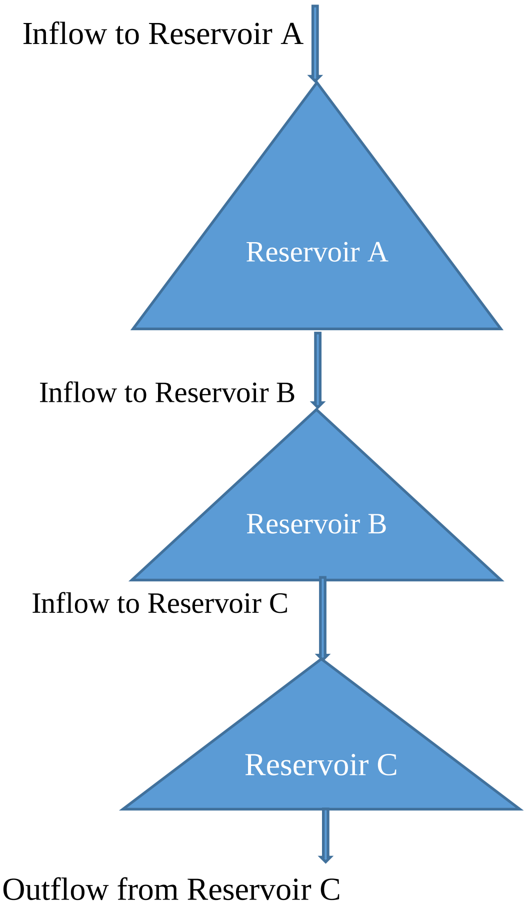


Fig.2.2 Conceptual Rules for Reservoir in Series

i. Energy Storage Rules

The objective of the energy storage rule for reservoirs in series is to maximize the total energy stored at the end of a refill season or period. Here, the refill season is defined as the season when system inflows exceed those needed to meet water supply or hydropower production demands. The energy storage rule for reservoirs in series is to always fill the upper reservoirs first. To maximize the energy stored for a future time, water storage is preferred in upstream reservoirs. Water stored at higher elevations has a higher energy content (kilowatt-hours/unit volume of water stored) than water stored at lower elevations. This is particularly true for water stored in reservoirs in series, where water eventually released from upper reservoirs generates hydropower at the lower reservoirs as well. Any spills from upper reservoirs are available for capture in space available in lower reservoirs. Kelman, et al. (1989) mathematically examines the allocation of energy storage and flood control storage capacity in complex multi-reservoir systems. Their results will often indicate the compatibility of the desirable distribution of energy and flood control storages in such two-purpose systems. Fortunately, energy storage and water supply storage rules for reservoirs in series are quite compatible for the refill season, at least in terms of where storage is preferred in the system and their general intent to accumulate the maximum amount of water. However, with the coming of the drawdown season, hydropower production rules are required.

ii. Hydropower Production Rule

When it comes time to produce energy, rules to maximize hydropower production may be employed. Upper reservoirs generate hydropower by releases which consequently also increase downstream power generation by increasing heads, if stored downstream, or by subsequent turbine releases downstream. The steady-state hydropower production rule attempts to maximize hydropower generation during a single time step, given a total storage target for the system, primarily during the drawdown season. This problem involves allocating a given total storage to maximize hydropower production. In general, the rule favors allocation of storage to those reservoirs which create a higher head per unit volume of storage, have higher generation efficiencies, and have higher releases, since hydropower production is the product of head, efficiency, and release.

B. The Tandem Operation Purpose

Tandem operation is the method in HEC-ResSim reservoir simulation model that used to analyses the reservoir operation in the system and the storage distribution among the reservoirs on the same stream. When a tandem reservoir system is defined, the model determines amount of release from the upper reservoir in order that the downstream reservoir is operating towards a storage balance. For every decision interval an end-of-data, storage is first estimated for each reservoir based on the sum of the beginning of date storage and daily average inflow value, minus all potential outflow volumes. The estimated end of date storage for each reservoir is computed to a desired storage that is determined by using a system storage balance scheme. The priority for release is then given to the reservoir that is furthest above the desired storage. When a final release decision is made, the end of period storage is recomputed. Depending on other constraints or higher priority rules, system operation strives for a storage balance such that the reservoirs have either reached their guide curve or they are operating at the desired storage (USACE, 2013).

C. Rules for Reservoir in Parallel

The operation of reservoirs in parallel, differs from reservoirs in series in that downstream reservoirs cannot be used to capture additional water from underestimated flows or benefit from the transfer of water stored upstream if flows are overestimated. the conceptual for rules in parallel is shown in the fig.2.3 below

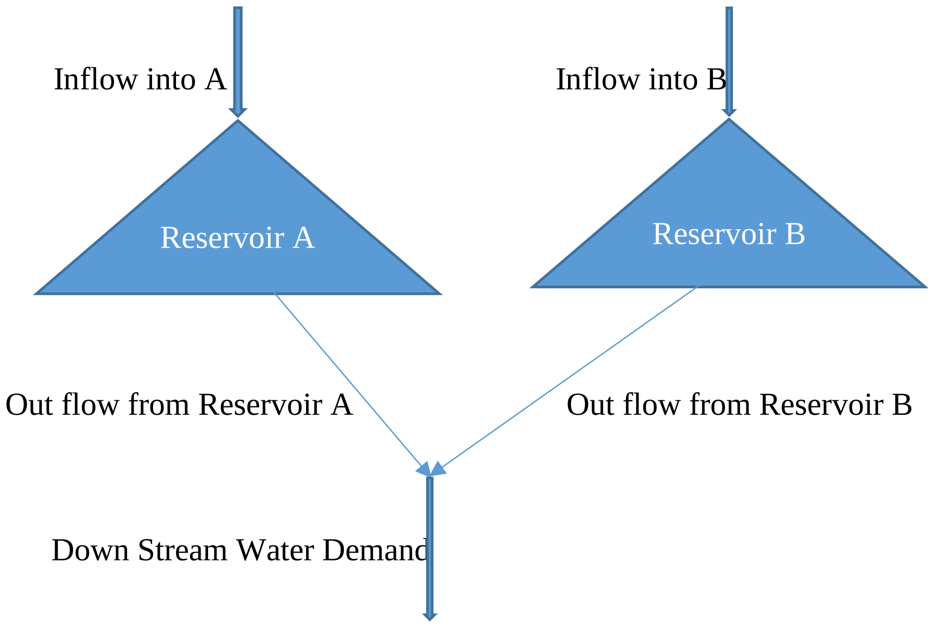


Fig.2.3 Conceptual Rules for Reservoir in Parallel

2.3.1 Reservoir System Analysis and Simulation Model

Systems analysis models are commonly categorized as being either descriptive or prescriptive (Wurbs et al, 1985). Descriptive models demonstrate what will happen if specified decisions are made. Prescriptive models determine what decisions should be made to achieve a specified objective. Simulation models are descriptive while Optimization techniques such as linear programming, and Dynamic programming are descriptive. but a descriptive reservoir system simulation model may incorporate an optimization algorithm, as linear programming, to perform key computations. Similarly, a simulation model may be embedded within a prescriptive optimization model. Hence, although models can be categorized as being either simulation (descriptive) or optimization (prescriptive), the alternative approaches are closely related and overlapping. The most effective strategy for analyzing certain reservoir operations problems may involve various combinations of optimization and simulation models.

2.3.2 Optimization

The term optimization often used synonymously with mathematical programming to refer a mathematical formulation in which a standard algorithm is used to compute a set of decision variable values that minimize or maximize an objective function to constraints. Optimization models automatically search for an optimal set of decision variable values (Labadie, J., 2004). Typical reservoir objective functions to be maximized or minimized could be a quantitative measure of an objective such as economic benefits and costs, water availability and hydropower generation. Decision variables might be targets and release rates whereas constraints include physical characteristics of the reservoir system (maximum and minimum storage, maximum and minimum release) and policy requirements (minimum in stream flow, restrictions on allocation) and mass balance.

2.4 Hydrological Modeling

Hydrological observations, experiments, and practices show that hydrological events are described through various characteristics, which are generally correlated. Taking into account this aspect, it is necessary when modeling hydrological events to consider their characteristics jointly. Hydrological models are classified as physical based, conceptual and empirical depending on the degree of complexity and physical competences in the formation of the structure. Models are further classified as lumped, semi-distributed and distributed depending on the degree of decentralization when describing the terrain in the basin. Today, most rainfall-runoff models, whether physical or conceptual are distributed to some degree and larger basins are split into sub basins (Bergstrom and Graham, 1998). Hydrological models are mathematical formulations to determine the runoff signal which leaves the watershed from the rainfall signal received by the basin. Models are classified into different model families based on data use systems intended to the model:

i. Empirical: data based statistical models where a versatile structure is assumed with minimal assumptions. Examples are cluster analysis, time series models, and regression analysis.

ii. Stochastic: general form models that have a standard structure allowing the incorporation of previous knowledge and uncertainty. Examples state space and hidden Markova models.

iii. Deterministic: have a set of structure specific to the process and justified by the prior theory.

iv. Conceptual: create a structure based on assumed cause-effect links e.g. Bayesian decision network and compartmental models. Hydrological models can be classified as lumped; semi distributed or distributed models based on the basin parameters variation.

1. Lumped models: Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub basins. Parameters of lumped models often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. The impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the entire basin. The most commonly employed procedure is an area-weighted average (Haan, 1982). Lumped models are not usually applicable to event scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models (Beven, 1999).

2. Semi-distributed models: Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into a number of smaller sub basins. There are two main types of semi-distributed models: 1) kinematic wave theory models (KW models e.g. HEC-HMS Model), and 2) probability distributed models (PD models).

3. Distributed models: Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning, the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amounts of (often unavailable) data for parameterization in each grid cell. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy.

There are a number of criteria that should be considered for choosing the right hydrologic model. These criterions are always project-dependent, since every project has its own specific objectives and goal. Among the various project-depended selection criteria, there are four common, fundamental questions that must be always answered (Juraj, 2003). These are listed below.

1. Does the model predict the variables required by the project such as peak flow, event volume and hydrograph, long-term sequence of flows?
2. Is the model capable of simulating regulated reservoir operation?
3. Is it possible to get the required inputs within the time and cost constraints of the project?
4. Does the investment appear to be worthwhile for the objectives of the project?

Based on the above and the following concrete reasons, HEC-HMS and HEC-ResSim models were selected for this study. The main reasons behind selecting the models for this study are;

- ➢ The HEC-HMS program was selected for the current study due to its versatility, capability for Stream flow generation, automatic parameter optimization and its connection with GIS through HEC-GeoHMS.
- ➢ The HEC-HMS model outputs is used by the HEC-ResSim as an input which help to further analyze the project.
- ➢ Hydrological processes that can be properly modeled will be directly result in the desired output from the model.
- ➢ They are freely available software’s.
- ➢ They have been used in wide geographical area including water balance and water allocation studies.

2.4.1 General Description of All Software Used for This Research

2.4.1.1 Arc-GIS

With the development of computer science, hydrological models combined with Geographic Information System (GIS) technology. The Arc-GIS is one of several Geographic Information Systems (GIS), which is a powerful integrated suite of GIS applications capable of performing advanced mapping, data management and geo processing of spatial data (Fuad, August, 2009). Making a connection between GIS and HEC-GeoHMS and arc-hydro, and standard software packages like HEC-HMS, allows the modeler to get the most out of GIS (i.e. to capture the spatial variability of the system) while continuing to work using familiar tools (Fuad, August, 2009).

2.4.1.2 Arc-Hydro

Arc Hydro is an Arc-GIS-based system geared to support water resources applications. It consists of two key components:

- Arc-Hydro Data Model
- Arc-Hydro Tools

The Arc-Hydro tools are a set of utilities developed on top of the Arc-Hydro data model. They operate in the Arc-GIS environments. Some of the functions require the Spatial Analyst extension. The tools have two key purposes. The first purpose is to manipulate (assign) key attributes in the Arc-Hydro data model. These attributes form the basis for further analyses. They include the key identifiers (such as Hydro ID, and Drain ID) and measure attributes (such as Length).

second purpose for the tools is to provide some core functionality often used in water resources applications. This includes DEM-based watershed delineation, network generation, and attribute-based tracing (Arc Hydro Tools Overview, 2002).

2.4.1.3 HEC-GeoHMS

HEC-GeoHMS developed as a tool kit of the geospatial hydrology for engineers and hydrologist with limited experience. The program allows users to visualize spatial information, document watershed characteristics, perform spatial analysis, delineate sub-basins and streams, construct inputs to hydrologic models, and assist with report preparation. Working with HEC-GeoHMS through its interfaces, menus, tools buttons, and context sensitive online help, in a windows environment, allows the user to expediently create Hydrologic Modeling system, HEC-HMS (USACE,2003). HEC-GeoHMS version creates background map file, lumped basin model, a grid-cell parameter file, and a distributed basin model, which used by HMS to develop a hydrologic model. The background map file contains the stream alignments, and sub-basins boundaries. The lumped basin model contains hydrologic elements and their connectivity to represent the movement of water through the drainage system.

The lumped basin file includes watershed areas and reserves empty fields for hydrologic parameters. To assist with estimating hydrologic parameters, GeoHMS can generate tables containing physical characteristics of steams and watersheds. If the hydrologic model employs the distributive techniques for hydrograph transformation, i.e. Mod Clark, and grid-based precipitation, then a grid-cell parameter file and a distributed basin model can be generated (USACE,2003).

2.4.1.4 HEC-DSS Microsoft Excel Data Exchange Add-In

Used to convert temporal data into HEC-HMS binary format, previously, data from one format would need to enter into another format by hand by each user. Each program would then use separate functions to analyze and graph the data. Therefore time-series and tabular data are not stored in the HEC-HMS dataset; rather, the data are stored in a separate HEC-DSS data file, which accessed by the HEC-HMS model. The database consists of six parts: The A Part (River basin or project name), B Part (Location of gage identifier), C Part (Data type (e.g. flow, rainfall, etc.)), D Part (Starting date), E Part (Time interval of data), and F Part (User defined descriptor of data). The data are stored under a unique pathname, which includes all of the parts: /A Part/B Part/C Part/D Part/ E Part/F Part. Using these parts, it is easy for the user and the model to query and manage the data, especially between models. Long-term data series (years and greater) can be stored in HEC-DSS and multiple model runs can be made in different times within the data series. The data can be accessed by other HEC family models.

2.4.1.5 HEC-HMS Modeling

HEC-HMS (the Hydrologic Engineering Center's-Hydrological Modeling System) is the United States Army Corps of Engineers' hydrologic system computer program developed by the Hydrological Engineering Center (HEC). The program simulates precipitation-runoff and routing processes, both natural and controlled. HEC-HMS is the successor to and replacement for HEC's, HEC-1 program and for various specialized versions of HEC-1. HEC-HMS improves up on the capabilities of HEC-1 and provides additional capabilities for distributed modeling and continuous simulation. HMS contains four main components.

a. An analytical model to calculate overland flow runoff as well as channel routing,

b. an advanced graphical user interface illustrating hydrologic system components with interactive features,

c. a system for storing and managing data, specifically large, time variable data sets, and

d. a means for displaying and reporting model outputs (USACE.2000).

2.4.1.5.1 The Analytical Component of HEC-HMS

HEC-HMS consists of separate models of the major hydrological processes and transports. It consists of runoff volume models, models of direct runoff (overland flow and interflow), base flow models, channel flow models. HEC-HMS gives flexibility to the user by providing each component with suit of models. The user can choose a suitable combination of models depending on the availability of data, the purpose of modeling and the required spatial and temporal scales.

2.4.1.5.2 Runoff Volume Model

HEC-HMS computes runoff volume by computing the volume of water that intercepted, infiltrated, stored, evaporated, or transpired and subtracting it from the precipitation. Interception and surface storage intended to represent the surface storage of water by trees or grass, local depressions in the ground surface, cracks and crevices in parking lots or roofs, or a surface area where water is not free to move as overland flow. Infiltration represents the movement of water to areas beneath the land surface. Interception, infiltration, storage, evaporation, and transpiration collectively referred to in the HEC-HMS program and documentation as losses. HEC-HMS considers that all land and water in a watershed categorized as either directly connected impervious surface, or pervious surface. Directly connected impervious surface in a watershed is that portion of the watershed for which all contributing precipitation runs off, with no infiltration, evaporation, or other volume losses. Precipitation on the pervious surfaces is subject to losses. HEC-HMS includes eight runoff volume methods.

- Initial and Constant Rate Loss Model
- Gridded Deficit Constant Rate Loss Model

- Gridded Green and Ampt Rate Loss Model
- Gridded SCS Curve Number Rate Loss Model
- Gridded Soil Moisture Accounting Rate Loss Model
- SCS Curve Number Rate Loss Model
- Smith Parlange Rate Loss Model
- Soil Moisture Accounting

from the above Runoff-Volume Model Initial and Constant rate loss model is selected for modeling of watershed in this particular study and discussed as shown below.

Initial and Constant Rate Loss Model

The initial and constant-rate model, in fact, includes one parameter (the constant rate) and one initial condition (the initial loss). Respectively, these represent physical properties of the watershed soils and land use and the antecedent condition. The constant loss rate can view as the ultimate infiltration capacity of the soils. The SCS (1986) classified soils on basis of this infiltration capacity, and Skaggs and Khaleel (1982) have published estimates of infiltration rates for those soils, as shown in Table 2.1. These may use in the absence of better information. Because, the model parameter is not a measured parameter, it and the initial condition best determined by calibration.

Table 2.1 SCS Soil Groups and Infiltration (Loss) rates (SCS, 1986; Skaggs and Khaleel, 1982)

Soil Group	Description	Range of Loss Rates (inch/hr.)
A	Deep sand, deep loess, aggregated silts	0.30-0.45
B	Shallow loess, sandy loam	0.15-0.30
C	Clay loams, shallow sandy loam, soils low inorganic content, and soils usually high in clay	0.05-0.15
D	Soils that swell significantly when wet, heavy plastic clays, and certain saline soils	0.00-0.05

In this Study, based upon the above information shown in the table 2.1. the Soil Groups of the Genale-Dawa River basin is almost all similar with Soil Group C. Hence, infiltration loss was defined in terms of an initial and constant loss rate equal to 2 mm per hour as initial condition and the best loss rate has been estimated by Optimization. Initial flow was given a value in the order of the maximum average monthly outflow from the individual sub-basins which was estimated with reference to the monthly flow series at key station Chena-Mansa.

2.4.1.5.3 Direct Run-off Model

Modeling direct runoff is transformation of the excess precipitation into point runoff at a given point outlet. HEC-HMS includes two options, systems type and conceptual type of transformation. The systems type transformation included in HMS consists of Snyder's unit hydrographs model, SCS UH model, Clark's model, Modified Clark's model. The conceptual model includes only a kinematics wave model of overland flow. In this study, the hydrograph model according to the Clark synthetic UH was chosen, whose parameters are defined as:

Tc - time of concentration (hours)

R - storage coefficient, or attenuation factor (hours)

Conveniently, the above parameters can be estimated for a given catchment by empirical formulae as a function of physical characteristics as detail has been presented in the next portion.

2.4.1.5.4 Base flow Model

HEC-HMS includes five models for modeling the base flow.

- Constant Monthly
- Bounded Recession method
- Linear Reservoir
- Nonlinear Boussinesq
- Recession

for this project Constant Monthly base flow model was chosen and the detail is described as below.

Constant Monthly

This is the simplest base flow model in HMS. It represents base flow as a constant flow; this may vary monthly. Initial flow was given a value in the order of the average monthly outflow from the individual sub-basins which was estimated with reference to the monthly flow series at key station Chena-Mansa. This user-specified flow added to the direct runoff computed from rainfall for each time step of the simulation.

2.4.1.5.5 Channel Flow

The channel routing models available in HMS includes Lag; Modified Pulls, Muskingum, Kinematic wave, and Muskingum Cunge. The Muskingum hydrologic routing method was chosen to perform channel routing in the three river reaches defined as from Mormor Confluence to Welmel Confluence into Upper Genale main stream (Reach-1), from Welmel Confluence to Wabe-Menna Confluence (Reach-2), and from Wabe-Menna Confluence to Genale main river increment (Reach-3). This method involves the assignment of just two parameters for each channel reach, comprising: wedge-storage coefficient (X), and flood wave travel time (K).

2.4.1.5.6 Model Calibration and Validation

2.4.1.5.6.1 Calibration;

Model calibration is a systematic process of adjusting model parameter values until model results match acceptably the observed data. The objective function described by the quantitative measure of the match. In the precipitation-runoff models, this function measures the degree of variation between the observed and the computed hydrographs. The calibration process finds the optimal parameter values that minimize the objective function. Further, the calibration estimates some model parameters that cannot estimate by observation or measurement, or have no direct physical meaning. Calibration can be either manual or automated (optimization). Manual calibration relies on user's knowledge of basin physical properties and expertise in hydrologic modeling. In the automated calibration model parameters iteratively adjusted until the value of the selected objective function is minimized (CFCAS, 2004). The latest version of HEC-HMS model includes optimization manager that allows automated model calibration. There are five objective functions available in the optimization manager (CFCAS, 2004):

1. Peak-weighted root mean square error (PWRMSE): Using a weighting factor, the PWRMSE measure gives greater overall weight to error near the peak discharge.

2. Sum of squared residual (SSR): The SSR measure gives greater weight to large errors and lesser weight to small errors (USACE, 2001):

3. Sum of absolute residuals (SAR): The SAR function gives equal weight to both small and large errors.

4. Percent error in peak flow (PEPF): The PEPF measure only considers the magnitude of computed peak flow and does not account for total volume or timing of the peak:

5. Percent error in volume (PEV): The PEV function only considers the computed volume and does not account for the magnitude or timing of the peak flow. Two search methods are available in HEC-HMS model for minimizing the objective functions defined above (USACE, 2001):

i. The univariate gradient method (UG): The UG method evaluates and adjusts one parameter at a time while holding other parameters constant.

ii. The Nelder and Mead method (NM): The NM method uses a downhill simplex to evaluate all parameters simultaneously and determine which parameter to adjust. Initial values of parameters that are subject to automated calibration are required to start an optimization process. The HEC-HMS model has default hard constraints that limit the range of optimized within reasonable physical intervals. Values within hard constraints do not cause numeric instabilities or errors in computations. Soft constraints can be defined by the user and allow limiting the range of values within the wider range of hard constraints.

2.4.1.5.6.2 Validation

Model validation is the process of testing model ability to simulate observed data other than used for the calibration, with acceptable accuracy. During this process, calibrated model parameters are not subject to change, their values kept constant. The quantitative measure of the match is again the degree of variation between computed and observed hydrographs.

2.4.2 The Reservoir operation simulation model (HEC-ResSim)

2.4.2.1 General

It has been designed by the Hydrologic Engineering Center of the US Army Corp of Engineers specifically to perform the reservoir system simulation. It is capable of modeling any reservoir system and designed to perform reservoir operation modeling at single or multi reservoir system. It has also HEC-DSSVue option which is used to view (and possibly edit) dss files that are used for storing primarily time-series data. HEC-DSSVue is a tool that allows to access data stored in HEC-DSS database files. DSS files refer to time-series data by Pathnames representing records. When HEC-DSSVue is selected from the Tools menu within the network module for storing time series data and within the simulation module, the simulation dss file is opened (USACE, 2007). The main input data used for HEC-ResSim are reservoir physical characteristic curves (Elevation-Area-storage curve), Evaporation, observed/simulated flow, key characteristic of reservoir, dam, spillway and different watershed characteristics obtained from GIS. The main modules that used for HEC-ResSim model setup are Watershed Setup, Reservoir Network, and simulation. Each module has a unique purpose and an associated set of functions accessible through menus, toolbars, and schematic elements. Each module also provides access to specific types of data or results.

Watershed setup module; the purpose of the watershed setup module is to provide a common framework for watershed creation and definition among different modeling application. A watershed may include all of the streams, projects (e.g., reservoirs, levees, diversions etc.), gage locations, impact areas, time-series locations, and hydrologic and hydraulic data for a specific area. All of these details together, once configured, form a watershed framework.

Reservoir network module; the purpose of the reservoir network module is to isolate the development of reservoir model from the output analysis. In the reservoir network module, river schematization, description of the physical and operational elements of reservoirs model can be build, and the alternatives that are required to be to analyzed can be developed. Using configurations that were created in the watershed setup module as a template, based on a reservoir network module, add routing reaches and possibly other network elements to complete the connectivity of reservoirs network schematic. Once the schematic is complete, physical and operational data for each network element are defined.

Simulation module; the purpose of the simulation module is to isolate output analysis from the model development process. Once the reservoir model is complete and the alternatives have been defined, the simulation module is used to configure the simulation. The computations are performed and results are viewed within the simulation module. While simulation is created, a simulation time window, computation intervals and the alternatives to be analyzed must be specified. Then, ResSim creates a directory structure within the rss folder of the watershed that represents the simulation. Within this module, edition of element data and view results is possible. Once a simulation is defined, a compute is performed and results are analyzed using graphical and tabular output (USACE, 2007).

2.5 Water Balance

The concept of the water balance has been successfully used to estimate the present and future water availability in different regions (Dominguez, 1997) and for water resources management (Neff and Killian, 2003). The term water balance is defined here as an accounting of the inflow to, outflow from, and storage in, a hydrologic unit, such as a reservoir (Langbein and Iseri, 1960). The simulated runoff and inflow to the reservoirs in the Genale river basin is carried out by HEC-HMS which will be used in HEC-ResSim for optimal release of the reservoirs. This is simplified as:

$Change\ in\ Storage = Inflow - Outflow - Loss$ ………………...**equation 2.1**

The Mathematical expression for Water Balance may written as;

$\Delta St = Pt - Qt - Lt$ ……………………………………………………**equation 2.2**

Where, $\Delta St = Change\ in\ Storage\ in\ each\ time\ step$

P_t = Precipitation in mm, at each time interval

Q_t = Surface runoff in mm, at each time interval

L_t = Losses due to evaporation, and infiltration in mm in each respective time

The desired value for Surface runoff and infiltration loss are computed by the use of HEC-HMS model by considering different mathematical modeling method and evaporation from reservoir surface is calculated by transposing nearby meteorological station at Nagelle Borena.

2.6 Previous Studies in the Genale-Dawa River Basin

2.6.1 Potential Sites and Studies

Weyib 1985, 1996, 2003

Under the UNDP a hydroelectric development study was carried out on the upper weyib river over an approximately 100km long reach between Denbel and Sof Umer (UNDP, 1985). In total 5 sites were identified and studied at a preliminary level, from which one site was selected and studied in more detail. The original site locations were selected on account of the natural gradient of the main river-giving rise to favorable head differences, as well as elevation between the main river adjacent river valleys. Site 1 and Site 3 concepts involved diverting the weyib river;

1) to the Wabi-Shebele basin taking advantage of a drop about 1100m which offers a potential of about 9 MW per m^3/Sec of water, and
2) diverting to the neighboring Asendaba valley with a head difference of 110m enabling 9 MW of generation.

Resulting from these investigations Site 4 studied in detail. At this location, near to Goro-Ginir road crossing, a head of 180m can be utilized to generate 18 MW. The project was found to be feasibly attractive, when compared to alternative diesel generation, for supply to the local area including the demand centers of Goba, Agarfa, Goro and Robe. Resulting from the consultant's own investigations for the EELPA Small Hydropower Development Focal Point Unit during the period 1993-1996, a detailed feasibility level revision of the above Site 3 was subsequently undertaken (Lahmeyer, 1996). It should be mentioned further that the Weyib-Wabi diversion concept has also been described in later studies, particularly: (WRDA, 1987) and most recently in the Wabi-shebele Basin Masterplan (WWDSE, 2003). In none of these previous documents, however, can technical details or results of objective evaluations of this concept be found.

1986 CESEN

In the principal findings this comprehensive energy study for the country (CESEN, 1986). It was estimated that a sizeable hydro energy potential is available in the Genale-Weyib basin, when expressed as "areal energy density". The calculated energy density of the Genale-Weyib head basins taken together amounted to 1.45 GWh/km^2-year, which is slightly higher than the Blue Nile basin but lower than the Baro basin. Furthermore, gross hydro energy potential available from the small slope (low head) plants without flow regulation was also estimated to be substantial, on average 168 MWh/km^2-year. This interesting analysis is summarized for the Genale river reaches in Table 2.2 below. The study did not, however, address the potential location of power plants or their technical characteristics.

Table 2.2 Energy Potential (lineal) of the Genale River according to CESEN.

River Section	Length (Km)	Mean flow (m^3/Sec)	Gross energy (GWh/year)	Energy Density (GWh/Km^2-year)
Bore to Chena-Mensa	207	52	2,550	12.3
Chena-Mensa to Welmel Confluence	113	190	5,730	50.7
Welmel Confluence to Bogol Manyo	216	271	2,520	11.7
Bogol Manyo to Dolo Odo	164	217	560	3.4
Total	700		11,360	16.2

1990 WAPCOS

Hydropower investigations were carried out within the National Water Resources Master plan (WAPCOS, 1990). The major findings generally superseded previous studies and, to a large extent, created the basis for potential hydropower development on the Genale-Dawa basin which is still the most valid and up to-date source when looking at the basin as a whole. Resulting from these study 31 sites were identified and preliminarily evaluated. The evaluation consisted simply of estimating mean flow and, together with site topography (river-reservoir levels and available head), calculation of continuous power and total energy. The technical potential (GWh/year) was estimated as 0.7x total energy. Preliminary cost estimation, based apparently on topography: dam crest length and head, was also made.

This enabled economic comparison of the various schemes in terms of specific capacity and energy costs. A replication of the WAPCOS evaluation is given in Table 2.3.

In viewing the table, it is interesting to observe the range of potential capacity (MW) and generating heads available in the respective sub-basins.

- Lower capacities, implying relatively small-scale plants, are predominant in the Weyib sub-basin.
- The total potential of Genale and Dawa sub-basins is very similar in which both contain medium to large developable capacities, some exceeding 100 MW. The highest head available at a single site, amounting to 400m, is located on the Mormora tributary of the Dawa river.

Table 2.3: Details of Identified Hydropower Sites in Genale-Dawa Basin (WAPCOS).

Code (GD-)	Latitude			Longitude			m.a.s.l		L-Dam (m)	Q (m^3/s)	Head (m)	Pcont. (MW)	Tot.Ener. (GWh/a)	Tech.Pot (GWh/a)
	Deg	Min	Sec	Deg	Min	Sec	River	FSL						
Genale Sub-basin														
1	**6**	**10**	**35**	**38**	**57**	**40**	**1370**	**1500**	**1000**	**19.2**	**200**	**37.7**	**330**	**231**
2	5	58	0	39	22	0	1210	1300	350	47.9	200	94	823	576
3	5	37	20	39	42	40	1000	1100	300	54.9	200	107.7	944	661
4	5	27	0	39	50	30	830	900	500	53.7	200	105.4	923	646
5	5	21	0	40	11	0	630	700	700	54.3	100	53.3	467	327
6	5	22	40	40	21	30	500	600	400	59.7	100	58.6	513	359
7	5	20	20	41	20	0	250	400	400	127.9	100	125.5	1099	769
8	4	55	0	41	30	0	200	250	400	105.9	50	51.9	455	319
9	4	19	40	41	59	0	180	200	300	82.5	20	16.2	142	99
									Sub-total Genale:			**650.2**		**3987**

Code	Latitude			Longitude			m.a.s.l		L-Dam	Q	Head	Pcont.	Tot.Ener.	Tech.Pot
(GD-)	Deg	Min	Sec	Deg	Min	Sec	River	FSL	(m)	(m^3/s)	(m)	(MW)	(GWh/a)	(GWh/a)
Dawa Sub-basin														
10	5	19	30	38	49	20	1100	1200	350	12.6	200	24.7	217	152
11	**5**	**11**	**40**	**38**	**50**	**20**	**920**	**1000**	**350**	**39.5**	**100**	**38.7**	**339**	**238**
12	**5**	**5**	**20**	**38**	**58**	**20**	**860**	**900**	**250**	**43.2**	**50**	**21.2**	**186**	**130**
13	**5**	**0**	**20**	**39**	**7**	**30**	**820**	**850**	**1000**	**104.5**	**50**	**51.3**	**449**	**314**
14	**4**	**43**	**20**	**39**	**27**	**40**	**720**	**800**	**750**	**82.5**	**100**	**80.9**	**709**	**496**
15	**4**	**44**	**30**	**39**	**59**	**45**	**550**	**700**	**500**	**91.9**	**200**	**180.3**	**1579**	**1106**
16	**4**	**47**	**34**	**40**	**21**	**30**	**400**	**500**	**1250**	**94.3**	**100**	**92.5**	**810**	**567**
17	**4**	**39**	**40**	**40**	**34**	**0**	**350**	**400**	**1000**	**87.1**	**50**	**42.7**	**374**	**262**
18	**4**	**17**	**30**	**40**	**46**	**0**	**310**	**350**	**400**	**64.3**	**50**	**31.5**	**276**	**193**
30	**5**	**20**	**30**	**38**	**58**	**35**	**1310**	**1000**	**1000**	**17**	**400**	**66.7**	**584**	**409**
31	**5**	**8**	**30**	**39**	**8**	**40**	**860**	**600**	**600**	**38.4**	**100**	**37.7**	**330**	**231**
									Sub-total Dawa:			**668.3**		**4098**
Weyib Sub-basin														
19	7	16	45	40	7	0	2200	2300	1000	12.3	100	12.1	106	74
20	**6**	**57**	**40**	**40**	**45**	**35**	**1400**	**1500**	**500**	**14.0**	**100**	**13.7**	**120**	**84**
21	**6**	**50**	**40**	**41**	**52**	**20**	**1100**	**1200**	**750**	**15.3**	**100**	**15.0**	**131**	**92**
22	**6**	**44**	**0**	**41**	**0**	**0**	**1000**	**1100**	**500**	**16.1**	**140**	**22.1**	**194**	**136**
23	**6**	**33**	**0**	**41**	**10**	**43**	**815**	**900**	**750**	**19.0**	**100**	**18.6**	**163**	**114**
24	**6**	**25**	**30**	**41**	**15**	**0**	**700**	**800**	**750**	**21.6**	**100**	**21.2**	**186**	**130**
25	**6**	**15**	**35**	**41**	**23**	**10**	**600**	**700**	**750**	**23.2**	**100**	**22.8**	**199**	**140**
26	**6**	**15**	**0**	**41**	**29**	**25**	**550**	**750**	**750**	**24.1**	**100**	**23.6**	**207**	**145**
27	**6**	**0**	**25**	**41**	**33**	**40**	**470**	**500**	**500**	**24.8**	**20**	**4.9**	**43**	**30**
28	**5**	**45**	**0**	**41**	**47**	**40**	**325**	**500**	**500**	**25.9**	**50**	**12.7**	**111**	**78**
29	**5**	**29**	**30**	**41**	**42**	**0**	**300**	**1250**	**1250**	**28.9**	**50**	**14.2**	**124**	**87**
									Sub-total Weyib:			**180.9**		**1109**
									Total for Basin:			**1499**		**9270**

In regard to actual site selection, the main criteria applied by WAPCOS, which are considered to be very sound and reasonable, are replicated below.

Selection of hydropower sites in the river basins is based on the study of topographic sheets on 1:250,000 scale and 1:50,000 scale maps wherever available. Besides the topographic sheets, other reports were referred wherever relevant.

A two weeks aerial reconnaissance of portions of Abbay, Baro-Akobo, Gilgel-Ghibe, Awash, Rift Valley, Wabi Shebelle and Genale Dawa was also helpful.

The general criteria adopted for the selection of a hydropower site was guided on the following broad principles:

- The length of dam/diversion weir is restricted to about 500m to 750m and height limited to 120m.
- The sites were selected after screening of the entire river from source to confluence. In Abbay and Baro basins both main rivers and tributaries were screened. In other basins, only the main rivers were examined.
- River reaches with goose-neck formation (a boulder reach) with valley spreading upstream and downstream are preferable.
- Wherever a series of projects on the same river or tributary are planned, it is preferable to have the upstream most projects with largest storage. The regulated release from this project will feed the lower projects in the cascade. This will result in reduction of cost of the lower dams.
- Sites where scope for grid tie or delayed grid tie is present were preferred.
- Easy access and availability of construction material for the dam or diversion structure in the vicinity were considered.
- Demand for power in the nearby area was assessed.
- The need of electric power in the nearby Awraja was estimated. At least one plant to meet the requirement of energy in any Awraja, however remote, was taken into account.
- In case of major powerplants, particularly on River Abbay, the export potential was kept in mind.

1997 MoWR: Genale Sites GD-2 / GD-3 / GD-4

A follow-up reconnaissance study (to the previous) was carried out by MoWR under the Medium Scale Hydropower Plants Study Program (MoWR, 1997). This study concentrated on the immediately most promising sites on the Genale river: denoted as GD-2, GD-3 and GD-4. These sites are located in the upper-central region of the Genale main river. Both GD-2 and GD-3 involve the construction of a large dam to provide sufficient storage and regulation in which a shaft/tunnel conduit connects with the powerhouse located a short distance downstream. Given design net heads of 103m and 93m, installed capacities resulted in 138 MW and 180 MW respectively. A somewhat different configuration of was defined for GD-4 consisting of a lower dam and smaller storage reservoir with a 25km long power canal in order to gain a net head of 150m. Installed capacity amounted to 300 MW. Through application of a costing and economic evaluation procedure commensurate with the study level, each scheme was found to be similarly favorable. The specific generation cost and benefit cost ratio of GD-4 resulted to be slightly inferior to that of GD-2 and GD-3. As a conclusion a stage development, possibly involving all 3 projects, was considered feasible in which the construction of GD-2 or GD-3 alone would alleviate the need to construct a dam exclusively for exploitation of irrigation potential downstream.

MoWR 1998

In the reconnaissance studies carried out by the MoWR a total of 29 potential dam sites were identified, serving individual or combined development purposes under: irrigation, hydropower and multi-purpose. An inventory of these sites, indicating purpose and MoWR (GDH-) identification code is given in Table 2.4 As indicated further in the table, a number of these sites appear to coincide with those identified by WAPCOS for hydropower development.

Table 2.4: Potential Dam Sites as identified by MoWR

Sub-basin	River	Deg. (Lat.)	Min. (Lat.)	Deg. (Lon.)	Min. (Lon.)	Purpose	Propo -sed	Code (GDH-)	WAPCOS Coincidence
Genale	Wabera	3	39	40	39	Irrigation		11	
Genale	Welmel	6	28	39	37	Irrigation	*	12	
Genale	Iya	6	25	39	22	Irrigation		13	
Genale	Dumel	6	43	40	16	Irrigation		14	
Genale	Genale-D	4	36	41	40	Multi-Purpose	*	15	
Genale	Genale-C	4	56	41	30	Hydropower		16	GD-8
Genale	Genale-A	5	43	39	34	Multi-Purpose		17	
Genale	Genale-B	5	37	39	42	Hydropower		18	GD-3
Genale	Wabe-Mena	6	39	40	46	Irrigation		1	
Dawa	Awata-C	5	44	39	10	Multi-Purpose		19	
Dawa	Awata-B	5	50	38	54	Multi-Purpose		20	
Dawa	Awata-A	5	58	38	43	Multi-Purpose	*	21	
Dawa	Melka-Guba	4	43	39	28	Multi-Purpose	*	22	GD-14
Dawa	Dawa-C	4	51	39	21	Hydropower		24	
Dawa	Dawa-B	5	0	39	8	Irrigation		24	GD-13
Dawa	Dawa-A	5	7	38	58	Multi-Purpose		25	GD-12
Dawa	Mormora	5	47	38	45	Multi-Purpose		26	
Dawa	Kilkile	5	4	38	43	Hydropower		27	
Dawa	Afelata	5	36	38	27	Hydropower		28	
Dawa	Didiga	5	17	38	15	Irrigation	*	29	
Weyib	Shaya	7	9	39	57	Irrigation		2	
Weyib	Upper Weyib	7	6	40	24	Irrigation		3	
Weyib	Middle Weyib	6	46	40	58	Irrigation		4	
Weyib	Lower Weyib	5	28	41	47	Irrigation	*	5	GD-29
Weyib	Wabe Gastro-A	6	32	41	10	Irrigation		6	GD-23
Weyib	Wabe Gastro-C	5	45	41	43	Irrigation		7	GD-28
Weyib	Wabe Gastro-B	5	54	41	38	Irrigation		8	
Weyib	Tebel	6	57	41	0	Irrigation		9	
Weyib	Togona	7	9	40	6	Irrigation		10	

1999 Norplan: Genale Sites GD-2 /GD-3

In this pre-feasibility study the Genale hydropower concept was taken one step further in which more detailed work concentrated on the development of GD-2 and GD-3 sites (Norplan, 1999). In the case of GD-3, several alternatives were evaluated from which the alternative denoted "middle-long" was chosen. Compared to the previous study the layout of this scheme was completely re-configured, whereby a 1,460m long headrace tunnel leads the water to a powerhouse cavern, from where a 6,500m long tailrace links up with the Genale River. The net head amounts to 180m. The optimized installed capacity resulted in 164 MW at a plant factor of 80%. It should be mentioned that GD-2, with modified cost parameters, has been included as a project to be implemented in the "all-hydro scenario" system expansion plan (ACRES, 2003).

GDMP by Lahmeyer, 2003

A study has been carried between 2004 to 2007 by a joint venture of Lahmeyer international consulting Engineers of Germany and Yeshi-Ber consult of Ethiopia. The overall goals of the master plan are defined in the Ethiopia Water Resource Management Policy (WRMP), which sets out guidelines for water resource planning, development and management. This policy aims at enhancing and promoting all national efforts towards the efficient, equitable and optimum utilization of the available water resources of the country for significant socio-economic development on sustainable development on sustainable basis. The target of the Hydropower Sector Study was to screen hydropower options in the Genale Dawa River Basin to identify projects which can generate power at a cost below that of thermal plant. GIS codes for the hydropower projects used in this study are cross-referenced to the codes used by the Ministry of Water Resources in the fold-out on the last page of the report. These projects are candidate projects for the ICS power system expansion and possibly also for export to earn foreign exchange, in line with the national policies for the sector. Over 40 hydropower options, identified in previous studies, were first pre-screened, eliminating all projects which not likely to be economic, e.g. projects with insufficient head, and projects with intermittent flow and without storage. The 22 remaining projects were then optimized by varying dam heights and powerhouse locations. Finally, 9 projects were found to have generation costs below that of equivalent thermal power plants. The economic hydropower potential is about 1,200 MW capacity with a corresponding energy generation of 5,500 GWh (not accounting for the Weyib-Wabi project).

2.6.2 Proposed Cascade Hydropower Project on Genale Main River

The Genale-Dawa cascade hydropower projects are one of the most attractive potential hydroelectric developments in the country and the Ethiopian Electric Power Corporation (EEPCO) selected as one of its key hydroelectric development sites. Extensive hydropower development studies were undertaken by the Ministry of Water Resource on Genale-Dawa River basin. About 40 schemes were identified as potential sites for hydropower development. Nine of the projects proved to be economically attractive compared to equivalent thermal generation. Among these three of the cascaded hydropower schemes that lie on the main stream of Genale River were found interesting with the GD-3 project being the best hydropower project by far.

GD-3 Hydropower Project

Location: The project area is located some 400km (air distance) south-east of Addis Ababa and some 200km (air distance) north of the border with Kenya. The scheme, including the reservoir and power waterways, extends over a river corridor some 55km long. The approximate centroid of the project area lies at latitude 5º 38' North and longitude 39º 43' East.

Purpose: The GD-3 hydropower scheme is a comprehensive multipurpose water resource development project planned to utilize potential benefits for hydropower, flood control and irrigation with other downstream planned projects and hydropower generation as its main purpose.

Reservoir: The GD-3 reservoir created by a dam at the GD-3 will have a total storage capacity of 2,570 Mm^3 at full supply level (1120masl) and will cover an area of 98 km^2. The minimum operating level will be 1080masl and storage at MOL will be 260 Mm^3 and this will cover 23 km^2. The active storage is some 2310 Mm^3.

Hydrological Site Condition: The long term mean flow at the GD-3 site is estimated to be 92.5m^3/sec. The driest year on record (2002) had a mean flow of only 59.2m^3/sec, while the wettest year on record (1998) had a mean flow of 139.5m^3/sec. The catchment area amounts to 10,445 km^2. The flow regime shows a distinctive wet season from April to November, which makes up nearly 90% of the annual flow, and a dry season from December to March. The highest discharges normally occur in October, the lowest at the end of the dry season in March.

Expected Energy Generation: Considering a total installed capacity of 254 MW, a plant discharge of about 116 m^3/sec (equal to 1.25 times the mean flow) and a rated head of 254.5 m, the GD-3 scheme would show the following energy production features:

Average energy Production = 1640 GWh/yr

Firm energy Generated = 1600 GWh/yr

Mean Power production = 254 MW

Plant factor = 72% (GDMP Volume II, August, 2007)

GD-5 Hydropower Project

Location: This Hydropower plant is found partly in Oromia region, bale zone of Meda walabu Woreda and Filtu woreda, Liben Zone of Somalia region. The nearest access facility to GD-5 proposed hydropower scheme is a 24 km long dry weather track that branches off from the National Road 44 some 500 m east of Haya Suftu and ends at the river at a location some 15 km upstream of GD-5. The Dam site is located around 5°20'N and 40°10'E.

Purpose: The GD-5 hydropower scheme will benefit the almost constant inflow to produce very reliable power output. This project combined with hydropower projects GD-3 and GD-6, is a good candidate for power export to Kenya.

Reservoir: The reservoir created by a dam at the GD-5 will have a total storage capacity of 134 Mm^3 at full supply level (690masl) and will cover an area of 6.5 km^2. The minimum operating level will be 672masl and storage at MOL will be 75 Mm^3 and this will cover 3.5 km^2. The active storage is some 57 Mm^3. As the existing topography does not allow the provision of a large-scale reservoir, only limited additional flow regulation (with daily/weekly pondage) will be possible. GD-5 is one out of the sites with particularly narrow valley profiles that had been identified along the reach of Genale River downstream of GD-3.

Hydrologic Site Condition: As per the master plan study of the mean flow of Genale River at the GD-5 site has been estimated to be 97m^3/sec. The catchment area amounts to 12,906 km^2. The flow regime is very unbalanced and shows a distinctive wet season from April to November, which makes up nearly 90% of the annual flow, and a dry season from December to March. The highest discharges normally occur in October, the lowest at the end of the dry season in March.

Expected energy Production: Considering a total installed capacity of 106 MW, a plant discharge of about 120m^3/sec and a rated head of 83 m, the GD-3 scheme would show the following energy production features:

Average energy Production = 712 GWh/yr.

Mean Power production = 107 MW

Plant factor = 56%

Percentage of firm energy = 71% (GDMP Volume II, August, 2007)

GD-6 Hydropower Project

Location: The project area straddles the Somali and Oromia Regions with the Oromia Zone of Bale (Meda Welabu Wereda) on the left bank and the Somali Zone of Liben on the right bank. Road access to site will start at Siru, which is located on the main road between Negele Borena and Filtu. The Genale GD-6 Hydropower project is located on the Genale River of the Genale Dawa River basin, approximately 80 km east of Negele Borena, in Liben Zone of the Somali National Regional State. The project area is approximately 700 km by road south and east of Addis Ababa. The project forms the downstream power plant in a series of three utilizing the large reservoir of the planned hydropower project GD-3 located some 82 km further upstream along the Genale River. Just upstream of the reservoir of GD-6 is a potential Hydropower Project GD-5, which forms the middle hydropower project in the series. The project GD-6 exploits the head over an approximately 31 km stretch of the river with a maximum gross head of 234 m between the elevations 585masl, and 351masl.

Purpose: The GD-6 hydropower scheme will benefit the almost constant inflow to produce very reliable power output. This project combined with hydropower projects GD-3 and GD-5, is a good candidate for power export to Kenya.

Reservoir: The reservoir created by a dam at the GD-6 will have a total storage capacity of 183.6 Mm^3 at full supply level (585masl) and will cover an area of 8.15 km^2. The minimum operating level will be 580masl and storage at MOL will be 143.6 Mm^3 and this will cover 7.2 km^2. The active storage is some 40Mm^3. At full supply level 585masl the headwater of the reservoir extends more than 12 km upstream with a width of the reservoir of some 600 m near the dam site. 650 m will be the average width of the reservoir. The objective of a dam at GD-6 is therefore in the first place to create the required gross head for energy generation. As the existing topography does not allow the provision of a large-scale reservoir, only limited additional flow regulation (with daily/weekly pondage) will be possible. GD-6 is one out of the sites with particularly narrow valley profiles that had been identified along the reach of Genale River downstream of GD-3.

Hydrological Site Condition: The river basin, the mean flow of Genale River at the GD-5 site has been estimated to be 102.3 m^3/sec. The catchment area amounts to 13,356 km^2. The flow regime is very unbalanced and shows a distinctive wet season from April to November, which makes up nearly 90% of the annual flow, and a dry season from December to March. The highest discharges normally occur in October, the lowest at the end of the dry season in March.

Expected Energy Production: Considering a total installed capacity of 246 MW, a plant discharge of about 120 m^3/sec and a rated head of 182 m, the GD-3 scheme would show the following energy production features:

Average energy Production = 1575 GWh/yr.

Firm energy Production = 1540 GWh/yr.

Mean Power Production = 246 MW

Plant factor = 73% (GDMP Volume II, August, 2007)

The details of Elevation-Area-Storage curves for Genale-Dawa Cascade Dam is shown in Appendix H.

2.6.3 Energy Demand in Genale-Dawa River Basin

Fuelwood is the dominating energy source, making up 89.20% of total energy consumption in the project area. The weighted average per capita energy consumption of the project area amounts to slightly over 10.5 GJ per year. The per capita values vary widely across the weredas.

- The lowest per capita energy consumption 6.5 GJ, has been calculated for Meda Walabu (Regional State of Oromia, Bale Zone).
- Nensebo, located in the same zone, has the highest per capita energy consumption with almost 15GJ.

Of the estimated 4.6 billion people living in the basin, some 9% or 0.4 million have access to an electricity supply system. Coming from the north, ICS transmission line has recently been extended to the town of Negele Borana, in the center of the basin. Other transmission lines are ending at Robe and Shakkiso. The Somali region is not connected to the ICS network at all and, has only small diesel generators in some towns of the Liben and Afder weredas (GDMP-II.4. J.2)

3. METHODOLOGIES, MATERIAL USED AND PROCEDURE

3.1 General

The methodology of this specific research follows on inductive approval of the preliminary data for this research which is ingathered from National Meteorological Service Agency (NMSA), Ministry of Water, Irrigation and Energy (MoWIE), EEP, A review (journal, article, thesis and reference books), Interviews with experts from professional association.

It's critical to use relevant and good quality data to get a better result. The outcome or result mainly depends on the quantity and quality of data used. The model performance is greatly influenced by the length period of Hydro-meteorological, the resolution of temporal and spatial use of data. Both HEC-HMS and HEC-ResSim models are data driven and they require several types of data input like topography, land use, soil, hydro-meteorological, and reservoir physical data. These data are secondary and should collect from various sources and different processes have going to be carried out to utilize them.

Hence, in the process of planning, development and management of any Water resource projects the data listed in the above paragraph should be carefully prepared, well described, visualized, analyzed and modelled in order to reduce the error in design parameters. Thus, the data should be stationary, consistent, and homogeneous when they are used to simulate a hydrological model system. If it does not fulfill one of the above criteria's, it will result in a big problem that contradicts the actual situation. Therefore, using different methods, the inconsistency, homogeneity, infilling for missed data should be done. Engineering studies of water resources development and management depends heavily on spatial and temporal hydro-meteorological data. To process it and come up with the required outputs, different materials should have implemented. Some of the material required for this study are: Arc-GIS for spatial data analysis and in conjunction with HEC-HMS model which used to generate flow in to the required points of interest and finally, HEC-ResSiM is used to model the reservoir operation.

The following fig.3.1, below shows the conceptual framework for this study.

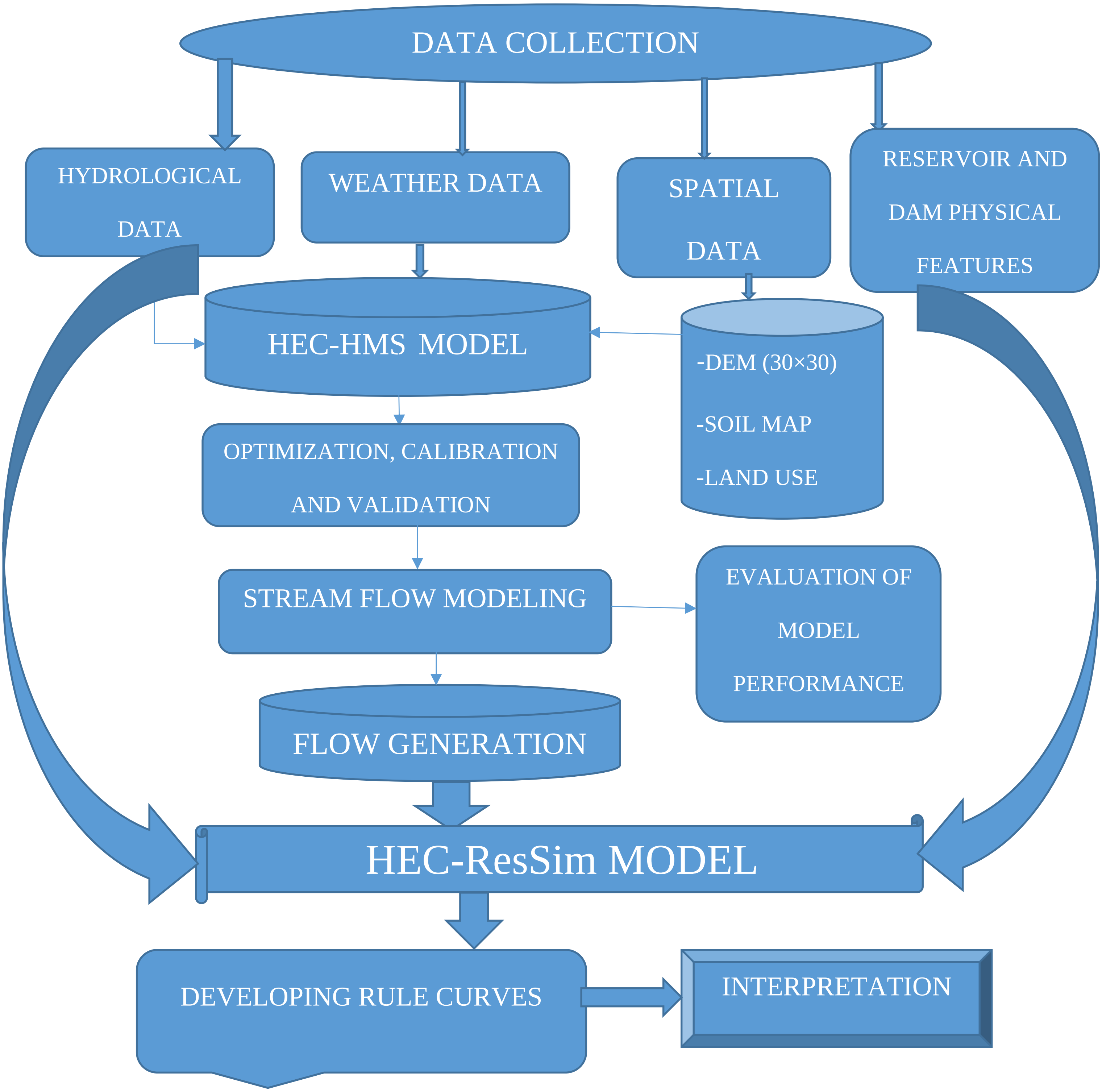


Figure 3.1 conceptual frame work methodology for this study

In general, this chapter explains with the procedure and task used to meet the objectives of the study:

a. Spatial configuration of the River basin system.
   - DEM ($30m \times 30m$) Projection.
   - Delineation of watershed (shape file of the River basin system).
   - Preparation of River basin map location, map of Soil group/type, Land use/cover with their percentage distribution over the basin.
   - Terrain preprocessing using DEM, Arc-GIS and Arc-Hydro tool for preparation of spatial hydrographic features used as an input for HEC-GeoHMS.
   - HEC-GeoHMS data processing for watershed delineation and for the generation of a basin model file and importing it into HEC-HMS.
b. Hydro-meteorological data collection and analysis.
   - Compilation, update, and qualitative and quantitative analysis of all principal meteorological and hydrological data.
   - Determination of climatological and hydrological characteristics of the study area.
   - Derivation of parameters and hydro-meteorological series required as an input for reservoir operation and power simulation.
c. Calibration and validation of rainfall-runoff modeling, generating volume of discharge and the runoff hydrographs of the study area using HEC-HMS by the use of historical data to improve on the water balance modeling over the River basin.
d. Reservoir system simulation in HEC-ResSim and checking model performance, reliability, and vulnerability of reservoirs for hydropower, irrigation and downstream release to analyze reservoir operation.

3.2 Description of Study Area

3.2.1 Location of Genale-Dawa River Basin

Genale-Dawa River Basin is the southernmost basin in Ethiopia and lies between latitude 3º30' and 7º20' N and longitude 37º05' and 43º20' E. In UTM Co-ordinates this is equivalent to 400,000-800,000 N and 300,000-900,000 E. In terms of surface area, it has the third largest surface area (about 170,000 km²), after the Wabi-Shebele and Abay river basins. Neighboring river basins are the Wabi-Shebele to the north and east, and the Rift Valley basin to the West. On the northern side of the basin, the highest peak is Mount Tullu-Dimtu (4,377m.a.s.l.). The altitude decreases from north to south and west to east. The general physiographic features of the Genale-Dawa River Basin have been defined in terms of four major landforms (GD-3 basic final report volume-iv).

- Highlands and plateau surrounded by a range of volcanoes.
- Steep sloping escarpments.
- Gently sloping lowlands adjacent to the foot of the escarpments.
- Lowlands and flood plain basins.

The project catchment area encompasses the upper and mid-sections of the Genale main river sub-basin. The main river drainage system is defined by three principal tributaries in the upper section. Upper Genale, Geberticha and Iya. These tributaries originate from the Sidamo Mountains which form the watershed-divide between Genale and the neighboring Rift Valley and Wabe Shebelle river basins. The highest point on the northern divide is Mount Korduro with elevation around 3,750m.a.s.l. Other mountain peaks with elevations exceeding 3,000m.a.s. l, can be found in this area.

The longest river course which defines the Genale River originates as the Logita tributary with headwaters in the Koro forest. The Logita River flows first westwards then south-west and meets the major Gelana tributary at around 1900m.a.s.l. On this course the Logita descends rapidly until meeting the Bonora tributary at elevation 1500m.a.s.l at this point the combined streams form the Upper Genale and Genale main river, which then flows generally south-eastwards with a moderate gradient over the remainder of its course up to the project site. Physiographic characteristics of the other major tributaries Geberticha and Iya are essentially similar to those of Logita and Bonora.

The principal gauging station at Chena-Mansa is located in the mid river section at elevation 1120m.a.s. l and commands an area of 9190 km^2 with a total river length of 250 km. From the gauging station to GD-3, GD-5 and GD-6 dam site, no tributaries enter the main river. The incremental distance along the river between Chena-Mansa gauging station and GD-3 dam site is 40 km.

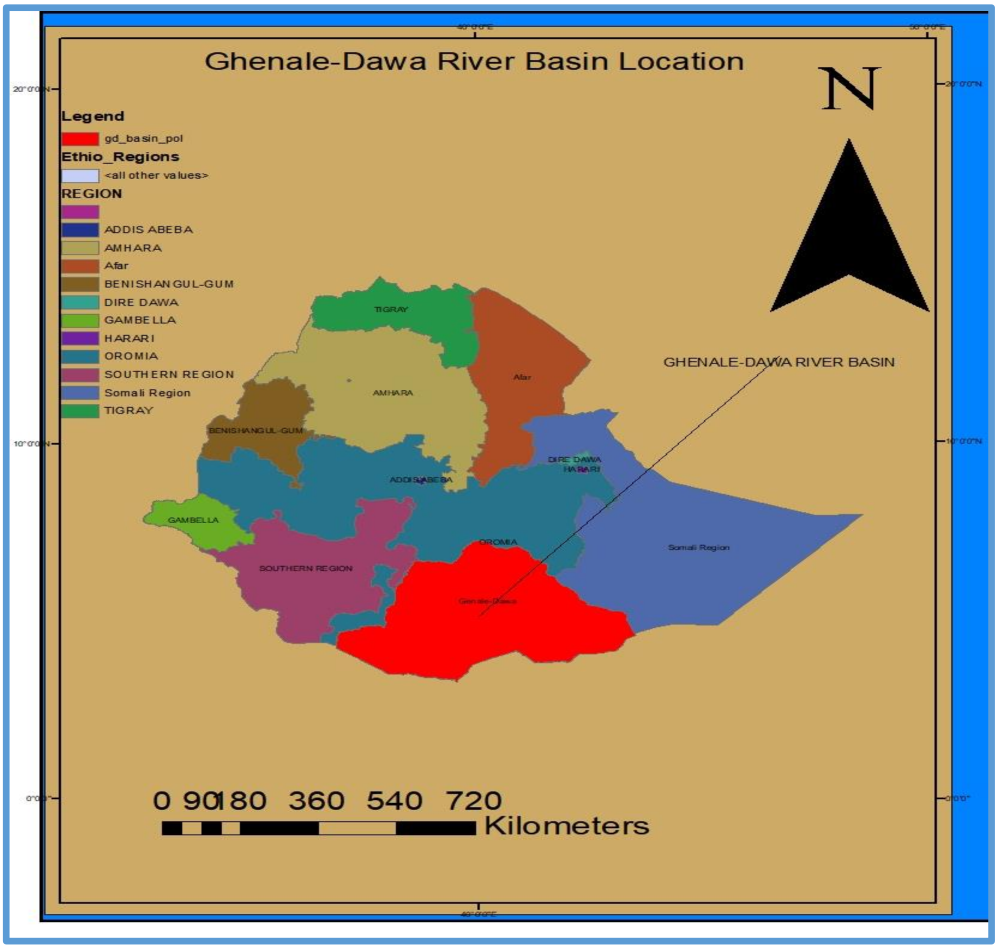


Fig.3.2 Location Map of Genale-Dawa River basin.

3.2.2 Topography and Geology of Reservoir basin

The reservoir basin for proposed GD hydropower project is generally flat and wide upstream of the start of the gorge at 5km upstream of the GD-3 dam site. It narrows again in its headwaters but most of the basin has an ideal shape for efficient storage. The basin also has an ideal north-west to south-east orientation to minimize the effect of wave action at the dam, spillway and intake structures that are located in the narrow north-east to south- west orientated gorge. The narrow gorges at the dam and headwaters of the reservoir are underlain by pegmatoidal granites while the main extent of the reservoir is underlain by the Archean basement gneisses and schists. These rocks are all tight and no leakage will take place from the reservoir basin. There are no lime stones or karst formations in the reservoir basin. Although these occur in the project area, they are situated on high ridges at least 300m to 400m above reservoir level.

There are no existing unstable slopes in the area and no potential for instability that could pose any threat to the proposed dams, spillway or power intake structures. In the main part of the basin, the slopes are too flat for any instability to occur with inundation by the reservoir even though there may be deeper soils in this area. In the gorges where steeper slopes are common the massive pegmatoidal rocks are too massive with either widely spaced near vertical joints or very occasional near horizontal joints. The only natural phenomena that may have negative consequences are wave and wind erosion of the sandy soils along the shore line. Most of the sands resulting from wind erosion of the granitic rocks are likely to be fairly coarse so may not easily be transported by wind. This would avoid the formation of dune sands that commonly occur in some reservoir basins.

3.2.3 Digital Elevation Model (DEM) Data

Digital Elevation Model (**DEM**) is one of the main inputs for Hydrological Model to delineate the watershed and further to divide it into sub-basin. **DEM** Resolution affect the watershed delineation, Stream network definition and sub-basin classification in the Hydrological model (HEC-HMS, HEC-ResSim). According to (**Chaubey et al., 2005**) a decrease in **DEM** Resolution resulted in decreased Stream flow and watershed area. Since the runoff volume depends on watershed area a poor Resolution **DEM** input to the model will result in wrong output from the hydrological model. For this study a Digital Elevation Model (**DEM**) was taken from Ministry of Water, Irrigation and Energy (MoWIE) with spatial Resolution of 30m×30m. The edited DEM was projected to **WGS1984 UTM Zone 37N** using the Raster projection in **Arc Map Tool box** before imported to the model. The DEM of Genale-Dawa study area is shown in the fig. 3.3 below.

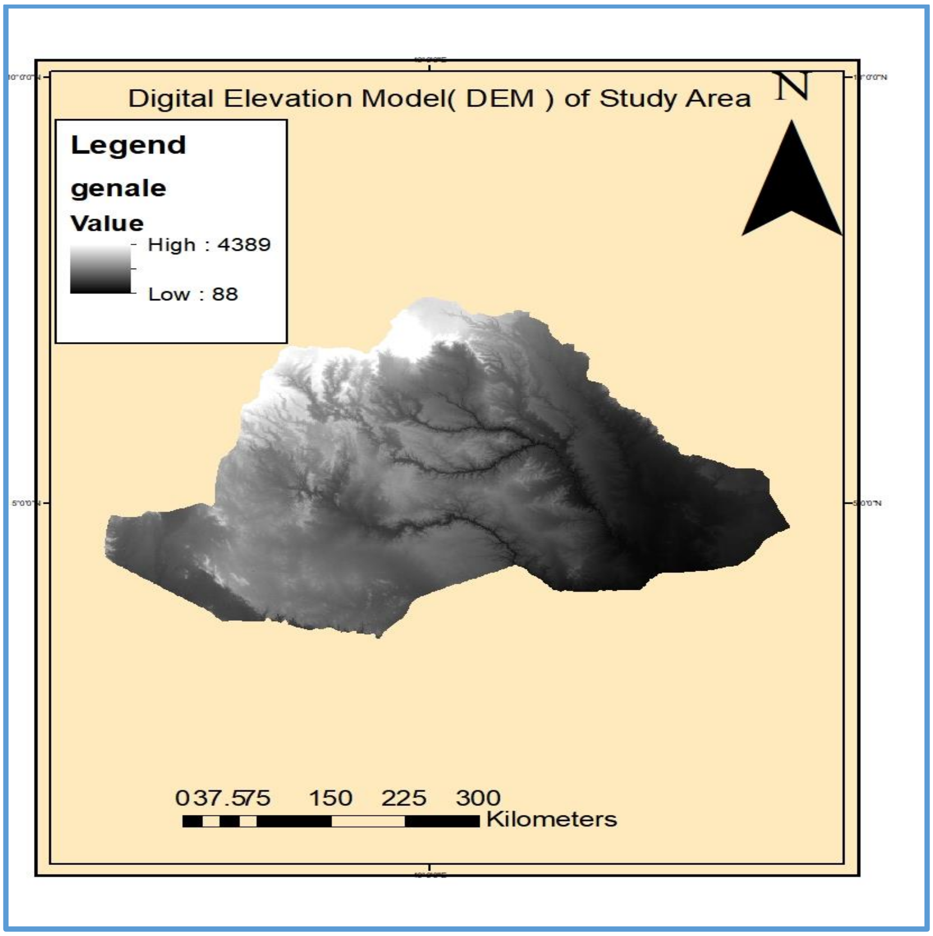


Fig. 3.3 Digital Elevation Model (DEM) of Study Area (GD River basin).

3.2.4 Land Use/Cover

Mainly the type of land use patterns is made from Wooded shrub/Bush grass land, Mixed high forest, Intensive cultivated small holder farm, Abandoned state farm, Dense wood land and Open wood land. Wooded shrub/Bush grass land Covers more percentages of River basin which counts about 80% and Mixed high forest covers about 5.5%. The River basin is sparsely populated and this allows the basin to be shielded by high percentage of Bush grass land and Mixed high forest. As the upper and mid-section of the basin is greatly covers by the wooded shrub/bush grass lands it has a high degree in prevention of erosion which helps the basin to maintain the Natural balances. The summary of the Land Use/Covers indicated as follows in the Table 3.1 below.

Table 3.1 Types of Land Use/Coverage and areal coverage in Upper Genale-Dawa basin.

Land Use/Cover	**Area (Ha)**	**%Coverage**
Mixed high forest	512838.3	5.450771
Intensive cultivated small holder farm	165597.8	1.760078
Abandoned state farm	12439.2	0.132212
Shrub grass land	43147.33	0.458597
Intensively cultivated small holders farm of perennial crop production	49396.24	0.525015
Dense wood land	6933.708	0.073696
Wooded bush land with patches of cultivation	77690.82	0.825747
Less moderately cultivated small holders farm	53397.5	0.567543
Wooded shrub/Bush grass land	6714659	71.36765
Grass land with scattered woods and shrub	2040.429	0.021687
Open wood land	87.923	0.000935
Wooded bush land	1770318	18.81607
Total	**9408547**	**100**

For this research, a Digital Elevation Model (**DEM**) was taken from Ministry of Water, Irrigation and Energy (MoWIE) with spatial Resolution of 30m×30m. The edited DEM was projected to **WGS1984 UTM Zone 37N** using the Raster projection in **Arc Map Tool box** before imported to the model. The processed DEM Land Use/Cover map of Genale-Dawa is shown in the fig.3.4 below.

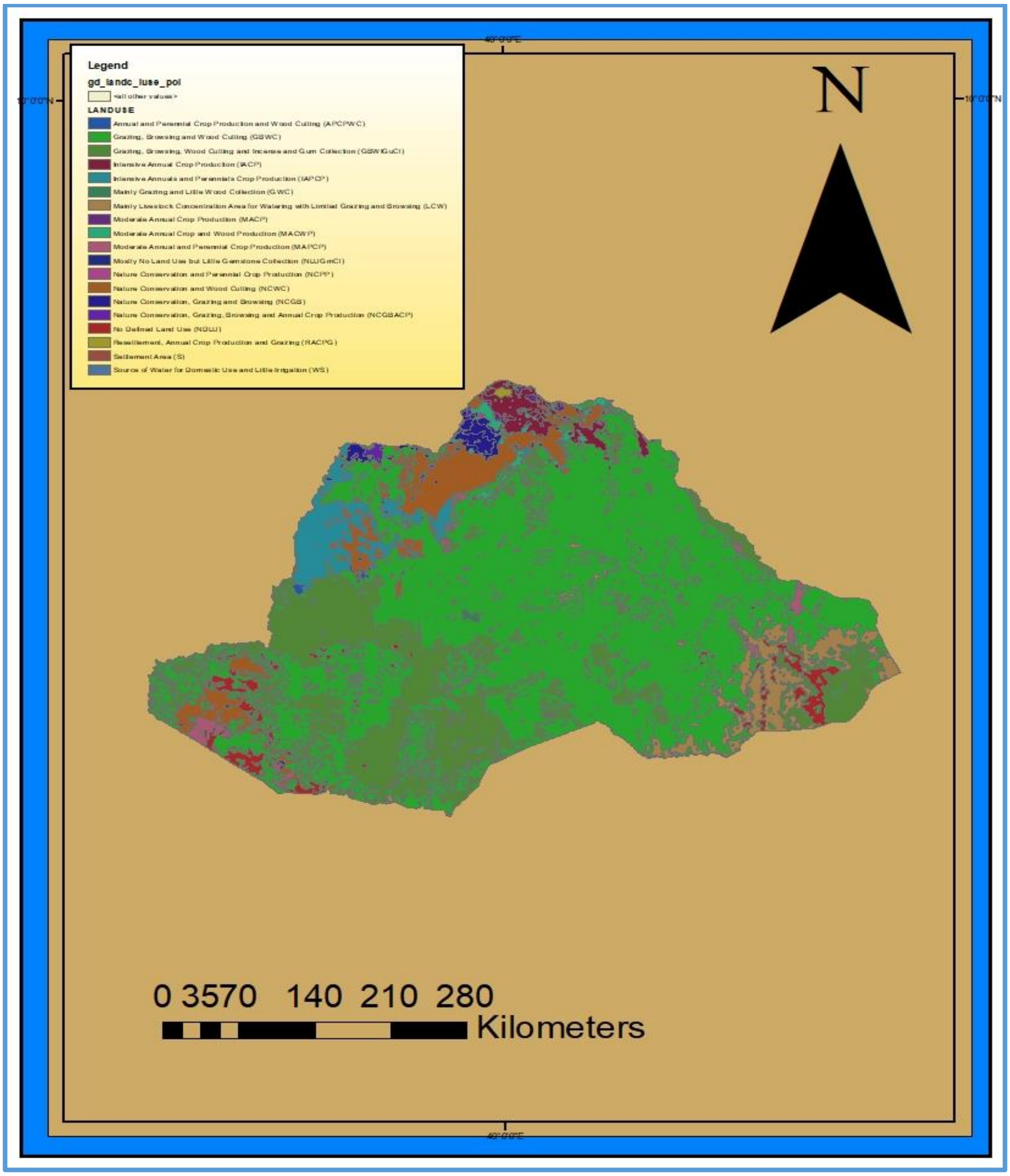


Fig.3.4 Land Use/Cover of upper Genale-Dawa.

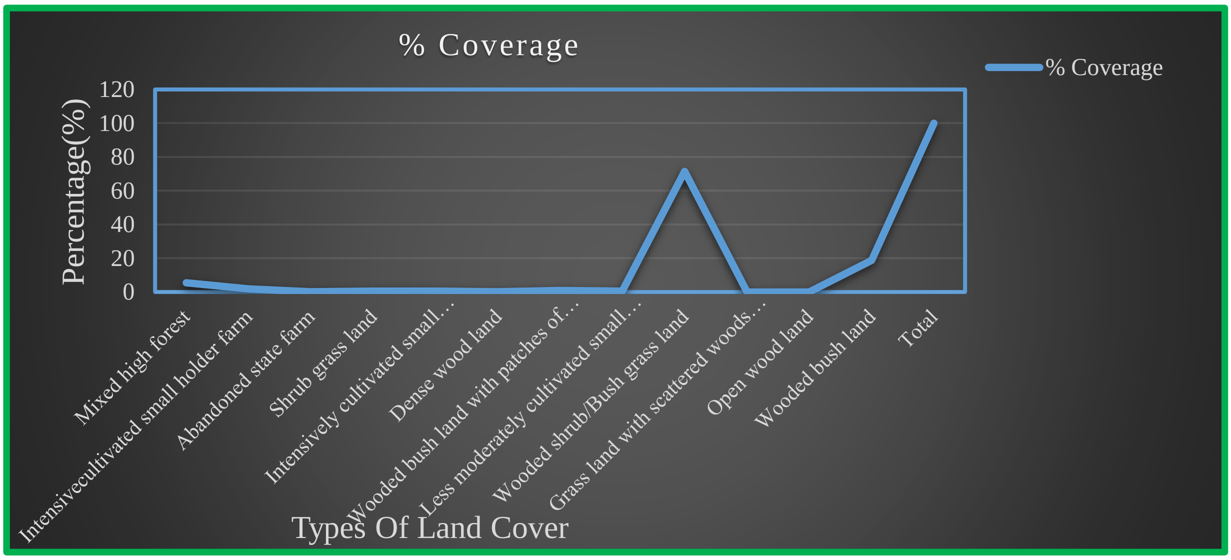


Fig. 3.5 percentage distribution of Land Use/Cover.

3.2.5 Soil Types

Soils that have predominantly available in the study area are Cambisols, Leptosols, Luvisols, Nitisols, Arenosols, Vertisols, Fluvisols and Regosols.

Cambisols (inceptisols) are characterized by slight or moderate weathering of parent material with high sand content and by absence of appreciable quantities of illuviated clay, organic matter, aluminium and/or iron compounds. Mostly familiar in the environment with level to mountainous terrain topographic features in all climates and under a wide range of vegetation types. Cambisols and vertisols erosion prevention capacity is based on land use management. Erosion is the greatest threat to **leptosols**. As a result, severe erosion problems may be observed in Leptosols under high anthropogenic effects. The erosion risk of Nitisols is on hilly sides, where there is lack of proper land use management practices.

The summary of soil type distribution in the Genale-Dawa River basin is shown in the table below.

Table 3.2 Soil Types and its areal coverage in Genale-Dawa River basin.

Soil Type	**Area (Ha)**	**%Coverage**
Acrisol	27718	0.180815
Arenosol	1019411	6.649996
Calcisol	19792	0.129111
Cambisol	5870783	38.29729
Fluvisol	830434	5.417229
Gelysol	8181	0.053368
Lavaflow	152915	0.997521
Leptosol	2118379	13.81897
Luvisol	2124781	13.86073
Nitisol	1301984	8.493324
Regosol	359001	2.341896
Solonchak	276509	1.803771
Solonetz	252893	1.649715
Vertisol	966718	6.30626
Total	**15329499**	**100**

The processed DEM Soil type map of Genale-Dawa is shown in the fig.3.6 below.

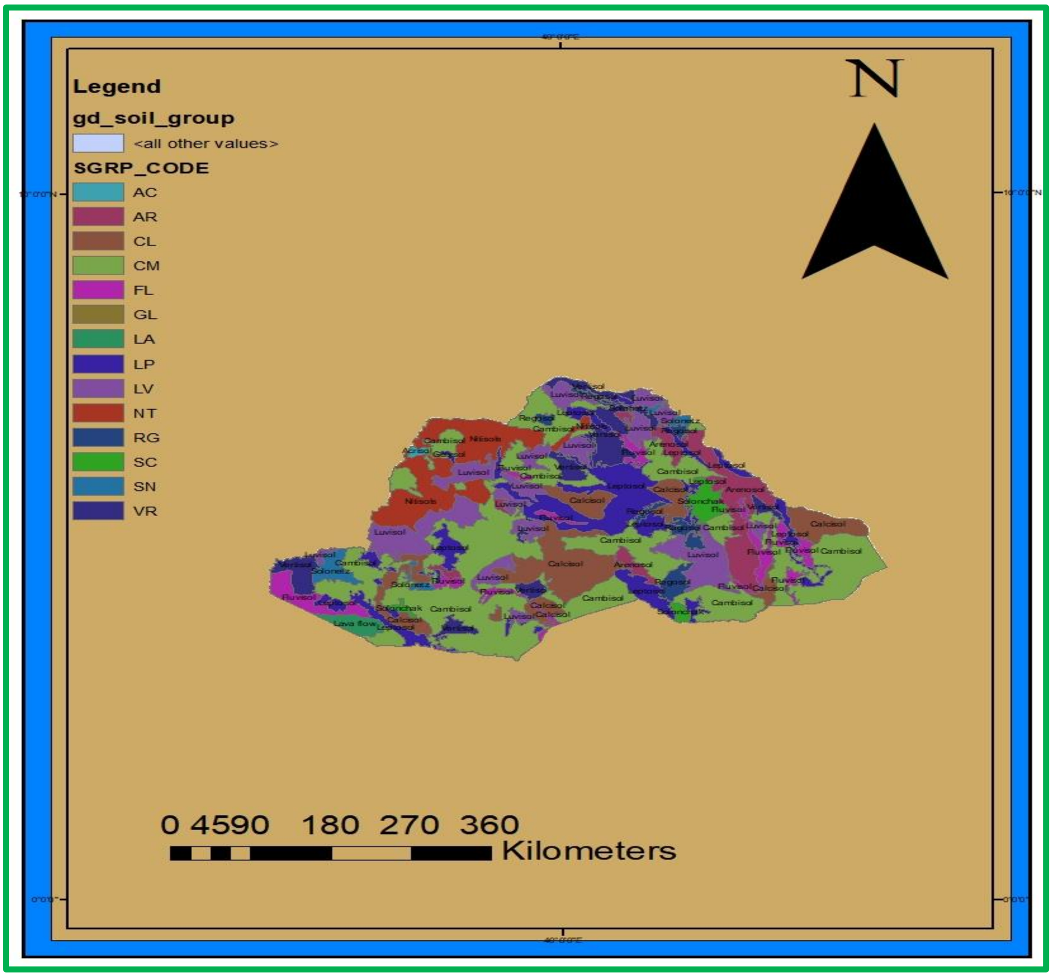


Fig.3.6 Soil Types in upper Genale-Dawa River basin.

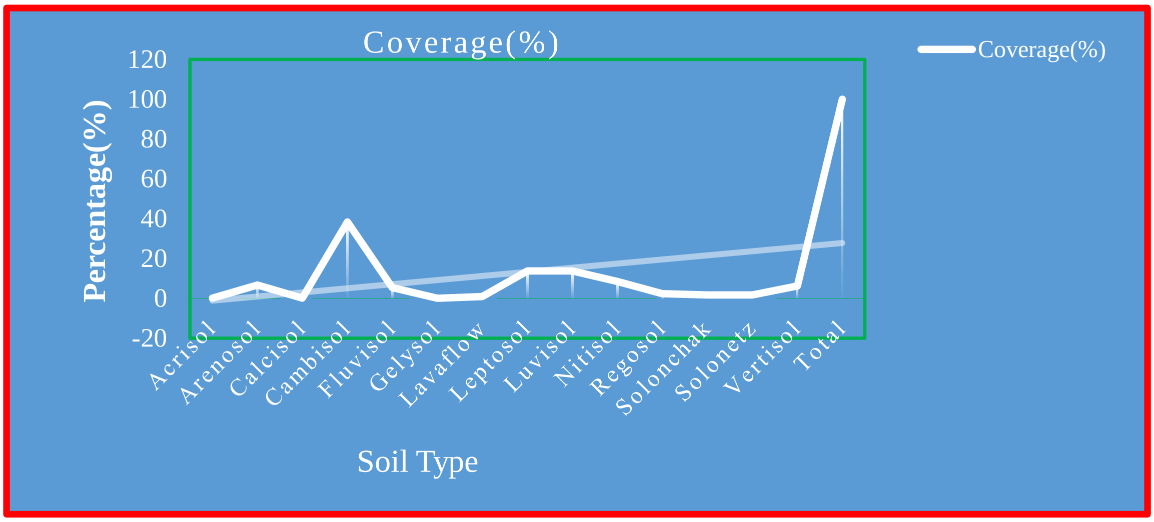


Fig.3.7 Percentage Coverage of Soil Type.

3.3 Hydro-Meteorological Data processing

More often than not, Hydro-meteorological data is used as the critical input parameter for all hydrological project studies. Hence, in the process of planning, development and management of any Water resource projects this hydro-meteorological data should be carefully prepared, well described, visualized, analyzed and modelled in order to reduce the error in design parameters. Thus, the data used for simulation purpose should be inconsistence, stationary and homogeneous.

3.3.1 Meteorological Data Processing

For this thesis, stations located in and near to the Genale project region were identified and a data set acquired from NMSA comprising the following records.

- Daily rainfall, Max. and Min. Temperature, Relative humidity, Wind speed and Sunshine hour from **5 principal stations** (Negele Borena, Kibre Mengist, Dello Menna, Hagere selam and Worka).
- 6 third class stations that only records Daily Rainfall and Max. and Min. Temperature (Bidire, Filtu, Meda-Walabu, Bore, Wadara and Yirba-Muda).

of the 11 stations above only 4 principal stations are actually lie within the project catchment area. Others are located on the Genale-Dawa sub-basin divide. The longest rainfall record is at Negele Borena, commencing in 1952. This and other longer-record stations are all located on the sub-basin divide. Although the Negele Borena record is almost complete, others are less continuous sometimes with gaps of several years.

Meteorological data have been measured at five of the stations. Of these, substantially long recordings of standard meteorological parameters are only available from the principal stations. The most representative of the meteorological station, their location, and area coverage in relation to the tributary and main stream sub-catchment’s, and project sites can be visualized by the use of Theisen polygon diagram as shown in the figure below.

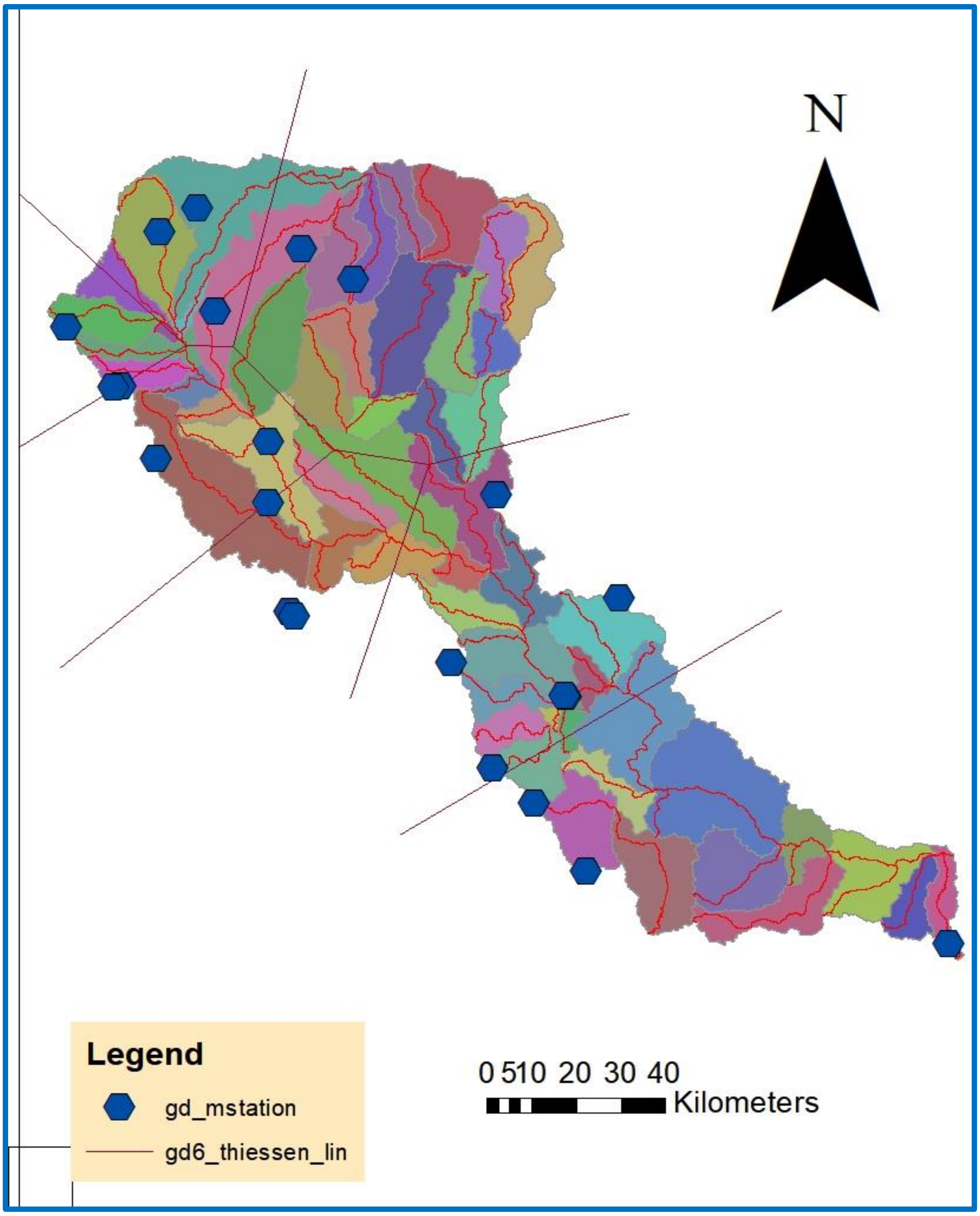


Fig.3.8 Location and Distribution of Meteorological Station by the use of Thiessen Polygon.

The Data collected were based on their homogeneity of the pattern which can be representative to the Reservoir area. The data collected from 3 stations covers a period of 1987-2017 and from two stations covers a period of 1988-2017 and 1990-2005.

The processed Monthly precipitation of the principal stations in the River basin is indicated in hyetograph forms as in fig.3.9 below.

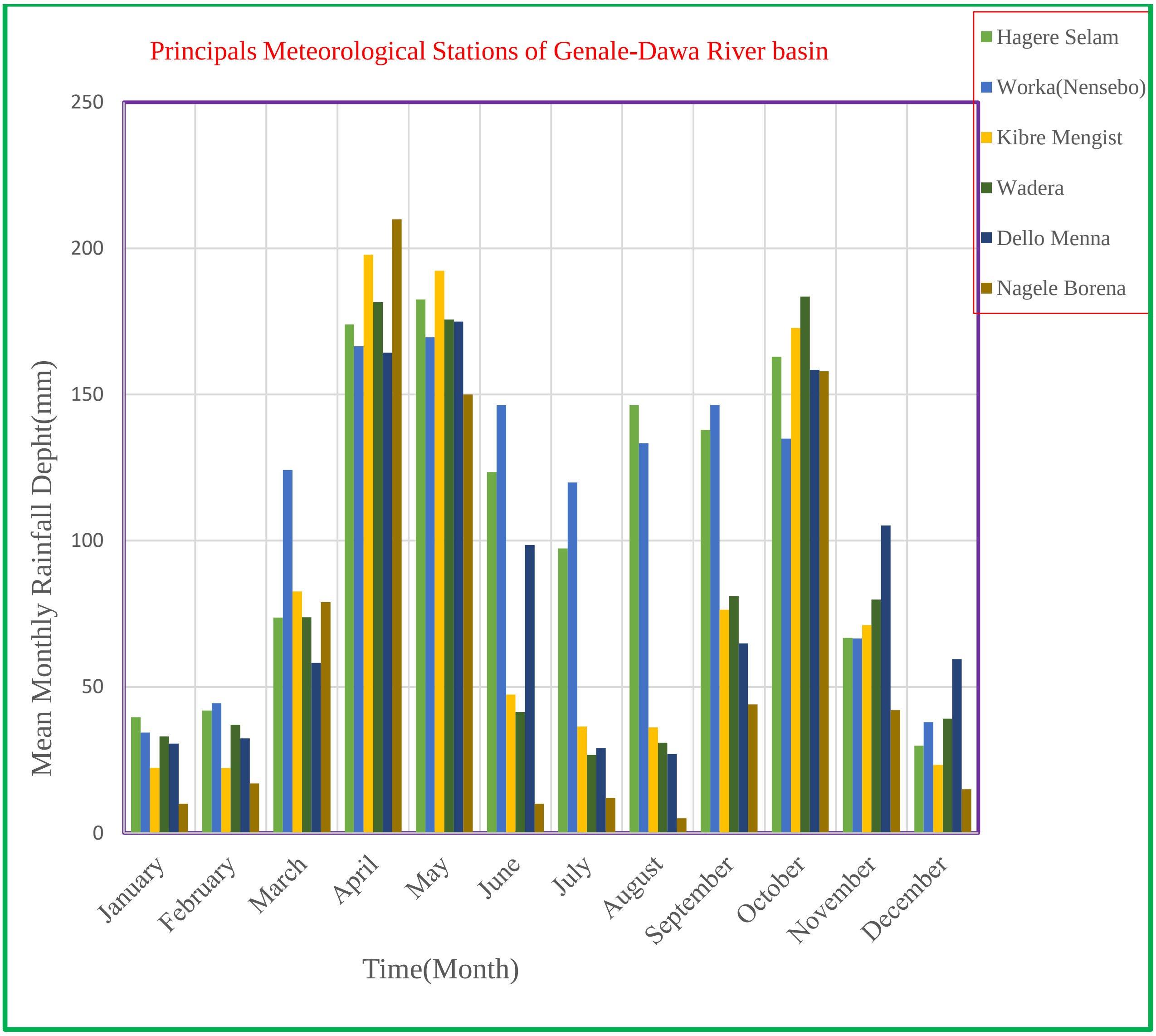


Fig.3.9 Mean Monthly Rainfall of selected stations(mm/month).

Maximum and Minimum Temperature data representing the upper Genale-Dawa River basin was collected for all station with different length of time. The yearly average temperature of the principal station is shown in graphical charts as in fig.3.10 below.

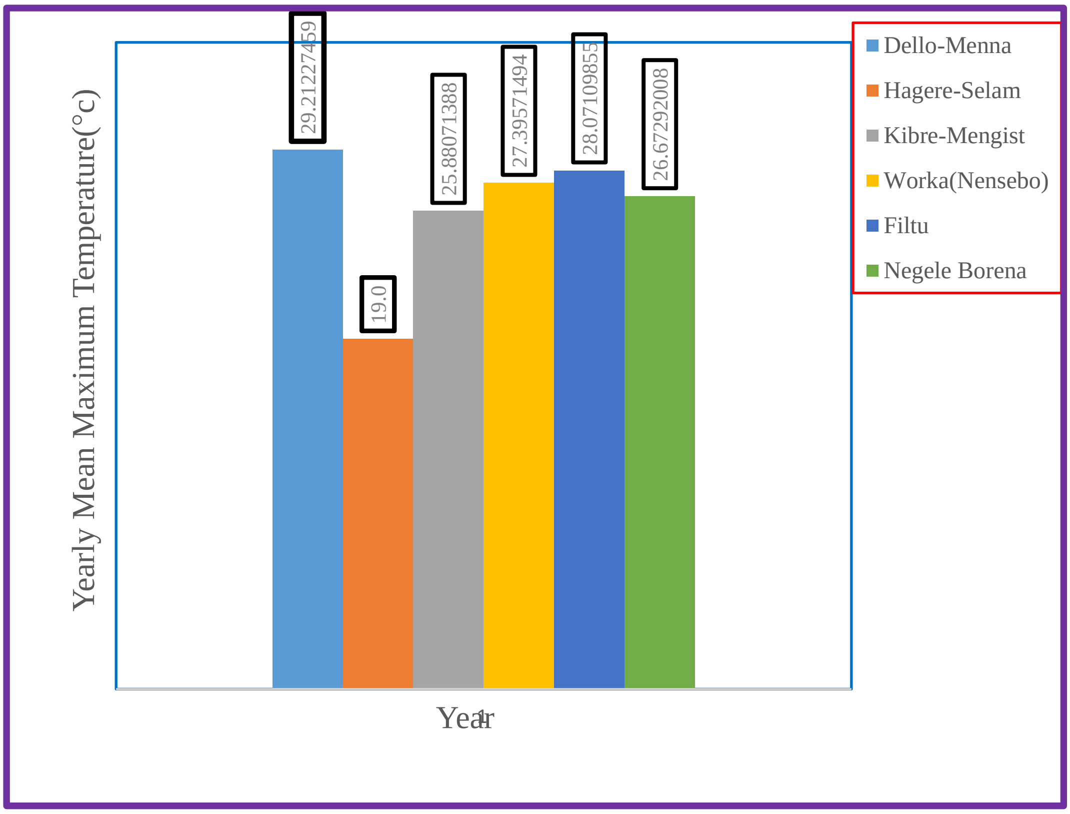


Fig.3.10 Yearly Mean Maximum Temperature of Selected Stations(°C/year).

Like most of basic science hydrology requires analysis to use the fundamental concepts in the solution of engineering problems. Hence, before using these data the quality of each data recorded at respectively station was evaluated using:

- Homogeneity test by non-dimensional parameterization,
- Consistency test by Double Mass Curve and
- filling missed data by the use of Normal Ratio Method.

A. Homogeneity test by non-dimensional parameterization

In order to select the representative meteorologically homogeneous station for the analysis of areal rainfall estimation, checking homogeneity of group station is essential. Homogeneity analysis is used to identify a change in statistical properties of time series. In this study homogeneity test is checked up by non-dimensional parameterization.

$$\boldsymbol{Pi} = \frac{\bar{P}\ \boldsymbol{Station\ i}}{\bar{P}\boldsymbol{All\ Station}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{equation 3.1}$$

Where, Pi – non-dimensional parameterization

$\bar{P}i$- Over years averaged monthly precipitation of station i

$\bar{P}$- Over years average yearly precipitation of all station.

For comparison of each other station with same mode and pattern, the selected station is observed. Hence, the selected group stations are homogenous as indicated in the fig.3.11 and fig.3.12 below by non-dimensional parameterization.

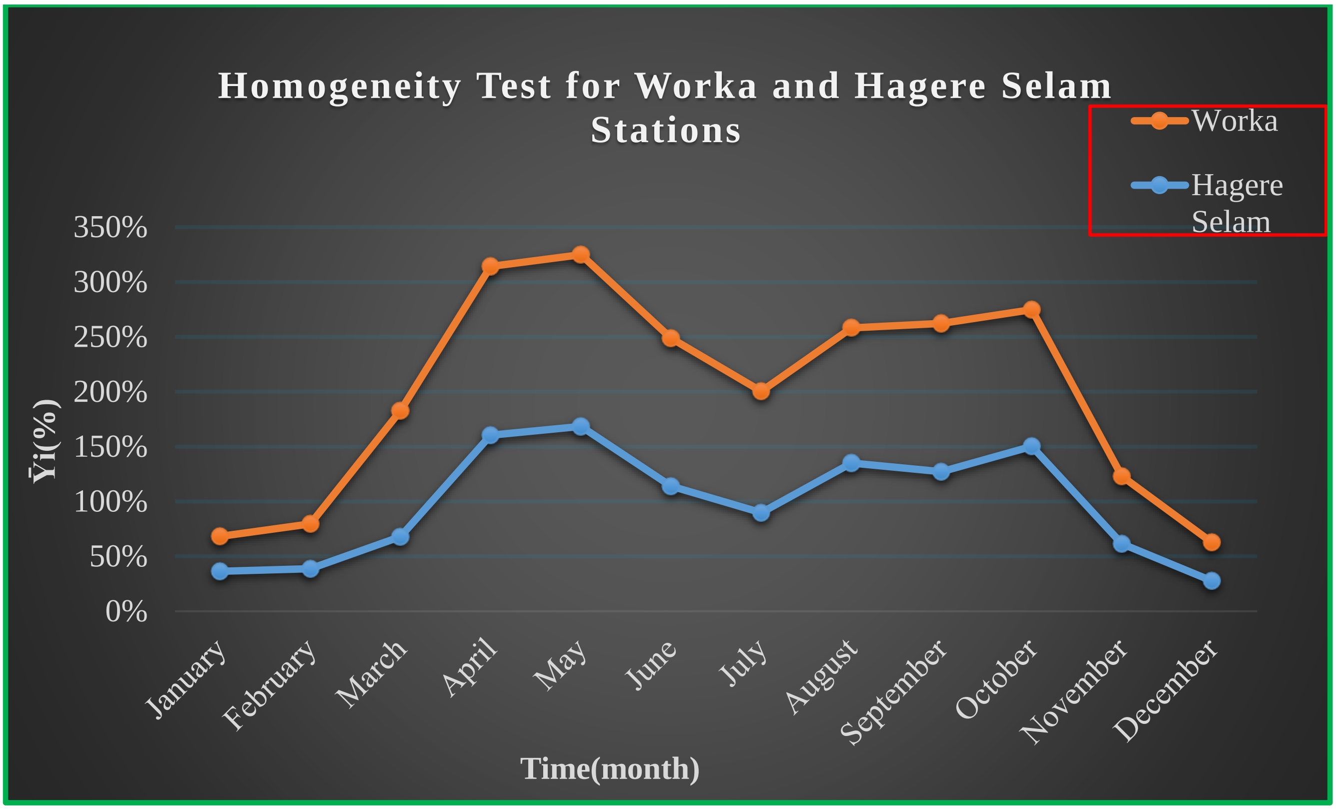


Fig.3.11 Homogeneity test for Worka and Hagere-Selam Stations.

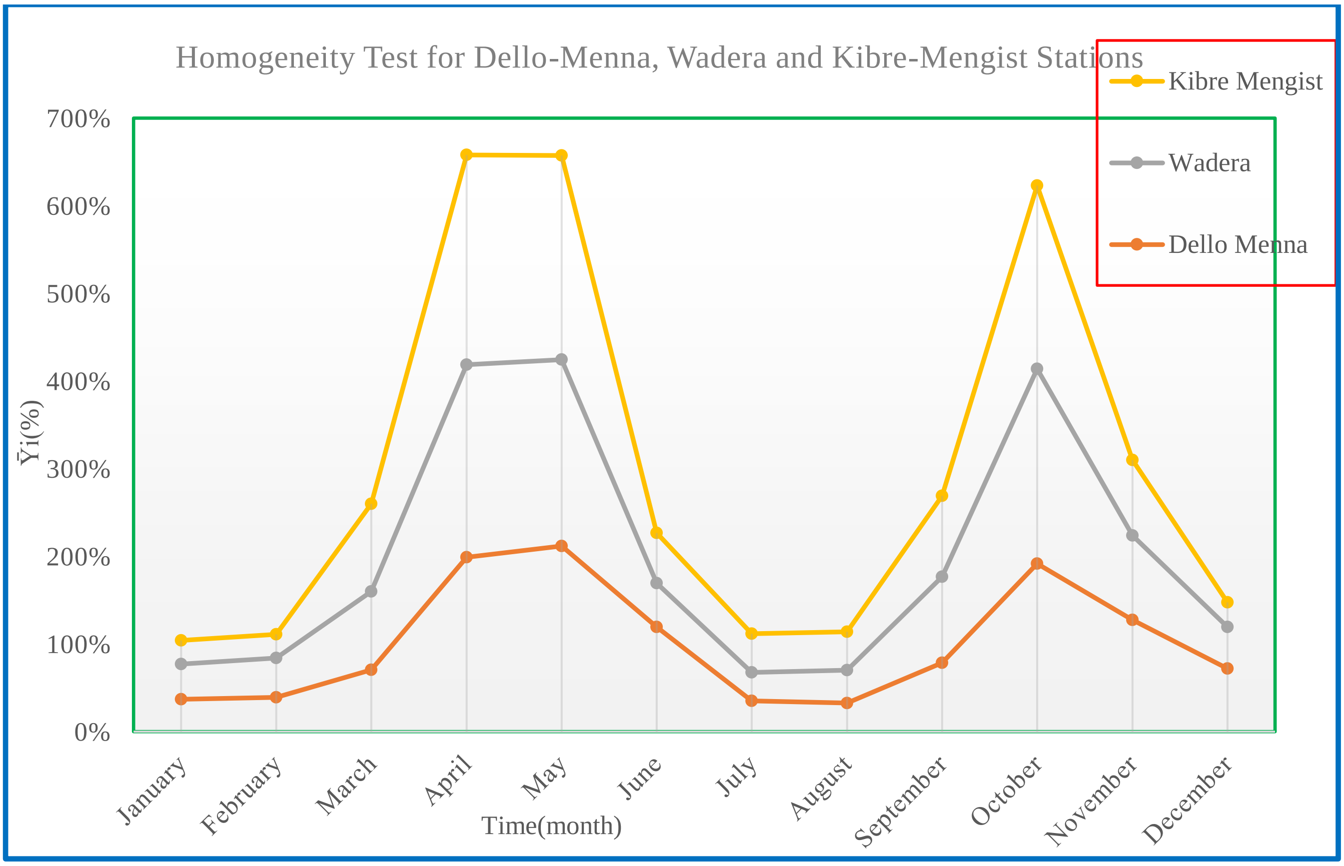


Fig.3.12 Homogeneity test for Dello-Menna, Wadera and Kibre-Mengist Stations.

B. Filling in Missing Data

Measured precipitation data are important to many problems in hydrologic analysis and design. Because of the cost associated with data collection, it's very important to have complete record at every station. Obviously, condition sometimes prevent this. For gauge that requires periodic observation, the failure of the observer to make the necessary visit to the gauge may result in the missing data. Vandalism 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 precipitation record. Rainfall data are an important input to hydrologic designs, whether measured storm data event synthetic data based on characteristics of measured data. For this study the record of Meteorological data for five principals (first class gauge) stations were collected from National Meteorological Service Agency (NMSA) and missing data from this station were filled in by Normal Ratio Method.

When the average annual catches differ by 10%, the Normal ratio method is preferable; such differences might occur in regions where there are large differences in elevation. For this particular project after analysis of rainfall record have undertaken it is found that the difference between the average annual precipitation at index station and missing station is differing by more than 10%. Thus, Normal Ratio Method is used.

The general formula for computing Px by Normal Ratio Method is given as;

$$\boldsymbol{Px = \frac{Nx}{n}\left(\frac{P1}{N1} + \frac{P2}{N2} + \frac{P3}{N3} + \cdots \frac{Pn}{Nn}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ \textbf{equation 3.2}$$

Where, Px - average annual precipitation at missing station.

P_1, P_2, P_3… Pn – Precipitation record of index station

Nx – Normal annual precipitation records at missing station

N_1, N_2, N_3 … Nn – Normal annual precipitation of index station

Details of analyzed Mean Monthly Rainfall at Principal Station After Filling for Missing Data is shown in Appendix B.

C. Checking Consistency of Selected Stations by Double Mass Curve Analysis.

A time series observational data is consistence and homogeneous if the periodic data are proportional to an appropriate simultaneous period. This proportionality can be tested by Double Mass Curve analysis in which accumulated rainfall/hydrological data is plotted against the mean value of all neighboring stations. For this study according to Double Mass Curve analysis all selected stations are consistence. The Double mass curve consistency test for the selected stations is indicated in the fig.3.13 and fig.3.14 below.

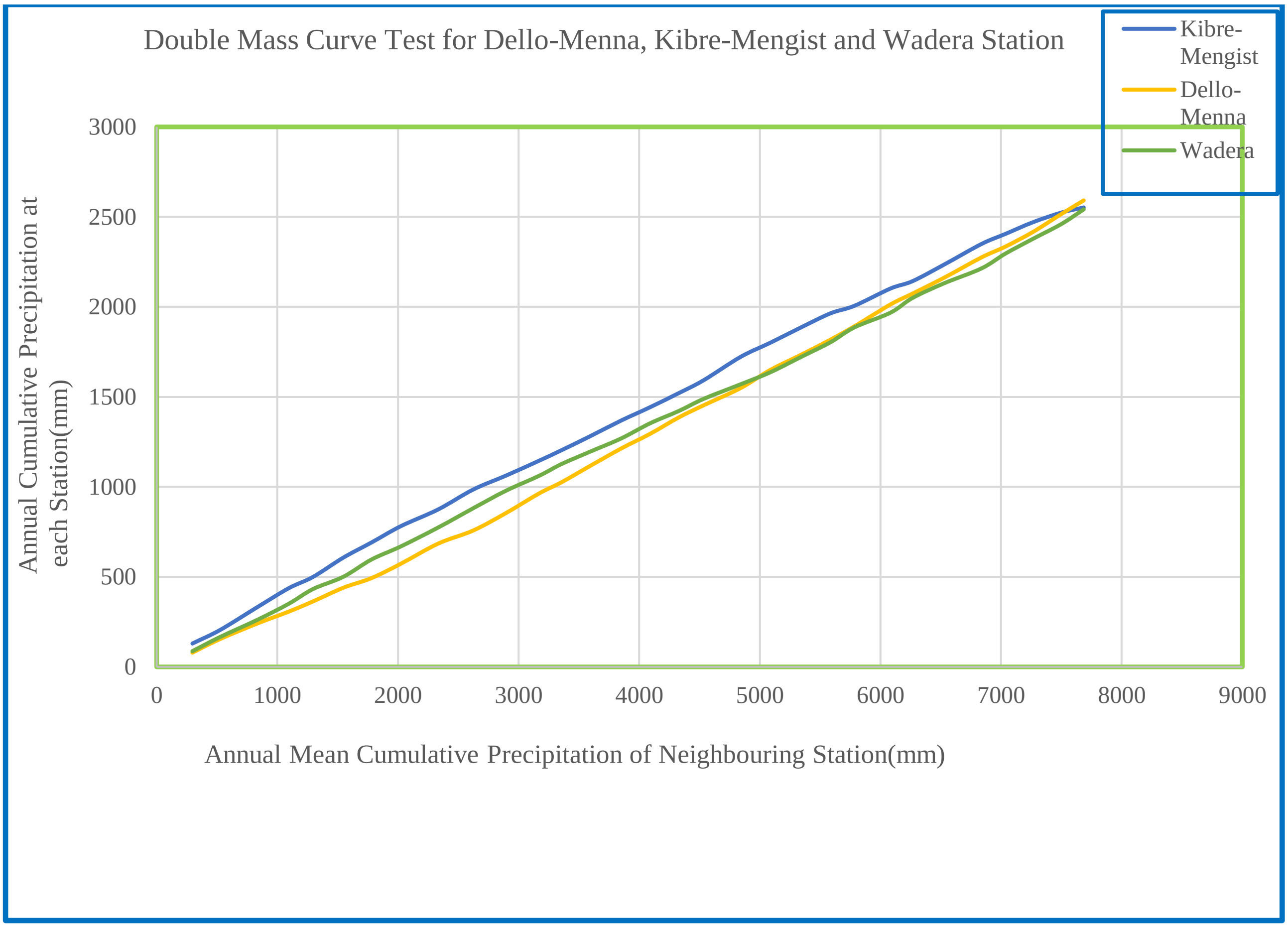


Fig.3.13 Double Mass Curve test for Dello-Menna, Kibre-Mengist and Wadera Stations.

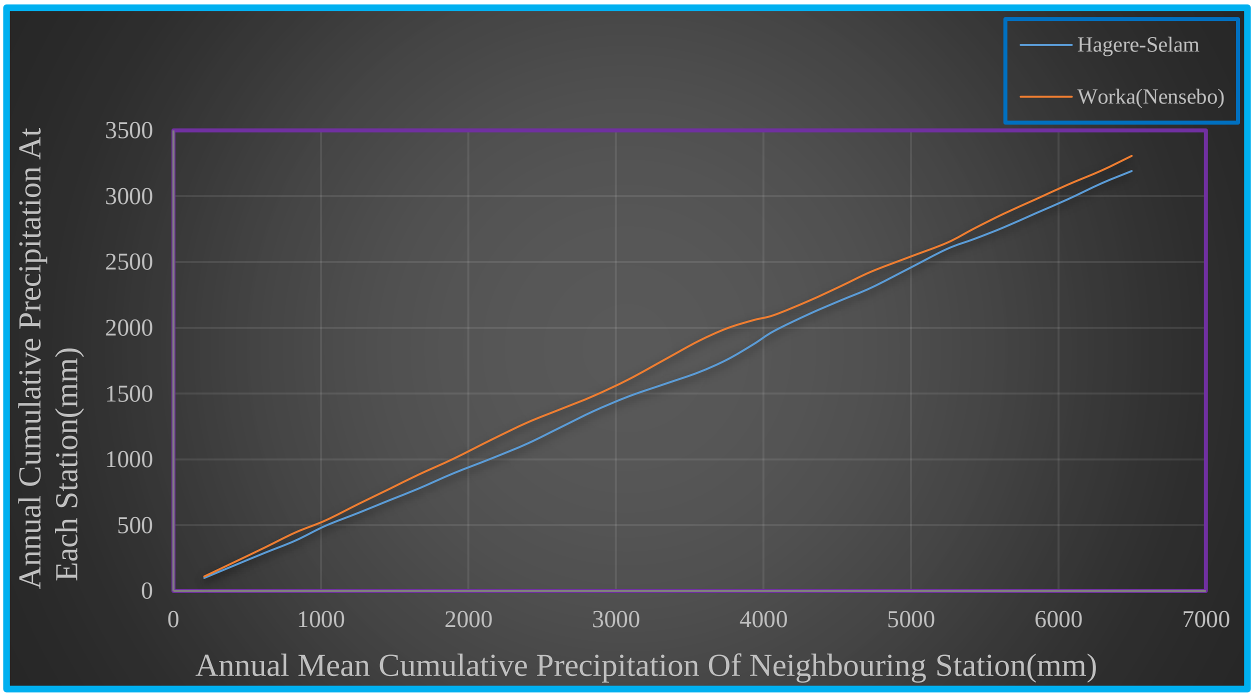


Fig.3.14 Double Mass Curve test for Hagere-Selam and Worka Stations.

3.3.2 Hydrological Data Processing

Like most of basic science hydrology requires analysis to use the fundamental concepts in the solution of engineering problems. Because of the complexity of most hydrologic engineering design problem the fundamental elements of the hydrologic science cannot be used directly. Instead, it is necessary to take the measurements of the response of the hydrologic process and analyze the measurements in an attempt to understand how the function proceed. Thus, to check for and address the personnel and machine error during the stream flow record analysis of the observed flow at the specified station should be performed. For this hydrological research, in regard to data collection and analysis, the geographical area of interest was defined to cover the upper and mid-section of Genale-Dawa River basin, including also the adjacent tributaries originating from Bale mountain and parts of the Dawa sub-basin area in the vicinity of the inter basin divide.

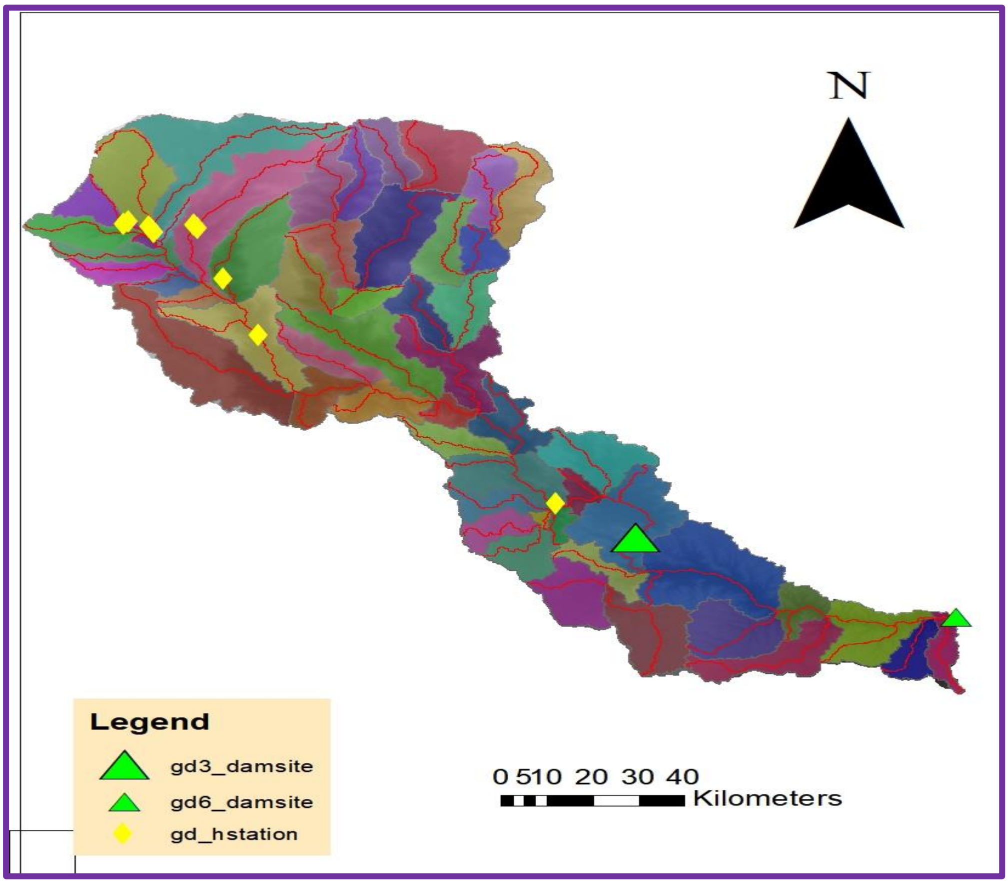


Fig.3.15 Location and Distribution of Hydrological Station in the Upper Genale River Basin.

In view of the importance of streamflow data at Chena-Mansa station, which was used as a base for prediction of inflow series to the GD-3, GD-5 and GD-6 project site, the complete record of measurements has been systematically scrutinized, verified and updated. For this purpose, and with the invaluable assistance from the Ministry of Water, Irrigation and Energy (MoWIE) the full history of discharge measurements was retrieved from the Hydrology Department archives. For this study, the daily stream flow collected from MoWIE, is almost complete and the small amount of infilling data were filled. Details of Mean Monthly Streamflow from 1990 – 2005 (m^3/sec.) is shown in Appendix C. Performing stream flow observation quality assessment is a crucial step before we use as an input for hydrological system. Hence, the following three major approaches were undertaken for this thesis, for the assessment of stream flow observation quality.

a. Rough Screening of the Daily Flow Observation.

This will allow visual detection of whether the observational data have been consistently or accidentally credited to a wrong day, or whether they contain misplaced decimal points. Visual observation of daily flow records implied no minor errors such as exaggerated numbers, misplaced decimal points, very high flows during dry months and/or very low flows during rainy months. Thus, the stream flow records look good enough for all years (1990-2007) at chena-Mensa station.

b. Plotting the Data.

Plotting stream flow observation record is an excellent visual check for periods of suspect data and helps to observe absence of trends or discontinuities of flow data. A plot indicates that a reliable and appreciable flow is observed as in the following fig.3.16.

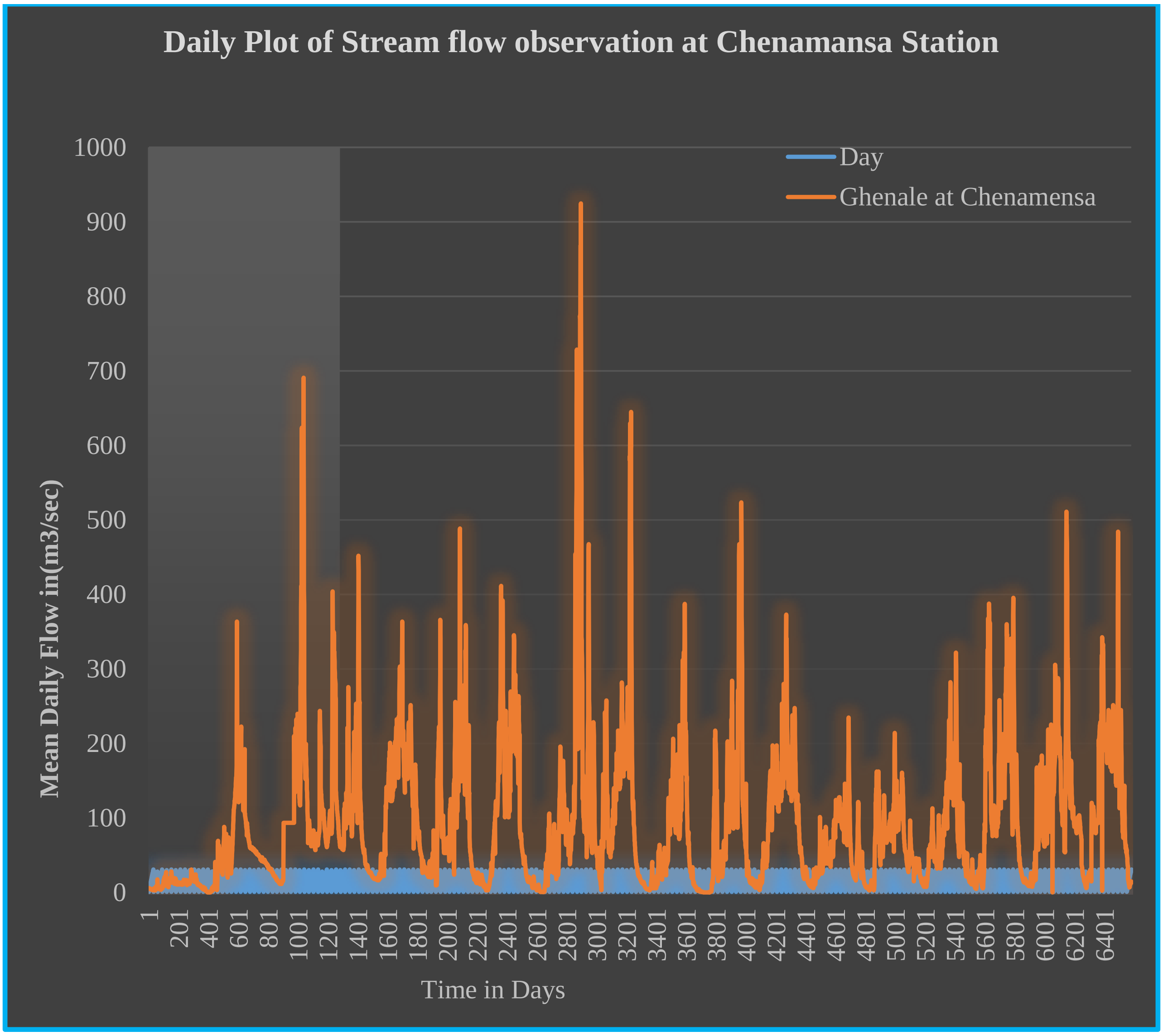


Fig. 3.16 Daily Plot of Stream Flow Observation at Chena-Mansa Station.

c. Tests for Outlier

After plotting Stream flow observation data, an event that is much larger or much smaller than the remainder may be evident. Some data samples may contain more than one extreme event. Extreme events can create a problem in data analysis and modeling. For instance, an extreme large value can cause sample mean and standard deviation to be much larger than the sample values. An outlier is an observation that significantly deviates from the bulk of data due to errors in data collection, recording and natural causes. Outliers can be identified visually by plotting the data and by a variety of statistical tests like Grubbs T test, Grubbs and Becks(G-B) test, Dixon's test of ratios and Youden's rank test. In addition to the visual observation of plotted flow data, Grubbs T test was used to identify outlying flow observation for this particular study. The Grubbs T test statistics is calculated as;

$\boldsymbol{T} = \frac{\boldsymbol{X}-\bar{\boldsymbol{X}}}{\boldsymbol{S}}$ ………………………………………………………….. **equation 3.3**

Where, x – Observed mean daily flow

$\bar{X}$ −Mean of observed mean daily flow

S – Standard deviation of observed mean daily flow during a period from 1990-2007. In this test, X is considered as an outlier if the value of T is greater than the corresponding Grubbs critical T values. The Grubbs T test statistics for all observation is calculated. The number of mean daily flow data used in Grubbs T test is 6581 which conducted at Chena-Mansa gauging station. It is generally recommended that a low significance level as 1% or 5% is used and a significance level greater than 5% should not be a common practice for statistical test for outlying observation (Grubbs 1969). Hence, for a significance level of 5% and daily observation of 6581:

Critical value for Grubbs T test = 4.473

Daily Mean flow value = 93.418 m^3/sec

Standard deviation = 92.859

Minimum flow value = 0.007 m^3/sec

Maximum flow value = 924.859 m^3/sec

The coefficient of variation measures the spreads of a set as a proportion of its mean. It can be used for cross comparison and often expressed as percentage. That is for comparison of the variability of the same variable at different places. It is the ratio of the sample standard deviation to the sample mean.

$\boldsymbol{cv} = \frac{Standard.dev}{\bar{X}} = \frac{92.859}{93.418} = \mathbf{0.99}\%$ which gives good result.

Although, the method shows there is an outlier for some days, the calculated Grubbs T test for this day exceeds the critical value of Grubbs T test (T = 4.473) by small fraction error which is less than 5%. Hence, flow observation on these days are not considered as real outlier for respective days and the flow records keep as it is. The values displayed above critical (4.473) value are shown as outliers by Grubbs T test from mean daily observation. Fig.3.17 below shows the plot of calculated Grubbs T test.

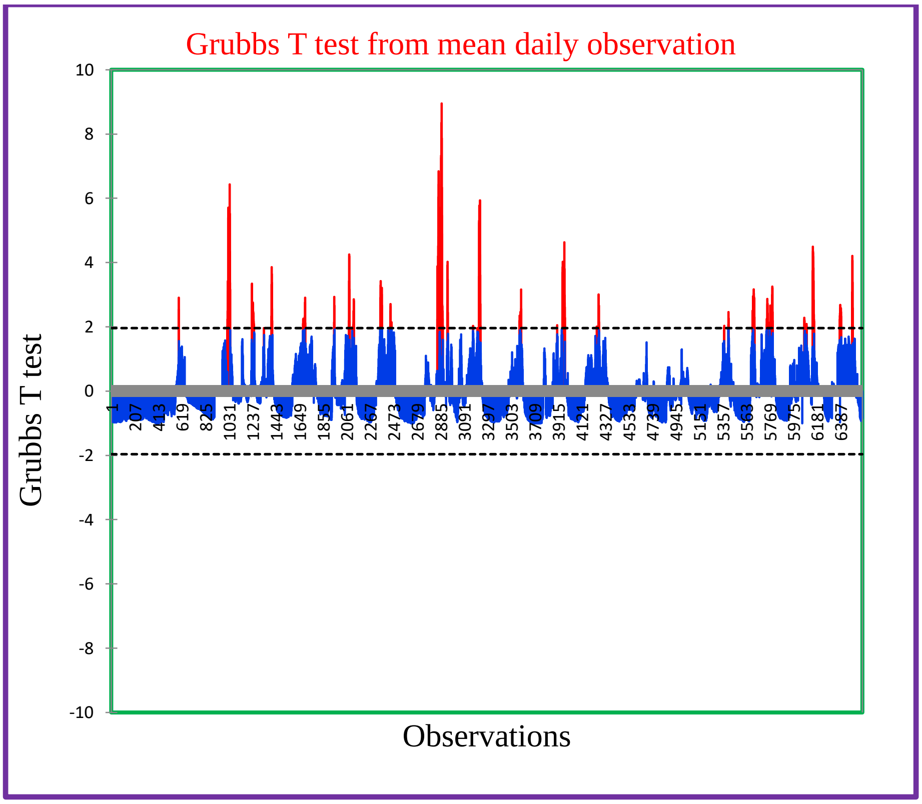


Fig.3.17 calculated Grubbs T test from mean daily flow observations.

3.4 Potential Evapotranspiration (PET)

3.4.1 Evapotranspiration from Land

On land, evapotranspiration is a combination of evaporation from soil surface and transpiration from vegetation. In addition to energy and water transport, the availability of soil water is also important. When water availability is not a limiting factor, evapotranspiration reaches its full potential and is called potential evapotranspiration. In practice, a value for the potential evapotranspiration is calculated at a local climate station on a reference surface (short grass; FAO, 1998). This value is called Reference evapotranspiration, and can be converted to a potential evapotranspiration by multiplying with a surface coefficient. The FAO Penman-Monteith method is recommended as the sole method for determining reference evapotranspiration when the standard meteorological variables including air temperature, relative humidity and sun shine hours are available.

Normally, the potential evapotranspiration is assessed by means of the FAO Penman-Monteith equation:

$$ETO = \frac{0.408(Rn-G)+\gamma(\frac{900}{T+273}U2(es-ea)}{\Delta+\gamma(1+0.34U2)}$$ ………………………………….. **equation 3.4**

Where; ET_o – reference crop evapotranspiration [mm/day],

R_n – net radiation at crop surface [MJ m^{-2} day $^{-1}$],

G – Soil heat flux density [MJ m^{-2} day^{-1}],

T – air Temperature at 2 m height [°C],

U_2 – Wind speed at 2 m height [ms^{-1}],

e_s – Saturation vapor pressure [Kpa],

e_a – actual vapor pressure [Kpa],

e_s-e_a – Saturation vapor deficient [Kpa],

$\Delta -$ Slope vapour pressure curve [Kpa°C^{-1}]

3.4.2 Reservoir Evaporation

Reservoir Evaporation was calculated by using Penman-Monteith method and then applies an aridity correction factor. According to FAO Irrigation and Drainage Paper 56 and page 114, the conversion of ETo to evaporation of open water, with depth higher than 5 m, clear of turbidity, in temperate climate, would be varied between 0.65 and 1.25(FAO, 1998). For Ethiopia the aridity correction factor was estimated to be 1.2 (MoWIE, 1995). The evaporation from the cascaded dams is an input for HEC-ResSim model to simulate optimal power and set guide curves. Monthly lake evaporation from three Genale cascade reservoirs is shown as in the following table 3.3 and fig.318 below. The figure shows lake's evaporation from GD-3 is small as compared with GD-5 and GD-6 due to natural morphology of River basin.

Table 3.3 Monthly Lake Evaporation

Reservoirs	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
GD-3	177	165	111	-60	2	121	124	145	123	-3	98	157
GD-5	180	170	136	-20	34	140	147	168	147	36	97	157
GD-6	184	175	161	15	65	160	169	191	171	80	96	157

Source **(MoWIE).**

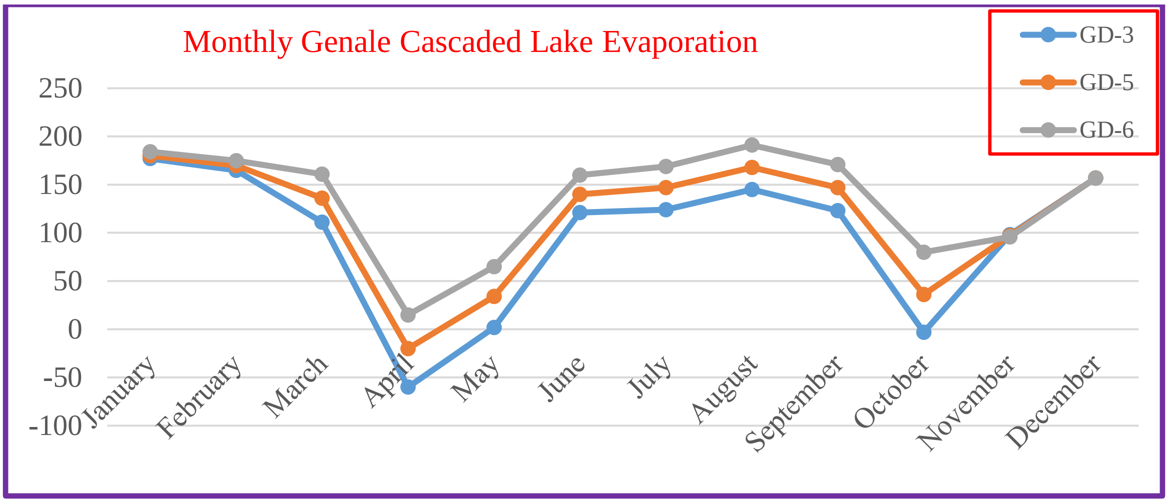


Fig.3.18 Lake's Evaporation (MoWIE).

Flow transfer to the Dam site

Flow values are transferred from gauged site to the ungauged site by the use of Dr. Admasu's empirical formulae which shown as follows:

$$\boldsymbol{Qungauged} = \boldsymbol{Qgauged}\ (\frac{\boldsymbol{Ag}}{\boldsymbol{Aug}})^{\mathbf{0.7}} \text{ .... } \textbf{equation 3.5}$$

3.5 HEC-HMS and HEC-ResSim Model Building for Upper Genale-Dawa River Basin.

3.5.1 HEC-HMS Model Set up

HEC-HMS (Hydrologic Engineering Center-Hydrological Modeling System) is the United State Corps of Engineer's hydrologic system computer program which developed by Hydrologic Engineering Center's (HEC). The program simulates Precipitation-Runoff, applies unit hydrograph(UH) principles and offers a wide varieties of possibilities for the analysis and generation of flood events including rainfall modeling, hydrograph model calibration, event generation by different methods, and flood routing both through natural channels and controlled(reservoirs) that occur as a result of changes in land use or meteorological inputs. Hence, for this particular study HEC-HMS model was chosen and applied to derive Stream flow hydrograph generation at the project site. Their use can be favorable when longer precipitation records are available than runoff, or when precipitation can be more reliably estimated from surrounding stations (Wilson et al., 2011).

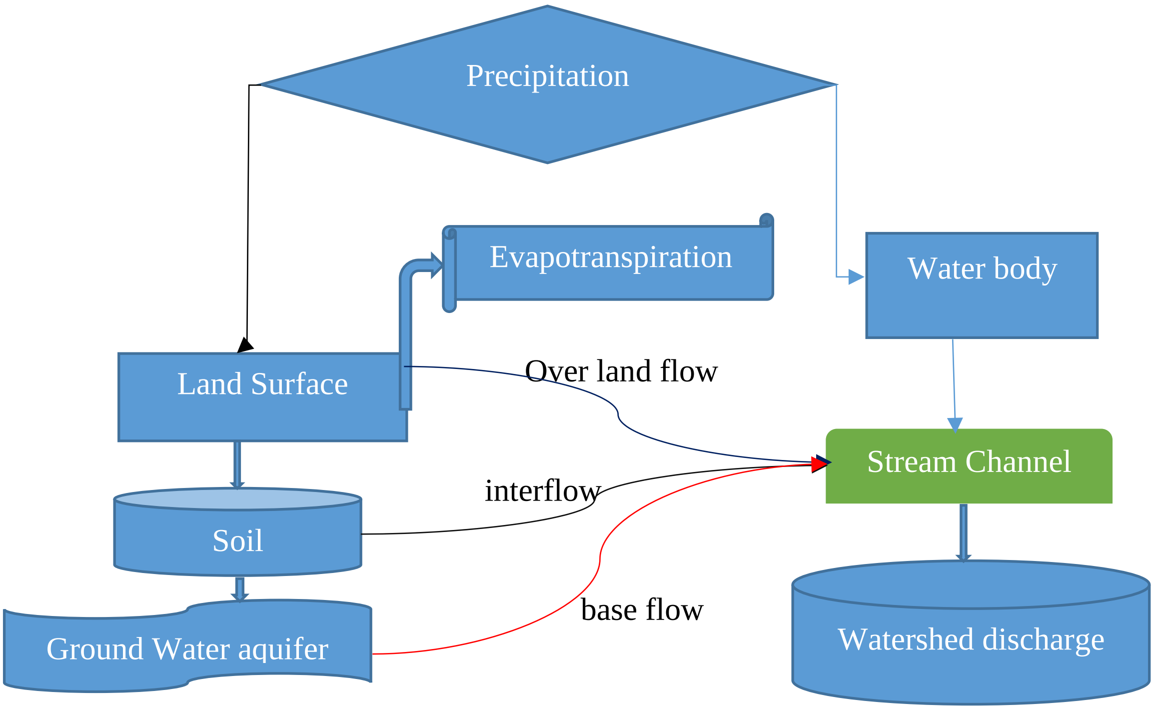


Fig. 3.19 Typical HEC-HMS representation of watershed runoff

HEC-HMS is the successor and replacement for HEC-1 program, improves up on capabilities of HEC-1, and provides additional capabilities for distributed modeling and continues simulation.

3.5.1.1 Terrain preprocessing

The purpose of terrain preprocessing was to perform an initial analysis of the terrain and to prepare the dataset for further processing. A Digital Elevation Model (DEM) of the study area is required as input for terrain preprocessing. A DEM is a grid which each cell assigned the average elevation on the area represented by the cell. In this study, Arc-Hydro tool (Version that work with Arc-GIS 10.3) was used to process a $30m \times 30m$ DEM to delineate watershed, sub-watershed, stream network and some other watershed characteristics that collectively describe a drainage patterns of a river basin. The results were used to create an input files for HEC-HMS model.

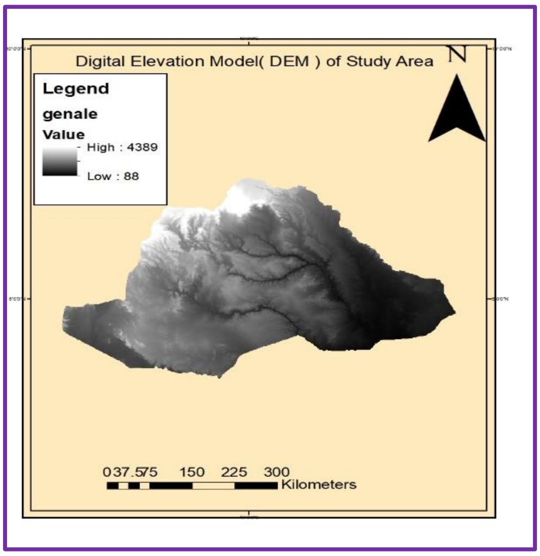
The steps used in preprocessing of Arc-Hydro are:

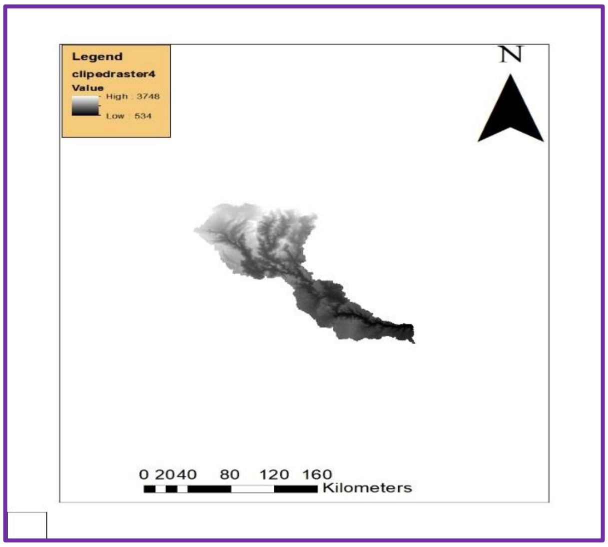
- **DEM Reconditioning**: the DEM Reconditioning function modifies Digital Elevation Model (DEM) by imposing linear features onto them (burning/fencing).

- **Fill sinks**: the fill sinks function fills sink in a grid. If a cell surrounded by higher elevation cells, the water is trapped in that cell and cannot flow. The fill sinks function modifies the elevation value to eliminate such a problem.
- **Flow direction**: takes a grid ("Hydro DEM" tag) as input, and computes the corresponding flow direction grid ("Flow Direction Grid" tag). The values in the cells of the flow direction tag indicate the direction of the steepest descent from that cell.
- **Flow accumulation**: by using flow direction grid as an input file it computes the associated flow accumulation grid ("Flow Accumulation Grid" tag) that contains the accumulated number of cells, for each cell in the input grid.
- **Stream definition**: takes a flow accumulation grid as input file and creates stream grid ("Stream Grid" tag) for a user defined threshold. This threshold defined either as a number of cells (default 1%) or as a drainage area in square kilometers.
- **Stream segmentation**: creates a grid stream segments that have a unique identification. A segment may be either a head segment or a segment between two segment junctions.
- **Catchment grid delineation**: creates a grid in which each cell carries a value (grid code) indicating to which catchment the cell belongs. The value corresponds to the value carried by the stream segment that drains that area, defined in the input Link Grid.
- **Catchment polygon processing**: takes as input a catchment grid and converts it into a catchment polygon feature class ("catchment" tag).
- **Drainage line processing**: converts the input Stream Link grid into a Drainage line processing feature class. Each line in a feature class carries the identifier of the catchment in which it resides.
- **Drainage point processing**: allows generating the drainage points associated to the catchments.
- **Longest flow path for the catchments**: generates the longest flow path for each catchment in the input catchment feature class.
- **Slope**: allows generating the slope grid in percent for a given DEM.
- **Slope greater than 30**: allows generating a grid where the cells having a slope greater than or equal to 30% have a value of 1, and all the others 0. It requires as input slope grid containing the slope in percent.

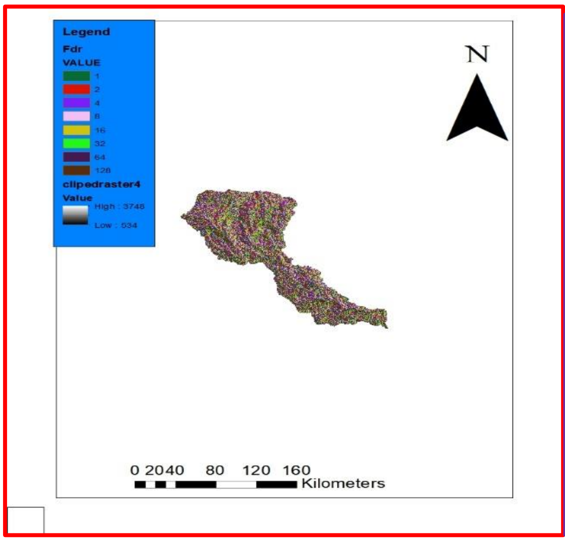
➢ **Slope greater than 30 and facing north**: allows generating a grid where the cells having a slope greater than or equal to 30% and facing north have a value 1. All the other cell takes a value 0.

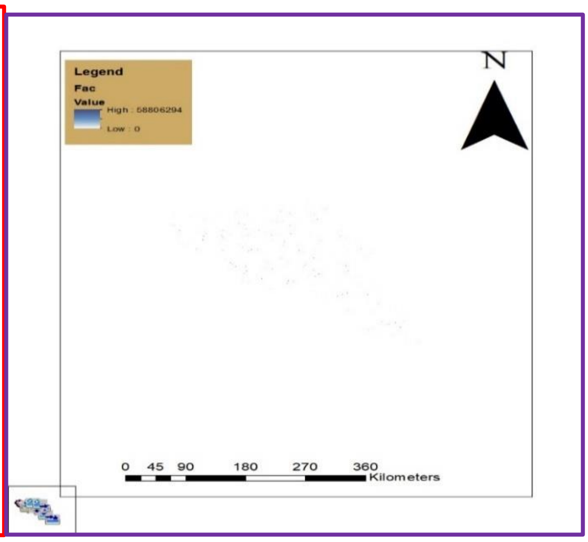
➢ **Weighted flow accumulation**: used to compute the runoff or the load for each cell. This function takes as input a flow direction grid and a weight grid. It computes the associated weighted flow accumulation grid ("Weighted Flow Accumulation Grid" tag) that contains the accumulated values (weight) of cells upstream of a cell, for each cell in the input flow direction grid. Fig.3.20 below shows the preprocessing task carried out by the use of Arc-Hydro tool which is an Arc-GIS extension.



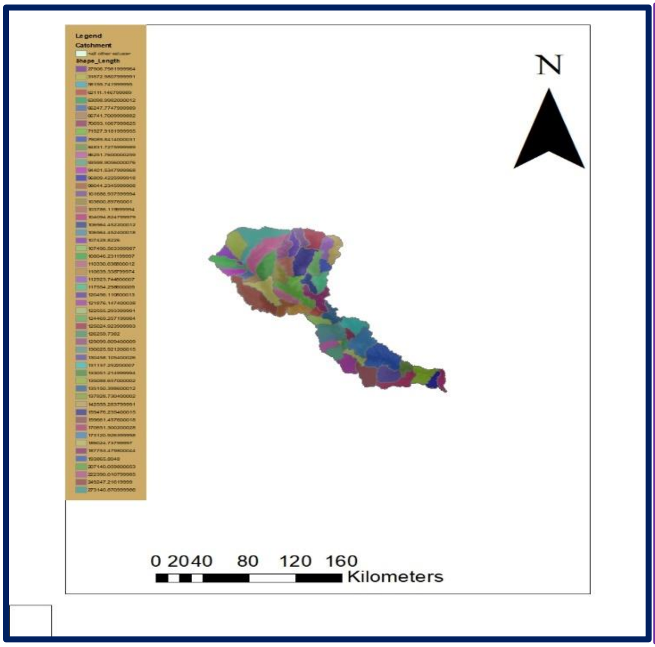


a. Unprocessed DEM for Genale-Dawa River basin   b. Clipped DEM for Genale River basin

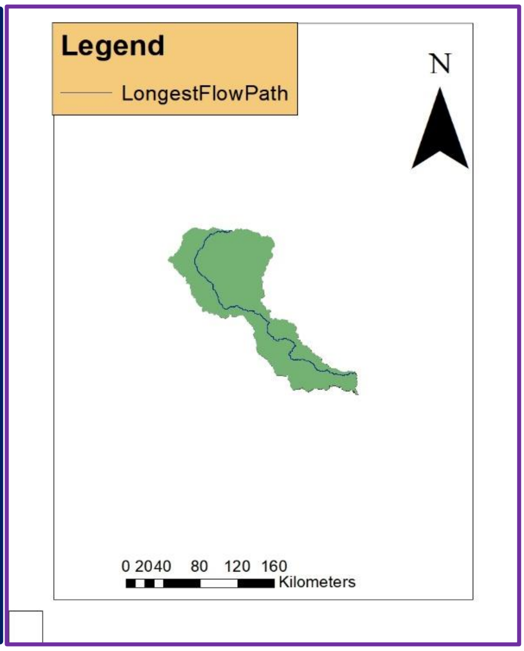




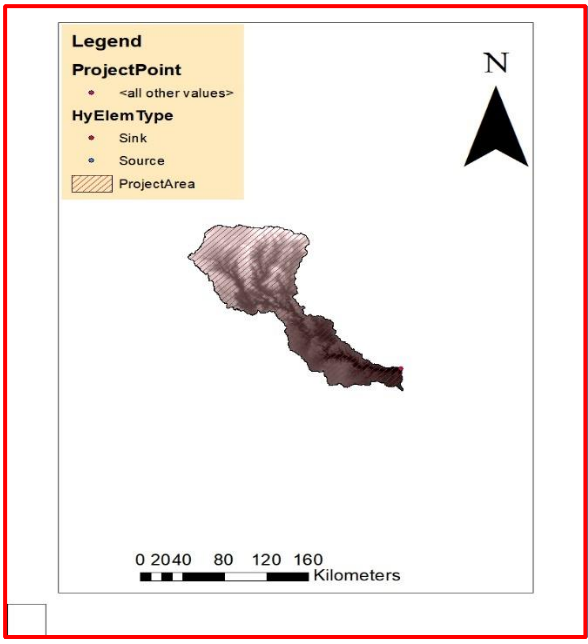
c. flow direction grid   d. Flow accumulation grid



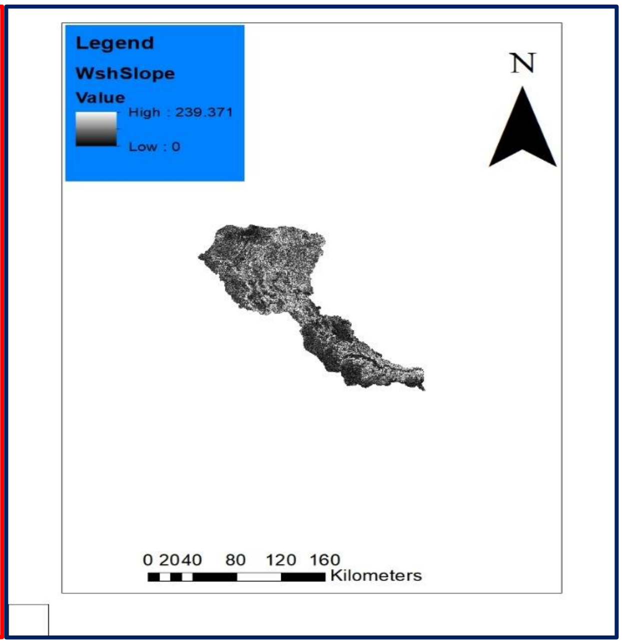
e. Catchment Polygon grid



f. Longest flow path grid



g. Project area



h. Slope grid

Fig 3.20 (a-h) Terrain Preprocessing of Genale River Basin by using Arc-Hydro Tool.

3.5.1.2 Basin Model Development Using HEC-GeoHMS

3.5.1.2.1 Hydrographic Features

One of the main input parameters for Geo-HMS processing is spatial hydrographic features. The Geo-HMS tool is designed to have the output files from the Arc-Hydro terrain preprocessing tools as inputs. These hydrographic features which are already executed using Arc-Hydro tool are flow direction grid (Fdr), flow accumulation grid (Fac), stream grid (Str), stream link grid (Lnk), catchment grid (Cat), curve number grid, slope grid.

3.5.1.2.2 Geo-HMS Data Processing

The point of extensive data preprocessing using Arc-Hydro was to create input files for the Geo-HMS tool. Geo-HMS uses the output files from Arc-Hydro and automatically create sub-basins, longest and centroidal flow paths, basin centroid and other watershed properties with in addition to parameters such as slope, length and average curve number are assigned to flow lines and basins. In general, Geo-HMS uses spatial analyst tools to convert geographic information into parameters for each of the basins and flow lines. These parameters are used to create HEC-HMS Model that can be used within the HEC-HMS program. Fig.3.21 below shows schematic representation of Genale River basin HMS which extracted after executed in HEC-GeoHMS.

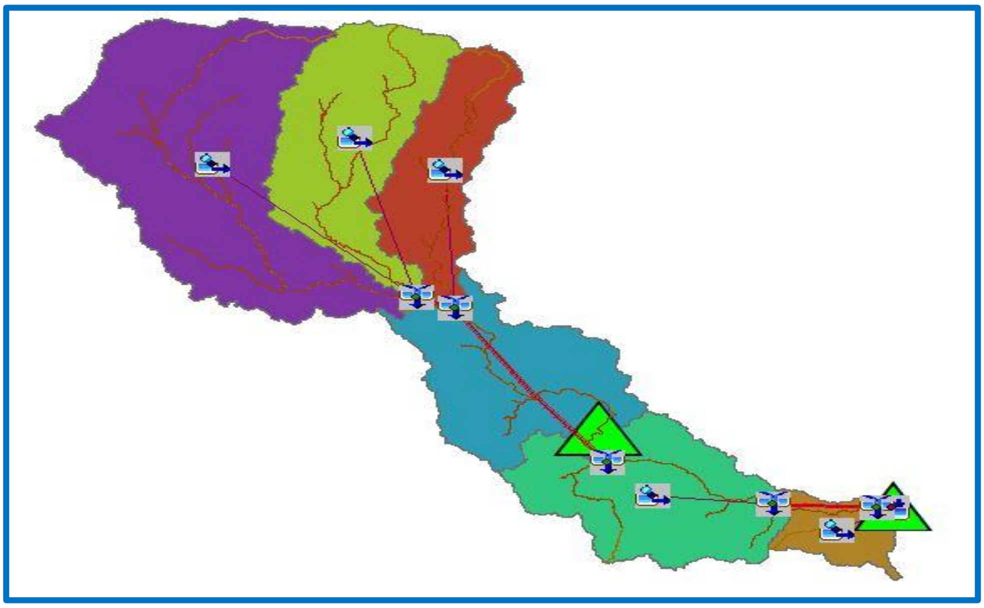


Fig.3.21 HMS representation for Upper Genale River Basin.

3.5.1.3 HEC-HMS Model Development

After converting data from a geographic to a hydrologic data structure in the HEC-GeoHMS the next step was configuration of the HMS model. HEC-HMS is a graphical user interface model that requires the construction of three-model components and data manager that are required for a run:

- Basin Model,
- Meteorological Model, and
- Control Specification Model.

The HEC-HMS Model component developed for Genale River basin by using an integration of Arc-GIS, Arc-Hydro Tool and HEC-GeoHMS is indicated as in the fig.3.22 below.

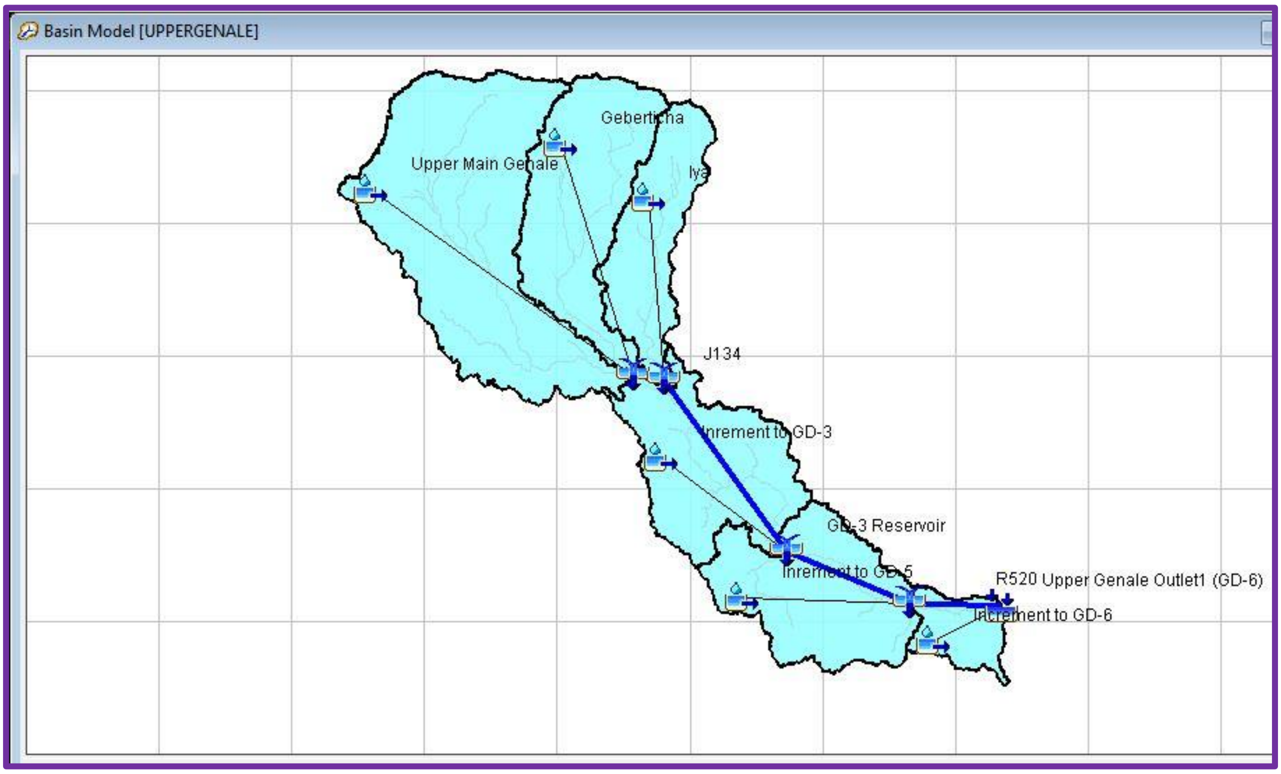


Fig.3.22 HEC-HMS Model component developed for Upper Genale River Basin.

The basin model: The basin model represents the spatial configuration of the watershed. This is where the stream network is defined. It contains information relevant to the physical attributes of the model such as basin areas, river reach connectivity. Sub basins are the only elements that receive precipitation and other meteorological inputs. They are broken into segments for infiltration (loss rate), surface runoff (transform), and subsurface return flow (base flow). Reaches represent the movement of water in an open channel. Reservoirs can be used for either natural lakes or man-made dams; anything that impounds water. Junctions are a convenient way to show where multiple streams come together. Diversions are used lateral weirs, pumps stations, or other places were water is removed from the stream; diverted water can be connected back into the stream network at a downstream location. Sources are usually used as upstream boundary conditions when it is inconvenient to include the entire watershed in the basin model. Sinks are just a formal way of terminating a stream network; they are helpful when a basin model needs to contain more than one outlet perhaps because of multiple adjacent watersheds included in the same basin model. In this research, the upper Genale River basin is subdivided into six sub-basins as appropriate for the study.

The meteorological model:

The meteorological model in HEC-HMS is the major component that is responsible for the definition of the meteorological boundary conditions for the sub-basins. It includes precipitation, evapotranspiration and snowmelt methods to be used in simulations. Among methods in the HMS model to distribute observed rainfall over the basin such as user hyetograph, user gauge weighting, inverse distance gauge weighting and gridded precipitation the user specified precipitation was used in the model simulations. It handles all of the atmospheric conditions over the watershed. Precipitation is always required if there is a sub basin, but the other meteorological model elements are optional. Potential evapotranspiration is the upper limit on plant water use based only on atmospheric conditions. Elements within the basin model will use the potential evapotranspiration and then compute actual evapotranspiration based on available water in the soil and possibly other factors. When used, the snowmelt module takes the computed precipitation and determines if it fell in a liquid (rain) or frozen (snow) state. It then tracks the accumulation and melt of the snowpack.

Control specifications: The control specification model specifies the beginning date and time of a simulation, the ending date and time, and the time interval for calculations. Most model elements compute at the time interval specified in the control specifications. However, some elements use adaptive time stepping and may run as short as 1 second intervals. These special elements only record results at the specified time interval.

3.5.1.4 Model Parameters Calibration and Validation

Model Calibration is the process of matching simulated outputs with observed outlet hydrographs by adjusting model parameters to obtain good estimates for the actual parameters of the watershed. Watershed models have large numbers of parameters, which are not directly measurable. Each method in HEC-HMS has parameters and the initial values of these parameters need to entered as input to the model to obtain the simulated runoff hydrographs. Some of the parameters were estimated by observation and measurements of stream and basin characteristics, but some of them cannot be estimated. When the required parameters cannot be estimated accurately, the model parameters are calibrated, i.e. in the presence of rainfall and runoff data the optimum parameters are found because of a systematic search process that yield the best fit between the observed runoff and the computed runoff. This systematic search process is called optimization. Optimization begins from initial parameter estimates and adjusts them so that the simulated results match the observed stream flow as closely as possible. Validation is comparison of the model outputs with an independent data set without making further adjustments. The process continues till the model errors between observed and simulated become minimized (USACE, August, 2016).

3.5.1.5 HEC-HMS Model Performance Measures

The performance of a model must be evaluated on the extent of its accuracy, consistency and adaptability. Assessing performance of a hydrologic model requires subjective and/or objective estimates of the closeness of the simulated behavior of the model to observations. On the extent to which the achieved level of accuracy persists through different samples of data (consistency) and on the extent to which it can sustain the achieved level of accuracy when subjected to diverse applications and tests other than those used for calibrating the model i.e. Versatility. Hence, for evaluation of the performance of the model, other efficiency criteria such as Nash Sutcliffe efficiency (NSE), Coefficient of determination (R^2), and percent difference (D) were used.

a. Nash-Sutcliffe efficiency, NSE

The efficiency, NSE proposed by Nash and Sutcliffe (1970) is defined as one minus the sum of the absolute squared differences between the predicted and observed values normalized by the variance of the observed values during the period under investigation. Moriasi et al (2007) recommended for monthly time steps that NSE values between 0.75 and 1 is very good and NSE-value between 0.65 and 0.75 is good.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Oi - Si)^2}{\sum_{i=1}^{n}(Oi - \bar{O})^2} \text{ ....equation 3.6}$$

Where, Oi is observed flow at ith period, Si is simulated flow at the ith period and $\bar{O}$ is mean of the observed flow.

b. Coefficient of determination, R^2

The coefficient of determination $\mathbf{R^2}$ is defined as the squared value of the coefficient of correlation. It can also be expressed as the squared ratio between the covariance and the multiplied standard deviations of the observed and predicted values. It is calculated as:

$$R^2 = \frac{[\sum_{i=1}^{n}(Qs - \overline{Qs})(Qo - \overline{Qo})]^2}{[\sum_{i=1}^{n}(Qs - \overline{Qs})]^2[\sum_{i=1}^{n}(Qo - \overline{Qo})]^2} \text{ .... equation 3.7}$$

Moriasi et al (2007) recommended for monthly time steps that R^2 values between 0.75 and 1 is very good and R^2 value between 0.65 and 0.75 is good.

c. The percent difference for a quantity, D

The percent difference over a specified period with total days calculated from measured and simulated values of the quantity in each model time step. A percent difference between +5% and -5% indicates that a model performs well while in between +5% and +10% and -5% and -10% indicates a model with reasonable performance.

$$D = \left[\frac{\sum_{i=1}^{n}Qo - \sum_{i=1}^{n}Qs}{\sum_{i=1}^{n}Qo}\right] \times 100\% \text{ ....equation 3.8}$$

3.5.2 HEC-ResSim Model Set up

The U.S. Army Corps of engineers' Hydrologic Engineering Centers' Reservoir System Simulation (HEC-ResSim) is a computer program comprised of a graphical user interface (GUI) and a computational program designed by the Hydrologic Engineering Center of the U.S. Army Corp's of Engineers to simulate reservoir system operations. Included are data storage and management capabilities, and graphics and reporting facilities. HEC's Data Storage System (HEC-DSS) is used for storage and retrieval of input and output time series data. It is capable of modeling any reservoir system and designed to perform reservoir operation modeling at single or multi reservoir system. HEC-DSSVue is a tool that allows to access data stored in HEC-DSS database files. DSS files refer to time-series data by Pathnames representing records. When HEC-DSSVue is selected from the Tools menu within the network module for storing time series data and within the simulation module, the simulation .dss file is opened (USACE, 2007). The main input data used for HEC-ResSim are:

- Reservoir physical characteristic curves (Elevation-Area-storage curve),
- Evaporation,
- observed/simulated flow,
- Key characteristic of reservoir, dam, spillway, Power plant, and
- different watershed characteristics obtained from GIS.

The main modules that used for HEC-ResSim model setup are Watershed Setup, Reservoir Network, and simulation. Each module has a unique purpose and an associated set of functions accessible through menus, toolbars, and schematic elements. Each module also provides access to specific types of data or results.

a. Watershed set up module

The purpose of the watershed setup module is to provide a common framework for watershed creation and definition among different modeling application. A watershed may include all of the streams, projects (e.g., reservoirs, levees, diversions etc.), gage locations, impact areas, time-series locations, and hydrologic and hydraulic data for a specific area. All of these details together, once configured, form a watershed framework.

The watershed setup module for upper Genale-Dawa is shown as below in the fig. 3.23

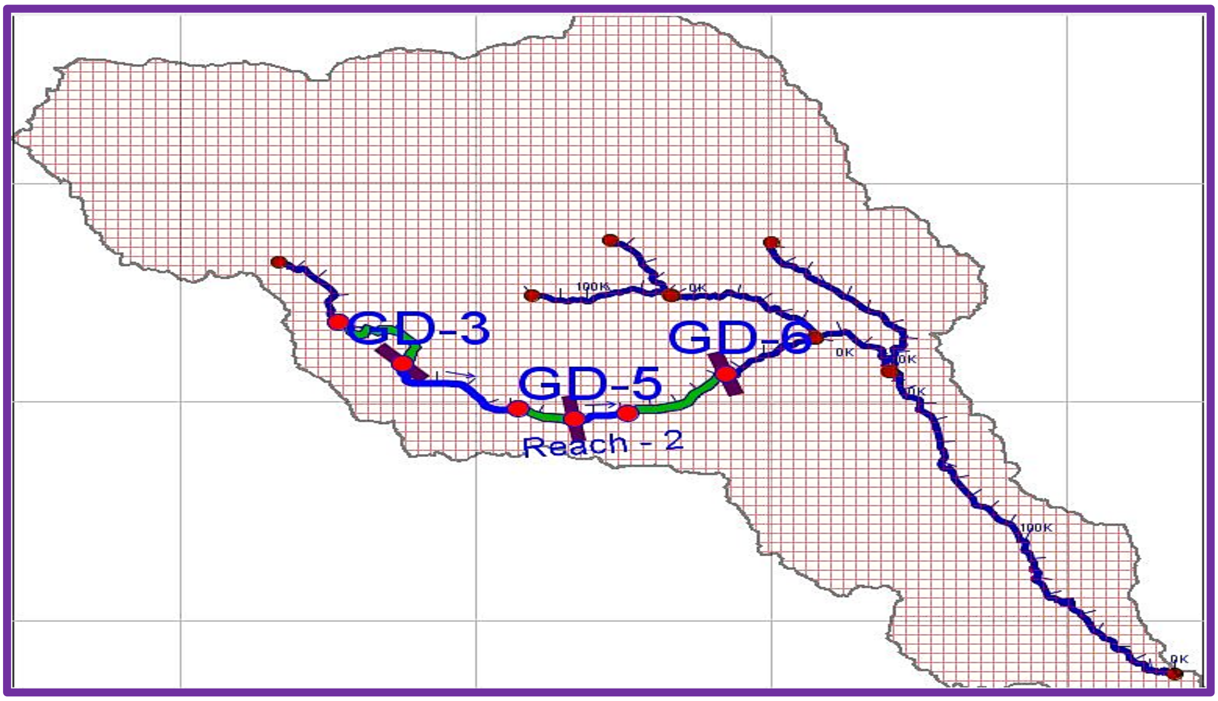


Fig.3.23 Watershed Setup Module for Upper Genale-Dawa River Basin.

b. Reservoir network module

The purpose of the reservoir network module is to isolate the development of reservoir model from the output analysis. In the reservoir network module, river schematization, description of the physical and operational elements of reservoirs model can be build, and the alternatives that are required to be analyzed can be developed. Using configurations that were created in the watershed setup module as a template, based on a reservoir network module, add routing reaches and possibly other network elements to complete the connectivity of reservoirs network schematic. Once the schematic is complete, physical and operational data for each network element are defined. Upper Genale-Dawa River basin reservoir network module is shown as in the following fig.3.24.

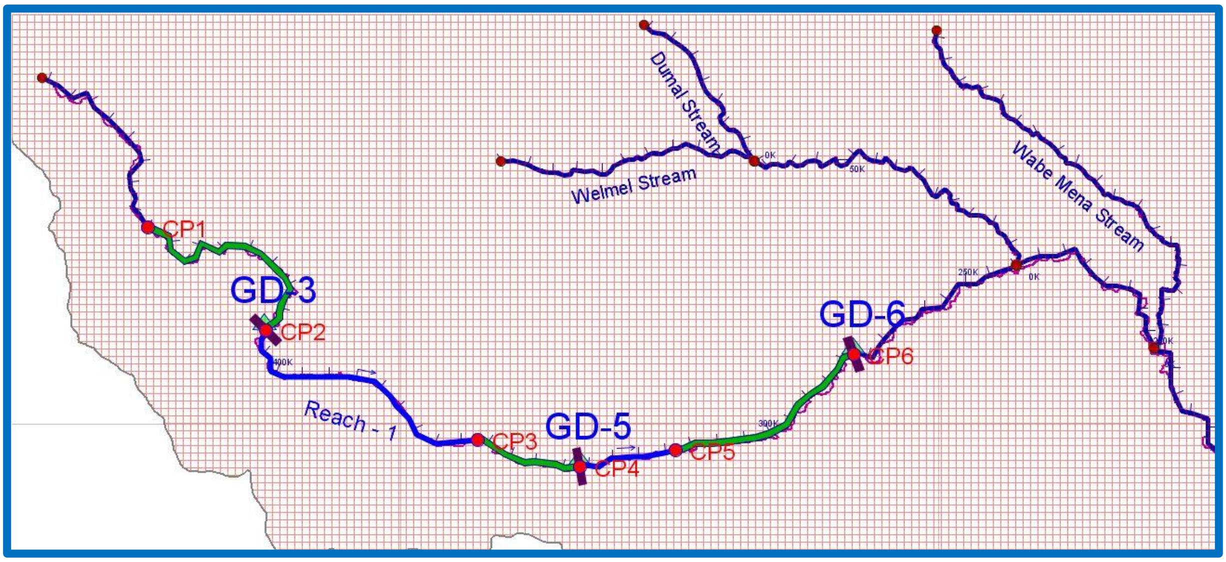


Fig.3.24 Reservoir Network for Upper Genale-Dawa River Basin.

Junction: simplest element type of reservoir network is the junction. Junctions represent stream confluences or points where external flows enter the system. This particular study consists of six junctions i.e. each reservoir elements has one inflow junction which paired with one outflow junction. Since, HEC-ResSim does not calculate runoff, all local inflows, which is generated by HEC-HMS model at each river confluences, must be introduced at junctions as external flows. The flow out of a junction is simply the sum of the flows into the junction.

Routing reaches: represent the natural streams in the system, and the lag and attenuation of flow in a reach is computed by one of a variety of available standard hydrologic routing methods, such as Muskingum, Modified Puls, Coefficient, or Muskingum-Cunge. In this thesis, Muskingum routing is used and the parameter values of Muskingum (K), (x), and the number of sub-rooting reach for river reach is estimated. This method involves the assignment of just three parameters for each channel reach, comprising: wedge-storage coefficient (X), and flood wave travel time (K). In this modelling procedure the X parameter (valid range between 0 and 0.5) was computed by HEC-HMS model value of: 0.109 and 0.327 for Reach-1 and Reach-2 respectively. The K parameter was calculated from the respective reach length and average velocity of the flood wave along the reach. In each case average velocity was assumed to be 2 m/s, resulting in K values of: 7.78 and 4.74 hours for Reach-1 and Reach-2 respectively.

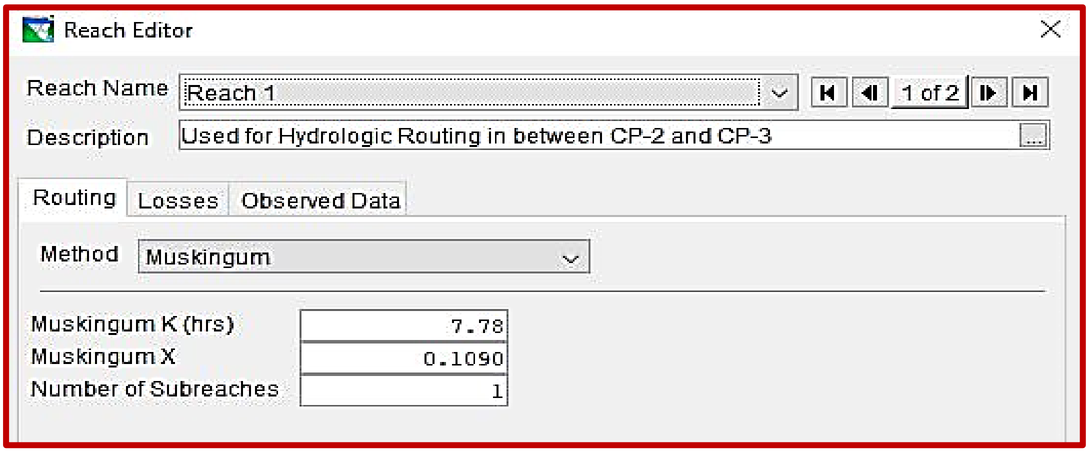


Fig.3.25 Reach Parameter for Reservoir System.

Diversion: is a more complex element. It represents a "withdrawal" of water from the natural stream. The quantity of the withdrawal can be specified as a constant amount or as a function of some parameter such as time or flow. Some or all of the diverted water can be routed and returned by a diversion or it can be removed from the system entirely.

Reservoir: is the most complex element of the reservoir network and is composed of a pool and a dam. HEC-ResSim assumes that the pool is level (i.e., it has no routing behavior) and its hydraulic behavior is completely defined by an elevation-storage-area curve.

Dam: is the root of an outlet hierarchy or "tree" which allows the user to describe the different outlets of the reservoir in as much detail as deemed necessary. There are two basic and two advanced outlet types. The basic outlet types are controlled and uncontrolled.

Uncontrolled outlet: can be used to represent an outlet of the reservoir, such as an overflow spillway, that has no control structure to regulate flow.

Controlled outlet: can be used to represent any outlet, such as a gate or valve, capable of regulating flow. The advanced outlet types are power plant and pump, both of which are controlled outlets with additional features to represent their special purposes. The power plant adds the ability to compute energy production to the standard controlled outlet.

c. Simulation module

The purpose of the simulation module is to isolate output analysis from the model development process. Once the reservoir model is complete and the alternatives have been defined, the simulation module is used to configure the simulation. The computations are performed and results are viewed within the simulation module. While simulation is created, a simulation time window, computation time intervals and the alternatives to be analyzed must be specified. Then, ResSim creates a directory structure within the rss folder of the watershed that represents the simulation. Within this module, edition of element data and view results is possible. Once a simulation is defined, a compute is performed and results are analyzed using graphical and tabular output (USACE, 2007).

3.5.2.1 Reservoir Operation Using HEC-ResSim

3.5.2.1.1 Reservoir Physical Characteristics and Power Plant Data

Physical and operational reservoir data including reservoir pool definition (elevation storage-area tables), outlet capacity curves, and hydropower plant data (turbine capacity and generation requirement, tail water level and installed capacities, efficiency, losses, etc.), operational zones, minimum and maximum release requirements, etc. for each project were taken from their respective feasibility and detail design document. The followings are the most worth mentioned operation characteristics parameters input data to HEC-ResSim model. Detail of physical and operational parameters of hydropower plant data are presented in the appendix F.

a. Parameters of the hydro-technical equipment

These parameters, which need to define the various hydro technical equipment's are the flood spillway, the plant intake, and the bottom duct.

i. The flood spillway

Elevation versus releasing capacity of spillway has setup for each dam. Spillways are structures constructed to provide safe release of floods pass a dam to a downstream river stretches. Every reservoir has a certain capacity to store water. If the reservoir is full and high flows enter the same, the reservoir level increases and may eventually result in over-topping of the dam. To avoid this situation, the flood has to be passed to the downstream side and this is done either through the spillway or turbine intakes. A spillway can be a part of a concrete or connected to an embankment dam.

ii. The bottom Outlet

Permanent ecological outlet or the bottom duct properties needs to be defined. For example, Howell Bunger Outlet Valve has been installed for GD-3 which comprises a steel cone installed in a cylindrical sleeve and held in place by radial upstream ribs. The nominal diameter of each valve will be 1.40m. With this arrangement, the total discharge capacity of two valves for reservoirs level down to minimum operating level will be as follows in the table 3.4 below.

Table 3.4 Bottom outlet duct discharge capacity

Reservoir level (masl)	Discharge Capacity (m^3/sec.)
1090	84
1088	82
1086	81
1084	80
1082	78
1080	77

Sources (GDMP Volume II. August, 2007)

From the above it is evident that even at minimum operating level, a significant discharge could be released downstream in the event that the GD-3 power scheme is out of operation.

iii. The Plant intake

The plant intake setting is concerned with the relation between the elevation of the water in the pool and the flow intensity in the pipe reaches the turbines. The design intake discharge for GD-3, GD-5 and GD-6 are 116 m^3/Sec., 120 m^3/Sec. and 120 m^3/Sec. respectively.

iv. Reservoirs (Pool) Parameters

The elevation storage area curve is the main characteristics of the reservoir pool defining the surface area and the volume of storage at the respective elevation. The input of elevation storage area from a spread sheet for the GD-3 Reservoir in ResSim is shown in fig. 3.26 below.

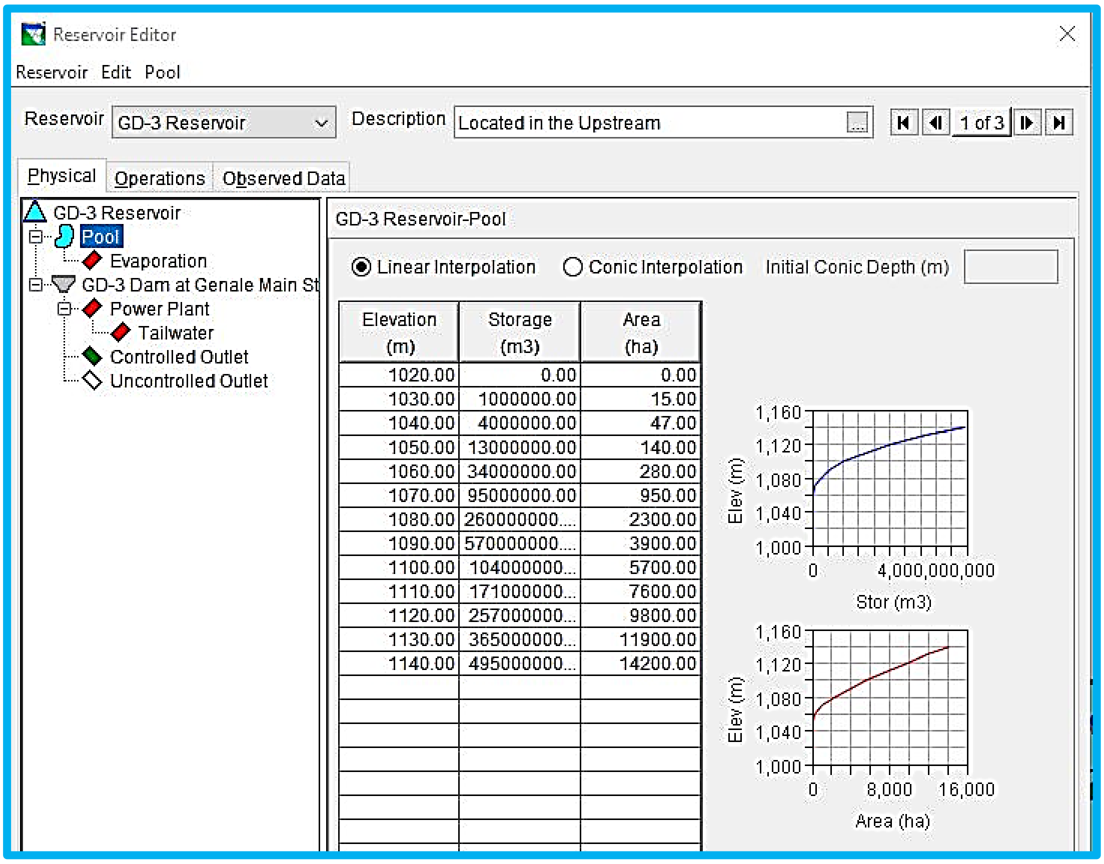


Fig.3.26 GD-3 Storage-Elevation-Area Curves.

v. The Power Plant Parameters

In HEC-ResSim, the power plant module is used in order to define the electric power generated by the turbines. For example, the total installed capacity of the GD-3 plant is 254 MW, station Use 0, total head loss 12.5 m, overall efficiency 91.2% and the average tail water elevation is 839m.a.s.l.

3.5.2.1.2 Operational Parameters

In a manner similar to the methods an operator may use, each reservoir in ResSim network must determine the quantity of water to release at each time step of a simulation run. For this to happen, scheme upon release decisions can be made or an operation plan should be described. This plan is called an Operation Set. (HEC, 2013). An operation set consists of three basic features: Zones, Rules and the identification of the Guide curve.

i. Zone

Zones are operational subdivisions of the reservoir pool. Each zone is defined by a curve describing the top of the zone. When an operation set is created, ResSim establishes a default set of zones within the operation set. These zones are Flood Control, Conservation and the Inactive. However additional zone could be added if necessary.

ii. Rule

HEC-ResSim uses an original rule-based approach to mimic the operational decision-making process that reservoir operators follow in setting release schedules. Just as operators must, the HEC-ResSim release decision-making process for a reservoir takes into account time of year, hydrologic conditions, water temperature, and simultaneous operations by other reservoirs in a system. The release decision process in ResSim has three basic steps. The first step is to identify the maximum and minimum physical limits on the release, which is the allowable release range. The maximum of the range is the total maximum capacity of the outlets for the current pool elevation, the minimum of the range is the minimum release capacity of the outlets, usually zero. The second step is to narrow the allowable release range by applying the rules in the current zone starting with the highest priority rule. If two rules contradict each other, the higher priority rule applies. The final step is to evaluate the desired release for the basic guide curve operation. This is the release needed to get the reservoir to the guide curve in the current time step (computation interval) based on the starting pool elevation, the prior release and the current inflow. If the desired release falls within the allowable release range, then the release decision will be the desired released determined by the last step. However, if the desired release is outside the allowable release determined in the first two steps above, the release will be set to the limit closest to the desired value range (**Joan D. Klipsch, Thomas A. Evans, PhD.**, 2007). The Tandem operation and Release function are the rules used for the reservoir pools of this research. Tandem rules are considered for the upstream reservoirs GD-3, and GD-5 while the release function is used for the downstream reservoir GD-6. The release function rule type is one of the most powerful rule types available. This rule allows specifying the maximum, minimum, or specified flow to be released through the release element.

iii. Guide Curve

A reservoir in HEC-ResSim must have a target elevation. A reservoir's target elevation, represented as a function of time, is called its *Guide Curve*. It is the dividing line between the upper zones of the reservoir (typically called the flood-control pool) and the lower zones (typically called the conservation pool). The release decision logic in HEC-ResSim starts and ends with the guide curve. When the reservoir's pool elevation is above the guide curve ("in flood control"), the reservoir wants to release more water than is entering the pool; when below guides curve ("in conservation"), the reservoir wants to release less water than is entering the pool. All operating rules and physical limitations act as constraints upon the reservoir's ability to meet the goal of returning the pool to its guide curve elevation. Without rules, the reservoir will be constrained only by physical capacity of the outlets to get to and stay at the guide curve elevation. Each reservoir operating goal is described by a flexibly-defined rule that, when evaluated, specifies a minimum or maximum limit on the release from the reservoir or outlet. The rules are placed in a prioritized list in one or more reservoir zones. As each rule is evaluated, its calculated minimum and/or maximum flow is applied to an evolving "allowable range of release". At the start of the release decision process, HEC-ResSim sets the allowable release range to the physical limits of the dam or outlet: the maximum of the range is the total maximum capacity of the outlets for the current pool elevation, the minimum of the range is the minimum release capacity of the outlets, usually zero. As a rule, is applied, it may narrow the allowable release range. If a rule does not either raise the minimum allowable release or lower the maximum, then that rule will have no effect on the range. Once all rules have been evaluated and applied to the range, the allowable range is considered complete and the "desired guide curve release" is computed (**Joan D. Klipsch, Thomas A. Evans, PhD.**, 2007).

3.5.2.1.3 Genale Reservoir System Storage Balance

It is not unusual for more, that one reservoir in a basin to be assigned the objective of controlling flow at a downstream location. In this particular study, both GD-3 and GD-5 reservoirs located in the upstream river basin contribute flow to and operate for the GD-6. In HEC-ResSim, multi-reservoir system constraints are orchestrated using a storage balancing approach. The system storage balance specifies the weighting or allocation of the total release from all the reservoirs to each reservoir in the system. By default, HEC-ResSim will try to maintain an even percent-of-storage balance between the reservoirs that are operating as a system. This default balance is referred to as the *implicit* storage balance. If the implicit balance is not appropriate, the user can enter an *explicit* description of the storage balance between the reservoirs. Several factors including relative size of the reservoirs and the proximity to the control point make it inappropriate for the reservoirs in this system to balance evenly to meet the constraints at GD-6. For this reason, an explicit storage balance was specified. The purpose of the explicit system storage balance illustrated in Figure 3.27 is to force the larger and more distant reservoir, GD-3, to fill first, allowing the smaller and nearer reservoir, GD-5, to stay empty as long as possible when operating for flood control. Explicit system storage balance is the user defined system storage balance. The user can modify the implicit balance lines explicitly to characterize the desired storage distributions using one or more system zones and placing inflection points along the balance line. In addition to the three default zones created by Hec-ResSim, the user can add appropriate zone if necessary.

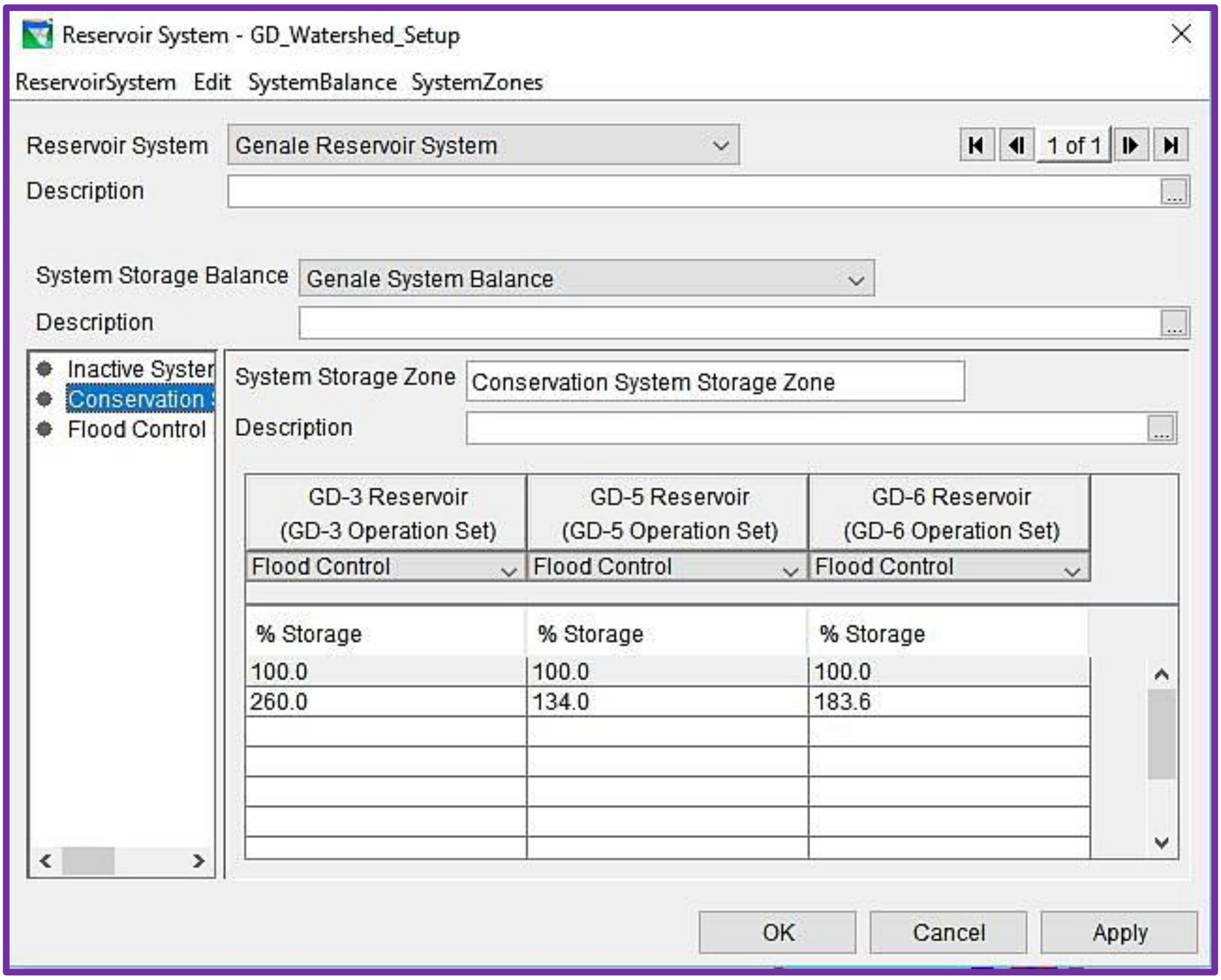


Fig.3.27 Genale-Dawa Explicit Reservoirs System Storage Balance.

3.5.2.1.4 Ecological Flow

Water storage reservoirs typically provide multiple benefits such as hydropower generation, water supply (municipal, industrial and agricultural), flood control and recreational opportunities. On the other hand, well-known detrimental effects include impoundment of free-flowing river habitat, blockage of fish migration and reduced water quality in reservoirs and downstream river reaches. Less-obvious effects include the interruption of geomorphologic processes that maintain aquatic habitat diversity required to sustain healthy river ecosystems. In this study, Release rule function is applied for the downstream reservoir (GD-6). The release rule is also used to fulfill the monthly average water requirement for the proposed irrigation project at the downstream of GD-6 hydropower plant, which is taken as a minimum release from GD-6. The monthly average water requirement of the downstream irrigation project which was designed in the feasibility study report of GD-6 Hydropower project is shown as follows in the Table 3.5.

Table 3.5 Minimum Ecological Release from Proposed dams (m^3/Sec.)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Release(m^3/Sec.)	13.2	7.2	1.6	21.2	22.2	13.8	9.8	15.0	24.7	28.6	26	20.4

Source (MoWIE, August, 2007)

3.5.2.1.5 Reservoir Operation Scenarios (Alternatives)

A reservoir network represents a collection of watershed elements connected by routing reaches. Elements created in watershed setup module belong to specific watershed configurations. The computation points defined for a configuration in the watershed setup module automatically become junction in the reservoir network module. The reservoir network provides tools to develop the alternatives to be analyzed and the connectivity of reservoir network as well as enter and edit physical and operations data. A number of inflection points have been used from each zone of each reservoir to search for the best alternative inflection coordinate that generates a maximum power. A number of combinations of inflection points are used for different scenarios of the trial and error iteration of the simulations. The iteration aims at getting the optimal coordinate of inflection that result the maximum power output of the multi-reservoir system. The GD-3, GD-5, and GD-6 project is cascade scheme dams in series with an average of **3,930 GWh** per year could be generated with a total installed capacity of **606 MW**.

4. RESULT AND DISCUSSION

4.1 Flow Simulation

The main objective of this particular thesis, is to develop the water resources in the upstream of the basin which helps us to estimate the water balance components of the reservoir systems and maximizing hydropower generation by simulating the established cascade hydropower projects. More importantly, the development of HEC-HMS and HEC-ResSim model were adopted to attain the objective of this thesis which incorporates meeting direct and downstream demands, providing a reliable source of power generation, achieving target elevations, making target releases, and meeting environmental impacts on the downstream ecology on basin level with hydrological fluctuation pattern. Hence, the model can support the decision-making process which will enables the government and policy makers to formulate and implement water resource management options and appropriate response strategies. This management action will be used to minimizes the possible conflict arises in trans-boundary rivers like Genale-Dawa and helps to maximize the "benefit sharing" between the countries without significant effect on the water resource of the basin.

HEC-HMS modeling of the upper genale main river was done by dividing the total basin into seven sub basins with the outlet of upper Genale at GD-6 and the whole basin at downstream of Dawa and Weyib confluence. The HEC-HMS model was calibrated and validated on a monthly basis with reference to Chena-Mansa gauging station to estimate the flow from Genale-Dawa river basin using a time series dataset of 16 years from 1990-2005. The calibration of the model was considered successful even though there is an absence of historical data availability due to depletion of gauging station at some key location in the river basin posed a significant limitation.

4.2 HEC-HMS Simulation Result

The rainfall-runoff modeling for upper Genale-Dawa river basin was conducted by three transformation mathematical modeling method by dividing the total basin into seven sub-basins in provision of outlet at GD-6 for upper part. These methods are, initial and constant rate loss for modeling the run-off volume, Clark's unit hydrograph modeling for direct run-off, and constant monthly base flow modeling for base flow models.

4.2.1 Flow Calibration at Chena-Mansa Station

The HEC-HMS program was selected for the current study due to its versatility, capability for flow generation, automatic parameter optimization and its connection with GIS through HEC-GeoHMS. The systematic search for optimum parameter is carried out using automatic HEC-HMS Model parameter optimization from model compute tool bar with reference to observed flow at Chena-Mansa station.

Model parameters were calibrated manually followed by HEC-HMS automatic optimization until satisfactory agreement between simulated and observed flow was obtained. The model goodness of fit and the model performance were evaluated after adjusting the parameters. Flow calibration was made by using twelve years (1990-2001) hydro-meteorological data with an equal length of time (12 years). During these periods, the simulated monthly flow matched well with the observed monthly flow. The first performance evaluation Nash and Sutcliffe Model Efficiency (NSE) [Nash and Sutcliffe, 1970] for monthly stream flow calibration is 0.8926. The second performance evaluation result that is Pearson's Coefficient of Determination (R^2) gives 0.903 for monthly calibration. The third performance evaluation result, volumetric fit (D), gives -0.002% for monthly calibration. Hence, HEC-HMS has the ability to predict the water potential of the basin. However, the model slightly overestimates the peak flow in most of the simulation periods. The results are summarized in the tabular and graphical form as follows.

Table 4.1 Upper Genale-Dawa Project Objective function Results.

Objective Function Results for Trial "Optimization Trial 1"

Project:UPPERGENALE Optimization Trial:Optimization Trial 1

Start of Trial: 01Jan1990, 00:00 Basin Model: UPPERGENALE
End of Trial: 01Jan2006, 00:00 Meteorologic Model:UPPERGENALE
Compute Time:05Jul2019, 17:14:27

Objective Function at Basin Element "Upper Genale Outlet1 (GD-6)"
Start of Function:01Jan1990, 00:00 Type: Peak-Weighted RMS Error
End of Function: 01Jan2006, 00:00 Value:428.50

Volume Units: MM 1000 M3

Measure	Simulated	Observed	Difference	Percent Difference
Volume (MM)	9707.90	3692.11	6015.80	162.94
Peak Flow (M3/S)	681.3	910.0	-228.7	-25.1
Time of Peak	14May1993, 00:00	04Dec1997, 00:00		
Time of Center of Mass	02Jan1998, 06:17	14Nov1997, 17:46		

Table 4.2 Upper Genale-Dawa Project Optimized Parameter Results.

Optimized Parameter Results for Trial "Optimization Trial 1"

Project:UPPERGENALE Optimization Trial:Optimization Trial 1

Start of Trial: 01Jan1990, 00:00 Basin Model: UPPERGENALE
End of Trial: 01Jan2006, 00:00 Meteorologic Model:UPPERGENALE
Compute Time:05Jul2019, 17:14:27

Element	Parameter	Units	Initial Value	Optimized Value	Objective Function Sensitivity
Gebertícha	Clark Unit Hydrograph - Storage Coefficient	HR	17.4	17.376	0.00
Gebertícha	Clark Unit Hydrograph - Time of Concentration	HR	18.8	18.868	0.00
Gebertícha	Initial and Constant - Constant Rate	MM/HR	0.352	0.73981	0.00
Gebertícha	Initial and Constant - Initial Loss	MM	0.2	0.34257	0.00
Iya	Clark Unit Hydrograph - Storage Coefficient	HR	14.2	14.221	0.00
Iya	Clark Unit Hydrograph - Time of Concentration	HR	15.4	15.488	0.00
Iya	Initial and Constant - Constant Rate	MM/HR	0.352	0.76473	0.00
Iya	Initial and Constant - Initial Loss	MM	0.2	0.37472	0.00
Inrement to GD-3	Clark Unit Hydrograph - Storage Coefficient	HR	19.3	19.461	0.00
Inrement to GD-3	Clark Unit Hydrograph - Time of Concentration	HR	19.3	19.712	0.00
Inrement to GD-3	Initial and Constant - Constant Rate	MM/HR	0.2	0.21886	-0.16
Inrement to GD-3	Initial and Constant - Initial Loss	MM	0.2	0.18166	0.00
Inrement to GD-5	Clark Unit Hydrograph - Storage Coefficient	HR	13.454	13.584	0.00
Inrement to GD-5	Clark Unit Hydrograph - Time of Concentration	HR	14.14	14.179	0.00
Inrement to GD-5	Initial and Constant - Constant Rate	MM/HR	0.2	0.21886	-0.14
Inrement to GD-5	Initial and Constant - Initial Loss	MM	0.2	0.18309	0.00
Increment to GD-6	Clark Unit Hydrograph - Storage Coefficient	HR	5.618	5.7248	0.00
Increment to GD-6	Clark Unit Hydrograph - Time of Concentration	HR	7.213	7.3402	0.00
Increment to GD-6	Initial and Constant - Constant Rate	MM/HR	0.2	0.20824	-0.04
Increment to GD-6	Initial and Constant - Initial Loss	MM	0.2	0.17252	0.00
R340	Muskingum - K	HR	1.7	2.2046	0.00
R340	Muskingum - Number of Subreaches		1		
R340	Muskingum - x		0.25	0.35815	0.00

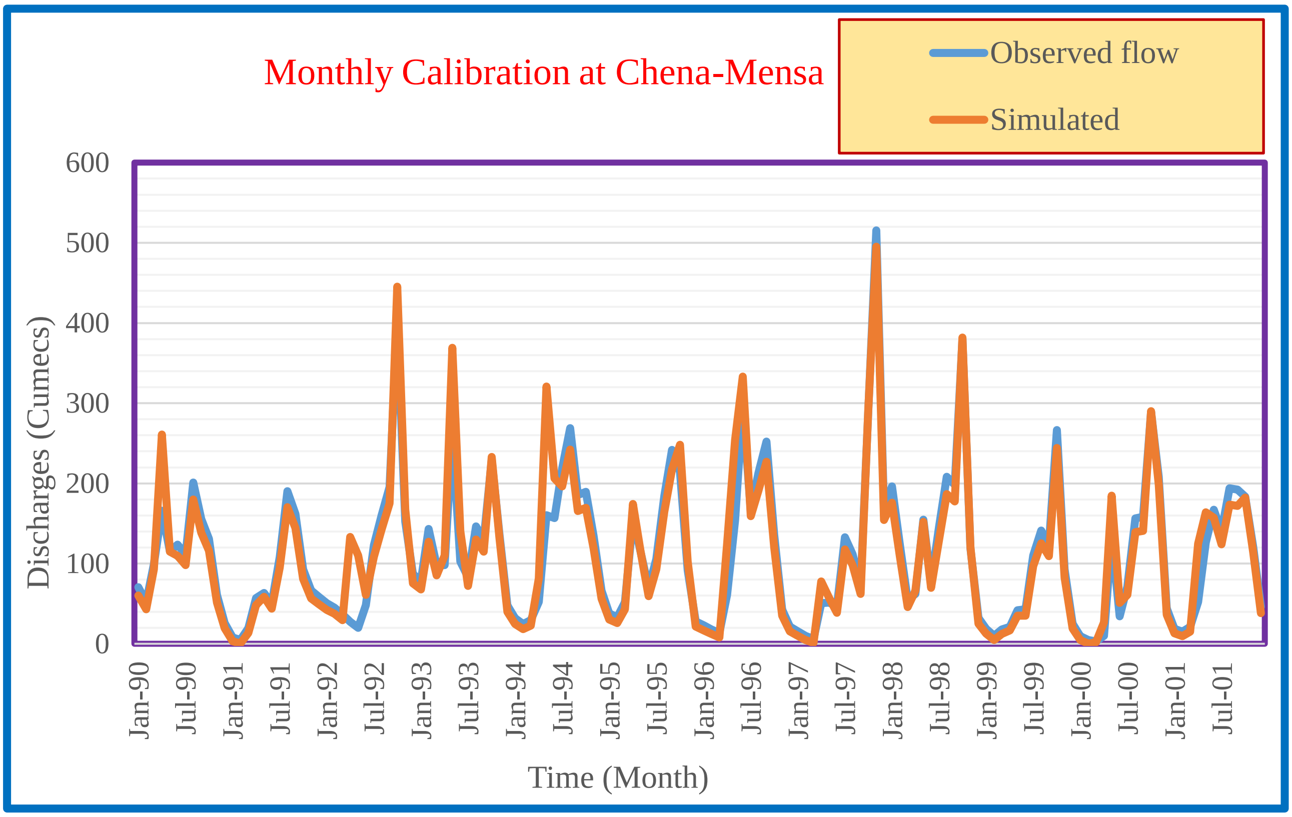


Fig.4.1 Monthly Average Simulated and Observed flow During Calibration Period.

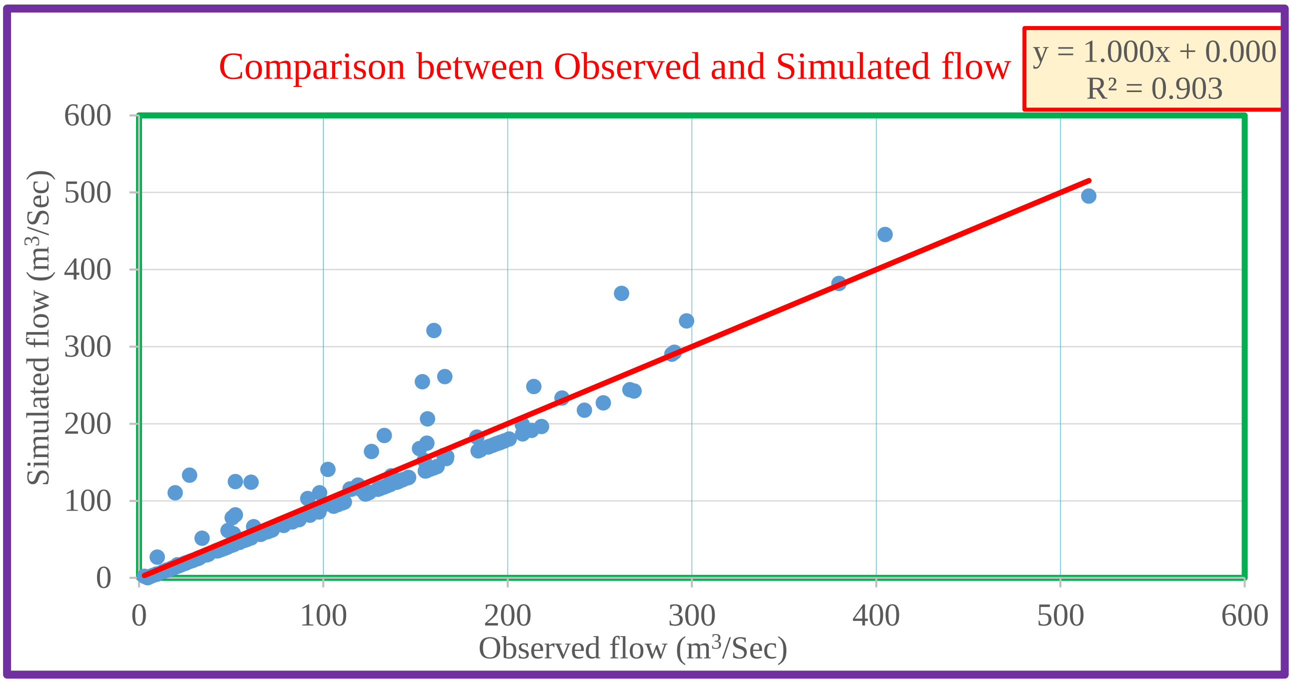


Fig.4.2 Comparison between Observed and Simulated flow by Scatter diagram.

4.2.2 Flow Validation at Chena-Mansa Station

The model with calibrated parameters was validated by using an independent set of measured flow data which was not used during model calibration. The model performance in validation was carried out from 2002-2005. Accordingly, good match between measured and simulated flow was obtained in validation period (R^2 = 0.866 and NSE = 0.8447). The model captures the peak flow and simulated flow follows the pattern of observed flow.

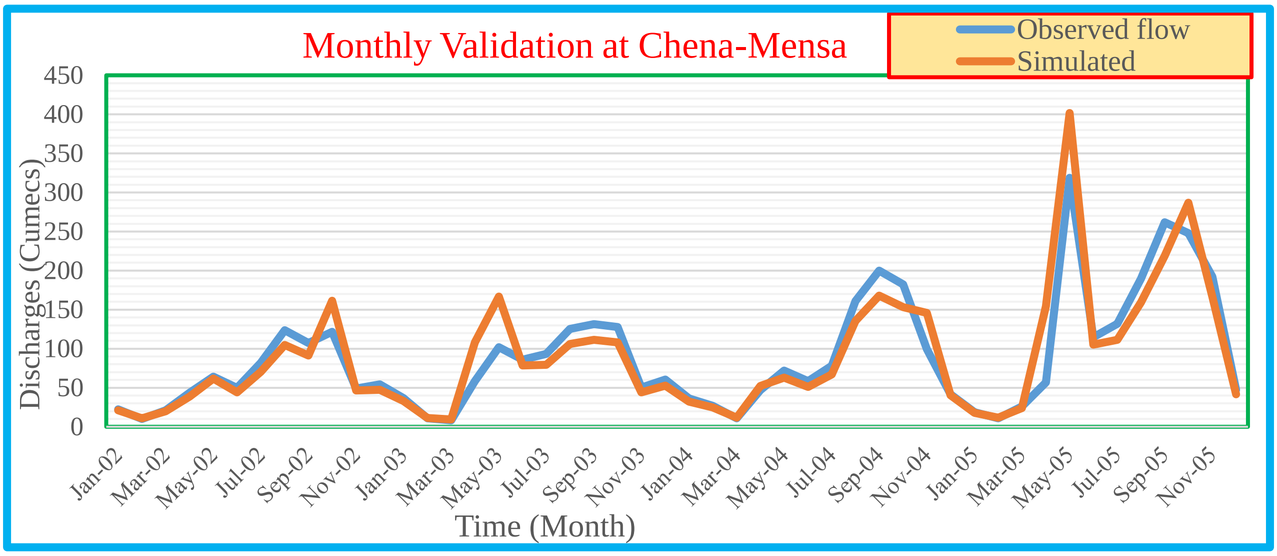


Fig.4.3 Monthly Average Simulated and Observed flow During Validation Period.

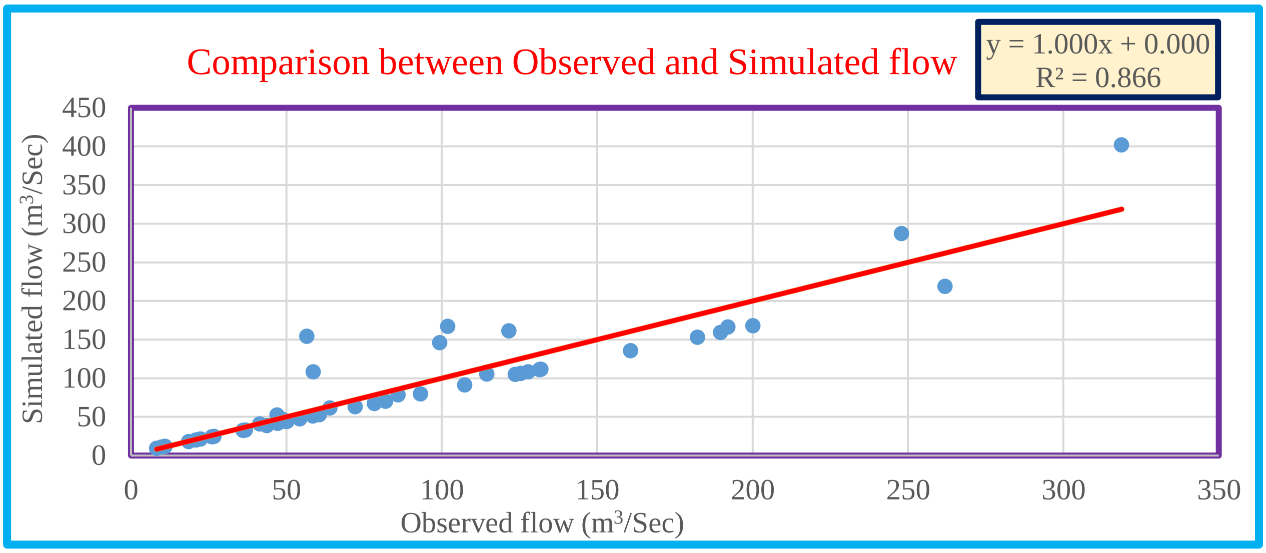


Fig. 4.4 Comparison between Observed and Simulated flow by Scatter diagram.

4.3 HEC-ResSim Simulation Results of Genale Cascade Reservoirs System

After generating reservoir inflows for the rivers, the next step is to simulate Genale-Dawa cascade hydropower reservoirs system using HEC-ResSim model to examine the operation and performance of cascade reservoirs. The daily inflows have been used in simulation of Genale-Dawa cascade hydropower using HEC-ResSim model by applying tandem operation rule for GD-3 and GD-5 while release function rule is used for GD-6. Different simulations trial has been carried out by changing the values of initial reservoir storage, guide curve position and acceptable reservoir release for power generation with the aim to obtain maximized annual energy output with improved uniformity of energy production. All simulations were done within the given limitation of reservoirs capacity, water conveyance system capacity, and maximum design flow for plant, spill over the dam and spillway, power plant capacity and bottom outlet release to downstream ecosystem.

4.3.1 Genale-Dawa Reservoirs System Storage Balance Results.

In this particular study, both GD-3 and GD-5 reservoirs located in the upstream river basin contribute flow to and operate for the GD-6. In HEC-ResSim, multi-reservoir system constraints are orchestrated using a storage balancing approach. By default, HEC-ResSim will try to maintain an even percent of implicit storage balance between the reservoirs that are operating as a system. During implicit storage balance system, several factors including relative size of the reservoirs and the proximity to the control point make it inappropriate for the reservoirs to balance evenly to meet the constraints at GD-6. For this reason, an explicit storage balance was specified. The purpose of the explicit system storage balance is to force the larger and more distant reservoir, GD-3, to fill first, allowing the smaller and nearer reservoir, GD-5, to stay empty as long as possible when operating for flood control. Explicit system storage balance is the user defined system storage balance. The user can modify the implicit balance lines explicitly to characterize the desired storage distributions using one or more system zones and placing inflection points along the balance line. However, in ResSim position of the guide curve assigned as predetermined rule for the simulation has significant effect to get the optimal power/energy that the reservoir system can generate using the time-series flow data and physical characteristics of the reservoirs satisfying the constraints., explicit system storage balance operation depends on placing of inflection points to the balance line within each system zone. It's concluded from this study that placing guide curve at MOL for GD-3 and at top of conservation zone in case of GD-5 and GD-6 along with explicitly defining storage balance by the use of inflection point result in the optimum power production output from this study.

4.3.2 Genale Reservoirs System Operation Scenarios (Alternatives)

Several alternatives have been undertaken in search of optimal power and analyzing the reservoir Operation with observed, and generated flow. Operation of these reservoirs have been driven by an operating rule called Tandem rule for upper reservoirs GD-3 and GD-5 and release function rule for downstream reservoir GD-6. This rule seeks to produce continuous power in each day without having the reservoir drop below minimum operating level (MOL) and seek to minimize spillage in any day. In HEC-ResSim, the dam operation is defined by three typical operation modes, also called zones which are called respectively; Flood control, Conservation and Inactive. These zones of operation are based on specific reservoir elevations and contain a set of rules that describe the goals and constraints that should be followed when the reservoir's pool elevation is within a particular zone. For each mode of operation, the rules are ordered by priority. A number of inflection points have been used from each zone of each reservoir to search for the best alternative inflection coordinate that generates a maximum power. A number of combinations of inflection points are used for different scenarios of the trial and error iteration of the simulations. The iteration aims at getting the optimal coordinate of inflection that result the maximum power output of the multi-reservoir system with minimum spill and maximum power or total energy. Out of the number of alternatives undertaken, three of them are expressed as below.

4.3.2.1 Simulation for Alternative 1:

In this alternative, the reservoirs system operation of GD-3, GD-5, and GD-6 was analyzed explicitly with natural flow and generated flow from ungauged catchment by using HEC-HMS. during this scenario the position of GD-3 inflection point is assigned at 10% (2621.713Mm^3), 15% (606.5Mm^3), and 100% (34Mm^3) of system storage balance for flood control, conservation zone, and inactive zone respectively, while keeping 100% for each of reservoirs system zone for GD-5 and GD-6 reservoirs. The position of guide curve was adjusted at respective storage zone. In this scenario, the reservoir system able to generate an average hydropower of 355.76 MW.

4.3.2.2 Simulation for Alternative 2:

This scenario has been analyzed by placing inflection point of GD-5, at 90%, and 85% of system Flood control, and conservation storage zone respectively. during this scenario, the reservoir system simulation was analyzed by keeping other parameters the same with alternative 1. In this alternative, the reservoir system able to generate an average hydropower of 489.01 MW.

4.3.2.3 Simulation for Alternative 3:

This alternative was analyzed explicitly by adjusting the position of GD-3 inflection point at 0% (2570 Mm^3), 0% (260 Mm^3), and 100% (34Mm^3) of system storage balance for flood control, conservation zone, and inactive zone respectively, while the inflection points for downstream reservoirs GD-5, and GD-6 were assigned at 100% for each of reservoirs system zone. The position of guide curve was fixed at minimum operative level for GD-3 and assigned at top of conservation zone for GD-5, and GD-6. In this scenario, the genale reservoir system able to produce an average hydropower of 492.15 MW which is considered as the optimal power generated from the joint operation of reservoir system after analyzing a number of alternatives (scenarios).

In general, it is concluded that the explicit system storage balance is used to force the upstream reservoir, GD-3, to fill first, allowing the downstream reservoirs, GD-5, and GD-6 to stay empty as long as possible when operating for flood control. Thus, the defined explicit system storage balance shows the tendency of emptying the upstream reservoir, GD-3, and filling the downstream reservoirs, GD-5 and GD-6 there by preparing the upstream (GD-3) reservoir to control the flood during peak flood flow which is one of the purposes of the plant. Moreover, while emptying the flood zone by release of more water through the outlet, the power generated by the hydropower plant gets increased and the regulated flow for the downstream hydro power plants, GD-5 and GD-6 is secured.

Comparison of system energy generated from joint operation of reservoirs system (Simulation results of combined reservoirs guide curves) and individual guide curves (annual energy output from design report) is shown as in the table 4.3 below.

Table 4.3 Annual Energy Generation (GWh) Simulation Results of Combined Reservoirs Guide Curves and Individual Guide Curves.

Parameter	Comparing Parameter	Individual Reservoirs			Total
		GD-3	GD-5	GD-6	
Yearly Average Energy Generation (GWh)	Original Design	1640	715	1575	3,930
	Combined Operation Model	1,617.80	675.75	2,017.70	4,311.3
	Increment of Generation	-22.2	-39.25	442.70	381.3
	Increasing rate (%)	-1.35	-5.49	28.11	9.701

Accordingly, GD-6 hydropower plants can generate an additional 442.70 GWh annually when using combined reservoir operation model. The whole cascade power generation increment is 381.3 GWh and it is a 9.701% improvement over the current design. Also, Combined reservoir system operation model is capable to store 517.13 million cubic meter flood water resources annually which shows 16.75% total reduction of spill release to the current design in GD-3. An energy increment at downstream dam GD-6 shows the flood regulation at downstream reservoirs improved by the operation of the most upstream dam GD-3.

4.3.3 Analysis of Guide Curves

Genale-Dawa cascade optimized combined reservoir system operation guide curves is obtained by the proposed reservoir system operation model. The standard HEC-ResSim reservoir plot for GD-3 and, GD-5 is shown in the fig.4.5, and fig.4.6 below. The upper plot region shows the computed reservoir pool level, guide curve and operating zone. The lower region shows the computed pool inflows and outflow.

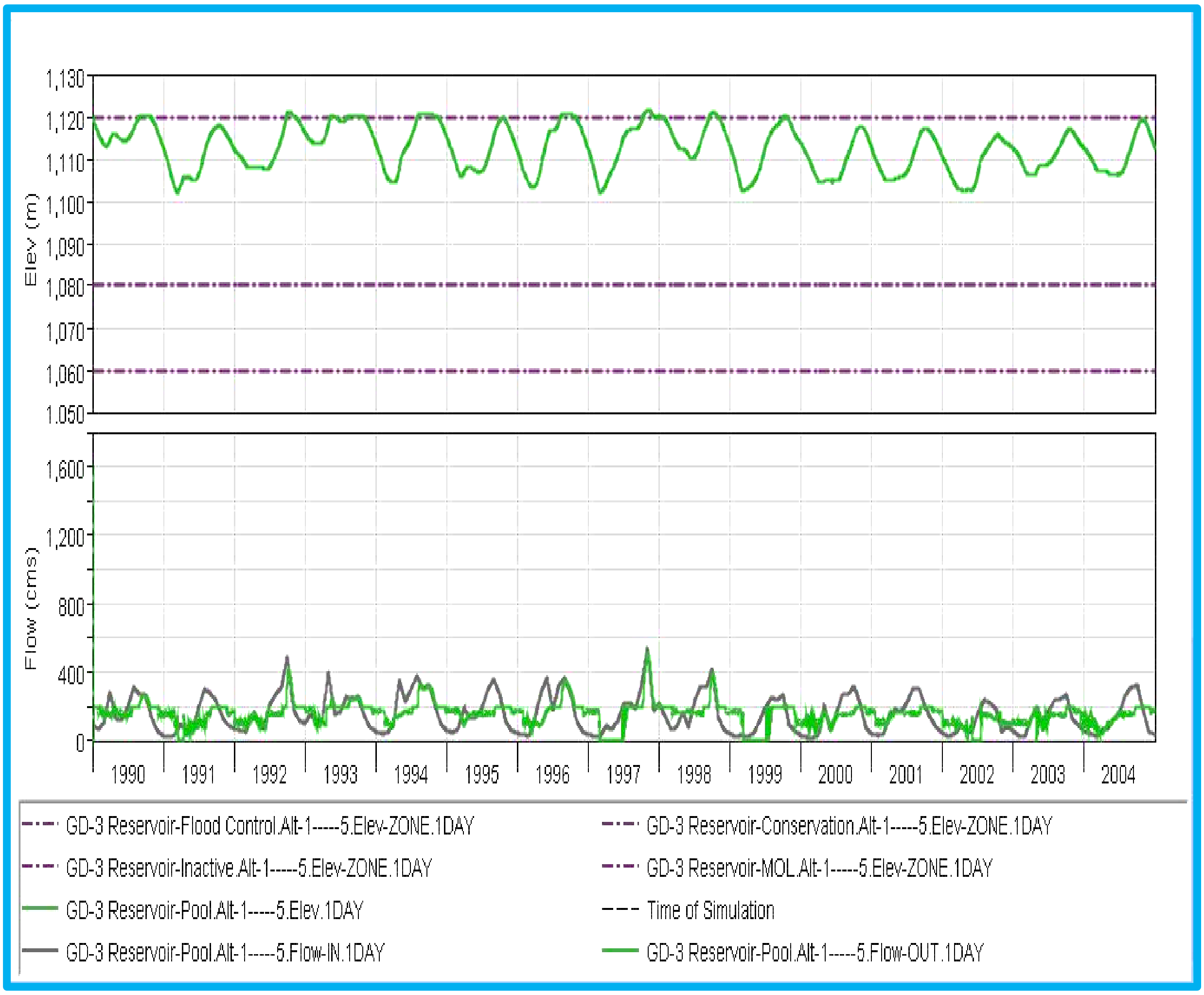


Fig. 4.5 Simulated GD-3 Reservoir Pool Level, Inflows, and Outflow Plots.

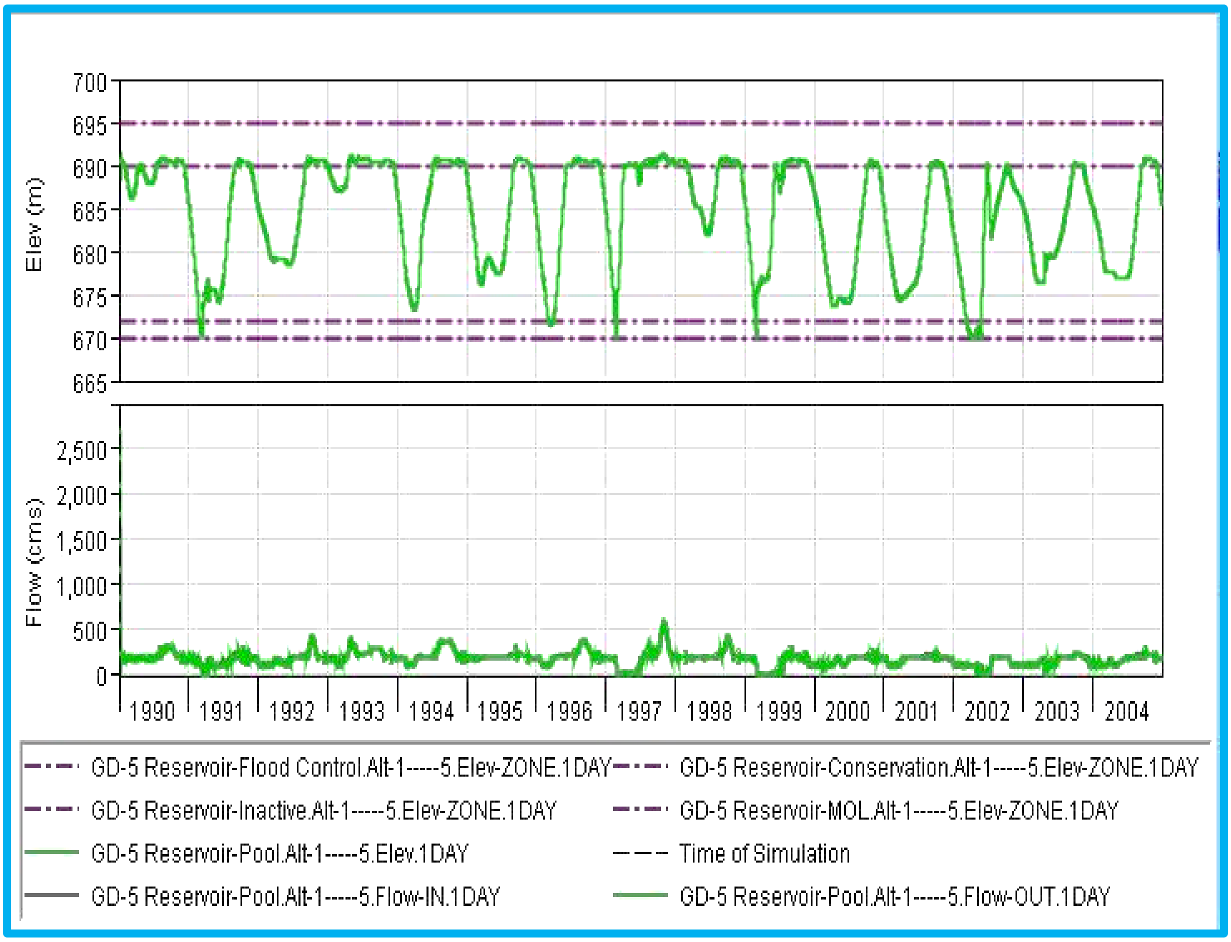


Fig. 4.6 Simulated GD-5 Pool Level, Inflows, and Outflows Plots.

It can be seen from fig. 4.5, and fig. 4.6 above, just during the flood season, the guide curve enlarges and increase the electricity generation capacity to avoid spilling, since the reservoirs tends to release more water than entering into it. After ceasing the flood season, the guide curve decreases and reduce water usage for electricity generation to avoid water level falling excessively which enables reservoirs to capture more water than outflow from it. This continues with similar fashion throughout simulation period with respect to inflow fluctuations. The standard HEC-ResSim plots for GD-6 is shown in appendix G.

Additionally, the simulation results of the monthly maximum, minimum and average water level of GD-3, and GD-5 are shown in fig.4.7 and fig.4.8 below after worked in excel spread sheet. From the figures, the green curves show the higher system capacity zone, the blue line indicates the average or firm system capacity zone, and the lower yellow one shows the lower system capacity zone. According to the runoff records, the mean runoff discharge of Genale-

Dawa basin is high during April to November and low during December to March. With the fluctuating inflow capacity, the corresponding guide curves also fluctuate, and it can be seen from fig. 4.7, and fig. 4.8 just during the flood season, higher capacity zones enlarge and increase the electricity generation capacity to avoid spilling. After ceasing the flood season, the area of the higher capacity zones decreases and reduce water usage for electricity generation to avoid water level falling excessively.

Accordingly, the mean maximum pool level in GD-3, and GD-5 is 1120.65m.a.s.l, in May, and 691.85.m.a.s.l, in April respectively. The mean minimum pool level in GD-3, and GD-5 is 1113.84m.a.s.l, and 686.27m.a.s.l. From the figure, it can be asserted that there are good distributions of water in each reservoir during simulation period.

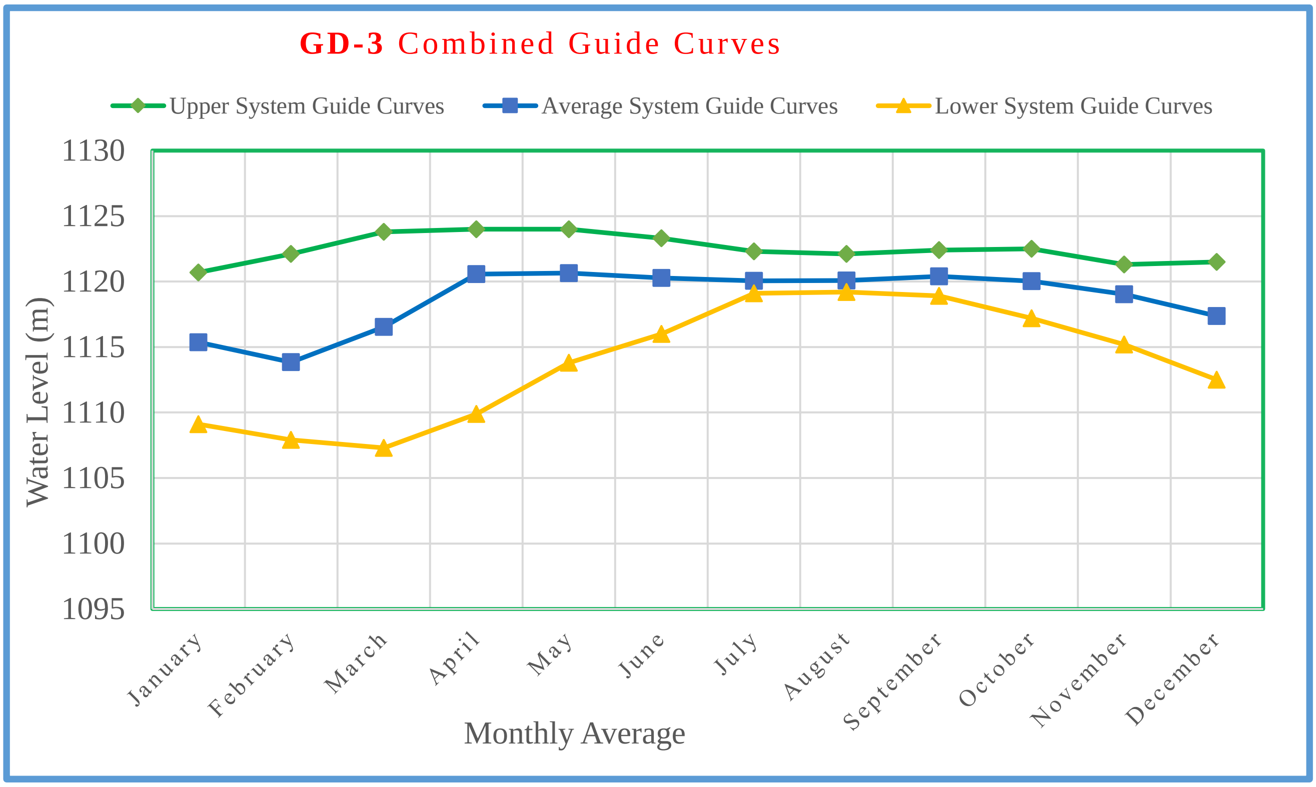


Fig. 4.7 Monthly Maximum, Average, and Minimum GD-3 Combined Guide Curves.

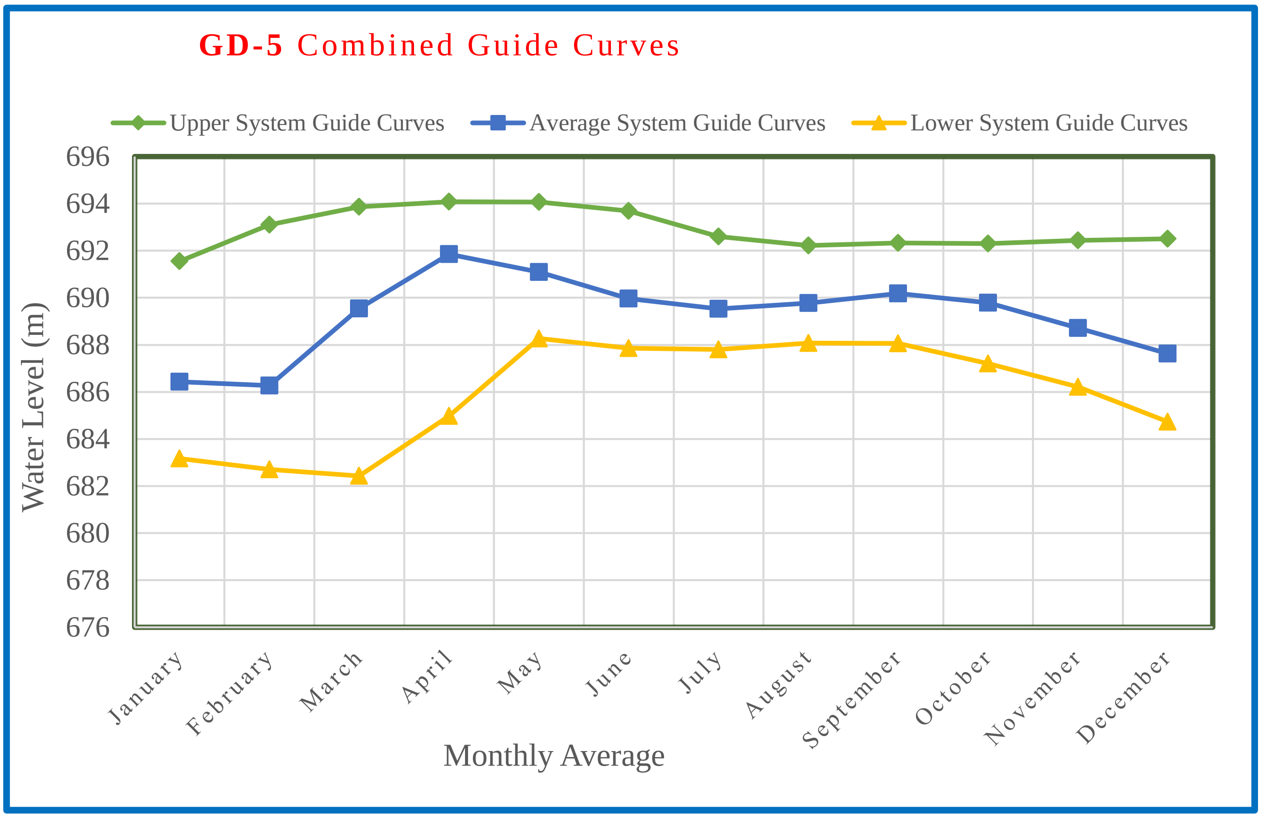


Fig. 4.8 Monthly Maximum, Average, and Minimum GD-5 Combined Guide Curves.

4.3.4 Reservoirs System Power /or Energy Generated, and Release Plots.

The optimal power generated from the joint operation of reservoir system is shown in the figure 4.9, and 4.10 below which refers the standard HEC-ResSim simulation plot of GD-3, and GD-5. Accordingly, from the plots we have seen that, the upper plot region shows the computed power generated and capability of the power plants while the lower region shows us the computed pool inflows, outflow, and power flow.

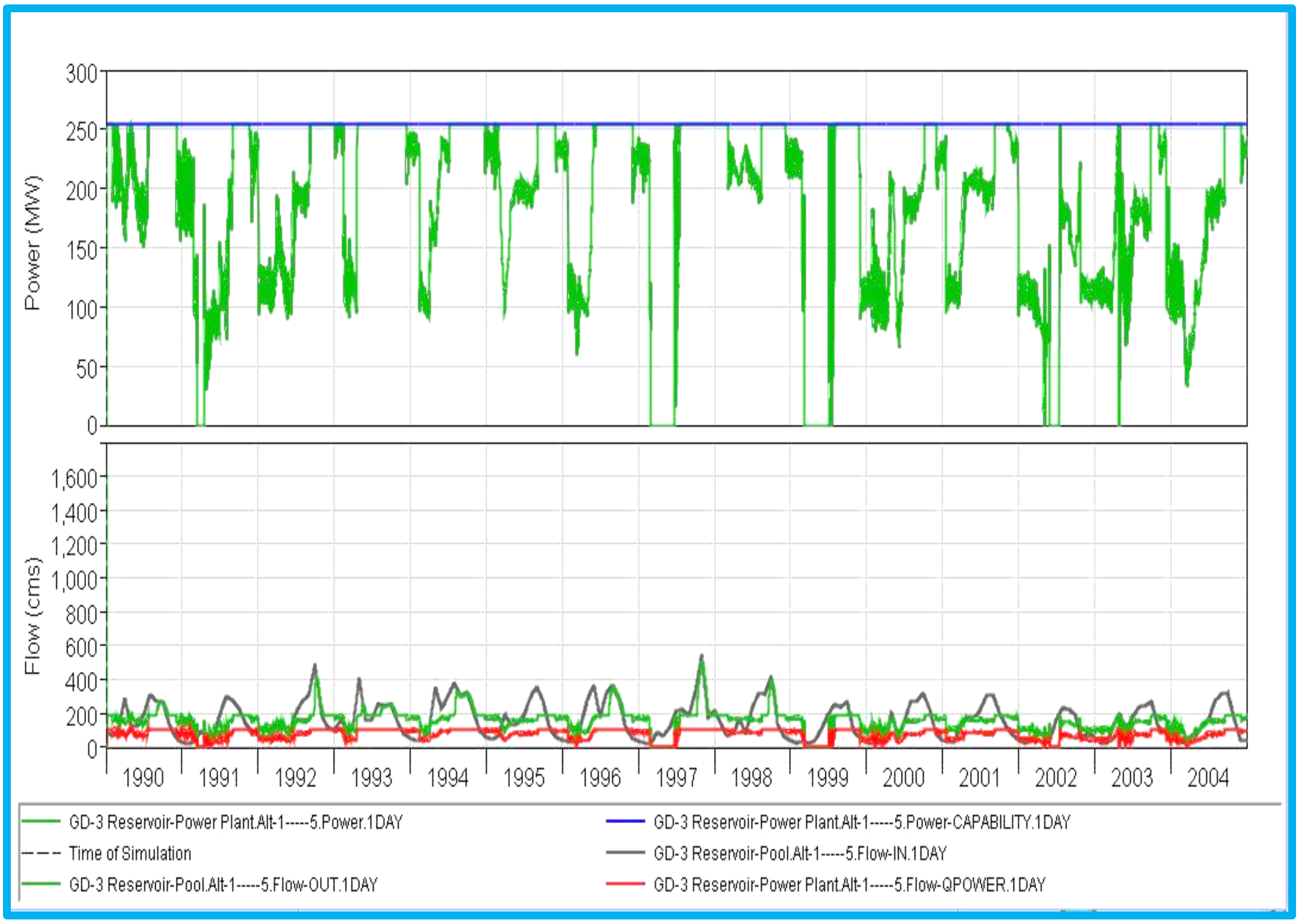


Fig. 4.9 Simulated GD-3 Power Plant, and Power flow, Plots.

The annual energy generation from the genale upstream reservoir GD-3 is 1,617.80 GWh with an average power output of 184.68 MW when the three hydropower plants are in cascade and ResSim was configured with tandem operation rule. Although, the result of energy generated from GD-3 shows slight decrement while comparing with the original design report, the all over energy generated from joint operation of Genale Reservoir System is increased by 9.701% over the original design report.

Fig. 4.10 Simulated GD-5 Power Plant, and Power flow, Plots.

The results from GD-5 reservoir indicates that the annual energy generated from the genale downstream reservoir GD-5 is **675.75 GWh** with an average power output of **77.14 MW** when the three hydropower plants are in cascade and ResSim was configured with tandem operation rule.

The whole cascade power generation increment is **381.3 GWh** and it is a **9.701%** improvement over the current design. Also, Combined reservoir system operation model is capable to store **517.13** million cubic meter flood water resources annually which shows **16.75%** total reduction of spill release to the current design in GD-3 reservoir.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The development of HEC-HMS and HEC-ResSim model were adopted to attain the objective of this research which incorporates meeting direct and downstream demands. The stream flow generation were estimated by using HEC-HMS model to enhance the water balance components at Genale cascade reservoirs in the semi-ungauged parts of upper river basins by dividing the total basin into seven sub-basins in provision of outlet at GD-6 for upper Genale river. The HEC-HMS program was selected for this study, to attain the water balance components of the basin due to its versatility, capability for flow generation, automatic parameter optimization and its connection with GIS through HEC-GeoHMS. The HEC-HMS model was calibrated and validated on a monthly time scale, with reference to Chena-Mansa gauging station to estimate the flow from Genale-Dawa river basin using a time series dataset of 16 years from 1990-2005. Hence, HEC-HMS model was adequately reasonable to adopt for semi ungauged upper Genale-Dawa river basin. Even if the model slightly over estimates the flow, for calibration the model results in the performance criteria of **R^2=0.903**, and **NSE=0.893**, and **D=-0.0002%**, and for validation performance criteria of **R^2 = 0.866**, and **NSE = 0.845**. Thus, HEC-HMS model has the ability to predict the water potential of the basin.

Following the configuration, and application of HEC-ResSim model, the position of guide curve was fixed at a minimum operative level for GD-3 and assigned at top of conservation zone for GD-5, and GD-6 along with explicit system storage balance which is used to force the upstream reservoir, GD-3, to fill first, allowing the downstream reservoirs, GD-5, and GD-6 to stay empty as long as possible when operating for flood control. It has been seen that the pool level of GD-6 is completely in the flood zone throughout the year. The results of annual average hydropower energy generated by the model from joint operation of the reservoirs system is **4,311.3 GWh/year**. The whole cascade power generation increment is **381.3 GWh/year** and it is a **9.701%** improvement over the current design which is **3,930 GWh/year**. Also, Combined reservoir system operation model is capable to store **517.13** million cubic meter flood water resources annually which shows **16.75%** total reduction of spill release over the current design.

5.2 Recommendation

The HEC-HMS, and HEC-ResSim models can be used for effective water resources developments, and managements of river basins if and only if the provision of well-organized hydro-meteorological stations are assured. Due to the limited data in the Genale-Dawa basin, and other influential factors, the researcher has recommended the following activities to be included in the futures studies in the basin for a better water resources management of the river.

- More installation of hydrological gauging station in addition with Chena-Mensa station at GD-3, and downstream of the genale main river should be provided so that the accurate inflow to the reservoirs can be obtained. This will assure the continuous and reliability of data on stream for improvement of further study, and better performance of any applicable model through calibration, and validation.
- The HEC-ResSim model does not able to simulate rainfall runoff from the catchment. Even if the flow generation is done with the help of HEC-HMS in this research, there is no hydraulic model in the HEC-ResSim model. Since input from the hydraulic model such as capacity curves, tailwater curves, and travel time will improve the results it must be specified in the model.
- When individual hydropower reservoirs deliver energy and capacity into a common power system, operating the projects as a system (joint operation of the reservoir) can often produce more energy than the sum of individual projects operating independently. So, further study should be made by considering joint operation of reservoirs system.
- The study was not considered seepage from the reservoirs. for more qualitative output future study should quantify the seepage from the pool.
- The impact of climate change will be resulted from the inappropriate, and unsustainable use of environmental resources. Thus, the future study will include the effect of climate change on land use and stream flow variation.
- From this thesis, the researcher identifies that the downstream reservoir GD-6 is completely in the flood zone throughout the year. Thus, it recommended that the structural modification should be required.
- Reservoir Sedimentation is one of the major problems in the planning of storage dam due to soil erosion and poor land managements which causes significant reduction of reservoirs capacity. in this research the effect of sedimentation was not studied. Thus, the researcher suggests it should be included in the future researches.

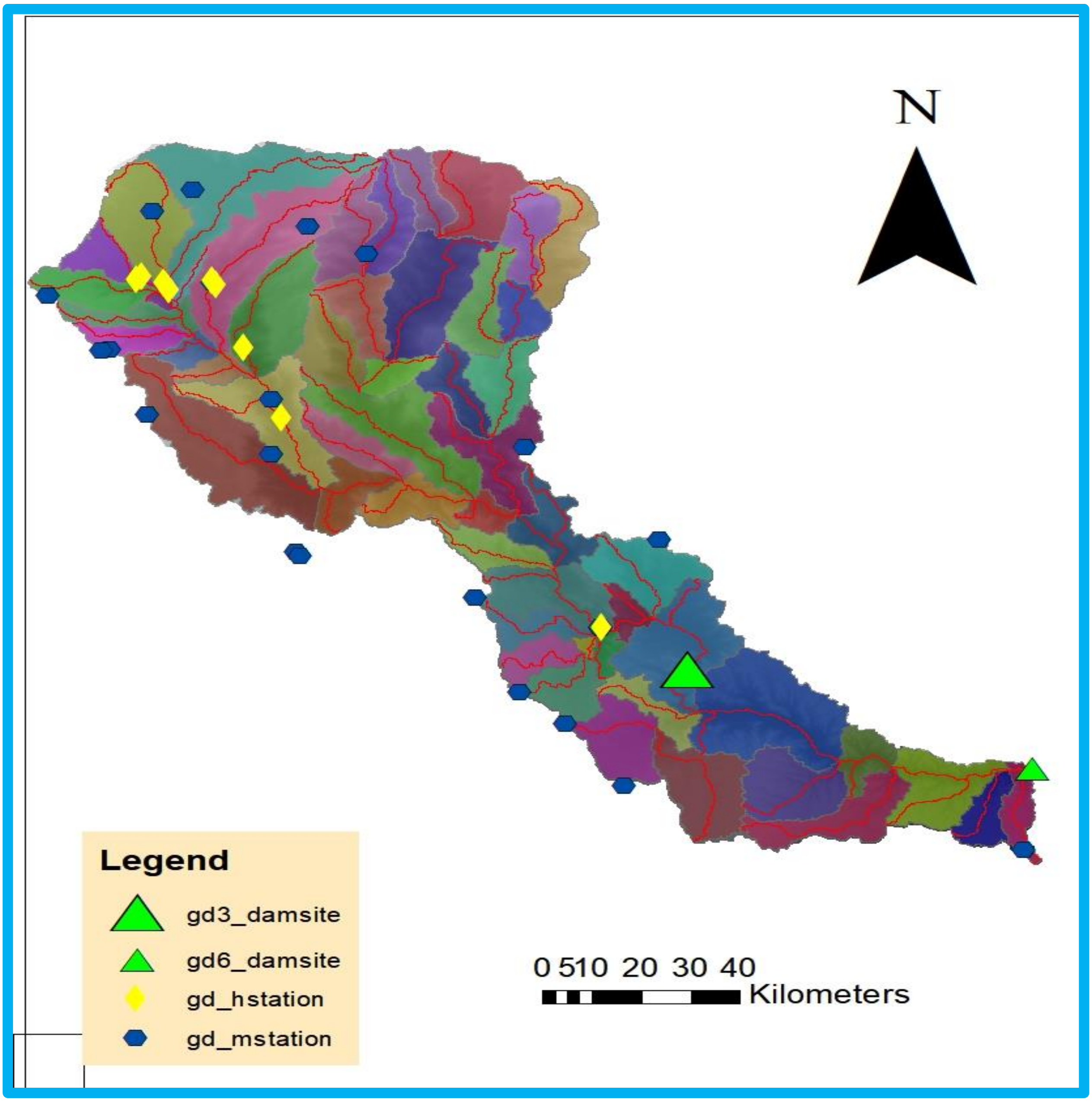
References

1. Chow VT, Maidment Dr., Mays LW. (1988), Applied Hydrology, Mc Graw-Hill, New York. USA.
2. C.-Y.XU. and V.P Singh (1998), A Review on Monthly Water Balance Models for Water Resources Investigations, Water Resources Management, Kluwer Academic Publishers, Netherlands.
3. Daniel A. (2011), Water Use and Operation Analysis of Water Resources Systems in Omo-Gibe River Basin M.Sc. Thesis, Addis Ababa University, Ethiopia.
4. EEPCO. (2005), Ethiopian Power System Expansion Master Plan, Addis Ababa, Ethiopia.
5. Fuad A. (2009), Investigation and Hydrological Characterization of Surface Water Storage Option in The Upper Blue Nile. M.Sc. Thesis, Arba Minch University, Ethiopia.
6. G.L. Asawa (2005), Irrigation and Water Resources Engineering, New Age International (P) ltd., Publishers, New Delhi.
7. Joan D. Klipsch, Thomas A. Evans, PhD., (2007), Reservoir Operation Modeling With HEC-ResSim, Hydrologic Engineering Centers, US. Army Corps of Engineers, Davis, CA.530-756-1104.
8. Labadie J. (2004), Optimal Operation of Multi Reservoir Systems: State of the Art Review, Journal of Water Resources Planning and Management 130(2):93-111.
9. Lahmeyer Interanational and Yeshi-Ber Consult. (2007), Genale-Dawa River Basin Integrated Resources Development Master Plan Study, The Federal Democratic Republic of Ethiopia Ministry of Water Resources. Volume.II.3, Addis Ababa, Ethiopia.
10. Lahmeyer International and Yeshi-Ber Consult. (2007), Genale GD-3 Multipurpose Hydropower project Feasibility Study Final Report. Volume II. Main Report, Addis Ababa, Ethiopia.
11. Norplan-NorConsult in Association with Shebelle Engineering (2009), Genale GD-6 Hydropower project Feasibility Study Final Report. Volume I. Main Report, Addis Ababa, Ethiopia.

12. Shenglian Guo, Xiang Li, Pan Liu, Fuqiang Guo. (2009), Optimal Operation of Cascade Hydropower Plants, Wuhan, 430072, Peoples Republic of China.
13. Skaggs, R.W, and Khaleel R. (1982), Infiltration, Hydrologic Modeling of Small Watershed, American Society of Agricultural Engineers, St. Joseph. MI.
14. Subramanya K. (1998), Engineering Hydrology, Tata Mc Graw-Hill, 2nd Edition.
15. S. Vedula, P.P. Mujumdar (2006), Water Resources Systems Modelling Techniques and Analysis, Mc Graw-Hill, New Delhi, India.
16. Tilahun A. (2015), Assessing Surface Water Potential and Water Demand in Genale-Dawa River Basin. M.Sc. Thesis, Addis Ababa University, Ethiopia.
17. USACE. (2013), HEC-ResSim, Reservoir System Simulation, User’s Manual Version 3.1, U.S Army Corps of Engineers.
18. USACE. (1991), HEC-ResSim, Optimization of Multi-Purpose Reservoir System Operations, Research No.34, 609 second street, U.S Army Corps of Engineers.
19. USACE. (2000), Hydrologic Modeling System HEC-HMS, Technical Reference Manual, US. Army Corps of Engineers, Hydrologic Engineering Center.
20. USACE. (2001), Hydrologic Modeling System HEC-HMS, User’s Manual, US. Army Corps of Engineers, Hydrologic Engineering Center.
21. USACE. (2013), Geospatial Hydrologic Modeling Extension HEC-GeoHMS, User’s Manual, US. Army Corps of Engineers, Hydrologic Engineering Center.
22. WAPCOS (1990), Preliminary Water Resources Development Master Plan for Ethiopia, Water and Power Consultancy Service, Addis Ababa, Ethiopia.
23. Wurbs, R.A., M.N. Tibbets, L.M. Cabezas, and L.C. Roy. (1985, June). "State-of-the-Art Review and Annotated Bibliography of Systems Analysis Techniques Applied to Reservoir Operation,". Technical Report 136. Texas Water Resources Institute, College Station, Texas.

APPENDICES

APPENDIX A: Location and Distribution of Genale-Dawa River Basin Hydro-Meteorological Station.



Appendix A-1: Location of Upper Genale-Dawa Basin Meteorological Station

Code	Station	Class	Latitude Deg.	Latitude Min	Longitude Deg.	Longitude Min.	Elev. (m.a.s.l)	M-Rainfall (mm/a)	Period Msr. from	Period Msr. to	#Coplt. years
7002	Negele Borena	1	5	20	39	34	1425	728	1952	2002	43
7006	Bore School	4	6	10	38	33	2660	1468	1981	1996	4
7010	Arbe Gona	3	6	42	38	43	2500	1260	1958	2002	6
7016	Wadera	4	5	47	39	17	1900	973	1972	2001	19
7025	Kibremengist	1	5	52	38	58	1680	1061	1974	2002	20
7030	Yirba Muda	3	6	12	38	42	2560	1270	1975	2002	12
7033	Bore	3	6	21	38	36	2660	1690	1979	2001	14
7039	Hare Kello	3	5	33	39	23	1600	716	1982	2002	15
7041	Bidire	3	5	55	39	38	1620	707	1982	2001	4
7043	Genale Donta	3	5	42	39	32	1150	785	1983	1990	7
7048	Hagere Salam	1	6	28	38	31	2620	1230	1986	2002	12
7053	Worka/Nensb.	1	6	29	39	13	1835	1454	1987	2001	8
7059	Aborso	3	6	8	39	24	1580	1247	1986	1990	1
6007	Sirofta	1	7	0	39	3	2600	962	1980	1989	8

Appendix A-2: Location of Upper Genale-Dawa Gauging Station

Code	River	Station Name	Lat. N		Long. E		Area (Km^2)	Elevation (m)
2023	Morodo	Nr. Bona Kike	6	31	38	41	85.9	2,140
2022	Ererte	Nr. Bona Kike	6	31	38	41	99.3	2,130
2021	Gelana	Nr. Bona Kike	6	31	38	44	376	1,960
2010	Logita	Nr. Bensa Daye	6	30	38	45	729	1,900
2014	Bonora	Nr. Bensa Daye	6	31	38	48	343	1,840
2024	Konkona	Nr. Bensa Daye	6	31	38	49	52.3	1,880
2025	Gambetu	Nr. Aroressa	6	22	38	52	270	1,510
2026	U. Genale	Nr. Girja	6	12	38	57	3177	1,360
2002	Genale	At Chena-Mansa	5	42	39	32	9190	1,120
2011	Genale	Nr. Kole Bridge	4	26	41	50	56,135	198
2001	Genale	At Helwei	4	22	41	53	56,583	195

Appendix B: Mean Monthly Rainfall at Principal Station After Filling for Missing Data

B-1: Mean Monthly Rainfall at Hagere Selam After Filling for Missing Data

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10	Column11	Column12	Column13	Column14
	Monthly Rainfall at Hagere Selam after filling for missing data												
Year	January	February	March	April	May	June	July	August	September	October	November	December	Yearly Mean
1988	38.3	47.5	52.4	121.5	127.2	150.3	190.9	121.5	171.6	143.5	9.8	13.4	98.991667
1989	38.5	20.4	106.2	145.6	80.4	111.8	77.4	145.9	152.3	151.9	47.9	75.2	96.125
1990	30.4	174.5	99.9	199.1	109.6	147.9	69.9	82.6	79	73.8	58.8	9.5	94.583333
1991	56.9	53.9	90.2	39.5	138.8	185.6	113	60.5	251.3	61.8	57.8	8.1	93.116667
1992	20.213273	31.21882	39.7	194.4	126.8	140.6	135.8	163.4	72	288.7	64.8	70.3	112.32767
1993	94.451125	134.2	30.4	171.2	206.5	70.8	64.8	83.1	146	159.7	12	27.5	100.05426
1994	7	13.1	113.3	184.8	219.3	62.9	212.4	140.6	103	38.1	43.7	6.5	95.391667
1995	21.6	59.3	170.9	157.4	51.5	72.3	90.1	147.5	128.7	90.1	27.4	19.5	86.358333
1996	102.7	28	8.3	260.09814	297.70681	244.6	82.1	147.7	101.4	78.8	39.7	16.3	117.28375
1997	73.7	0	146.7	229.4	136.3	100.9	82	111.8	25.6	239.3	188.3	38.7	114.39167
1998	70.8	64.4	34.7	161.9	228.4	71.1	108.8	175.7	156.3	243.6	14.2	13.7	111.96667
1999	28.7	25.3	164.7	217.1	209.7	89.5	117.1	199.6	74.4	349.5	33.3	8.5	126.45
2000	3.33519	3.39586	18	139	161	84.1	41.1	190.1	240	442.4	61.6	30	117.83592
2001	74.2	45.3	122.8	193.7	161.5	86	75.2	209.5	155	179.3	60.2	7.7	114.2
2002	33.7	43.1	132.8	106.9	163.5	85.1	130.7	39.1	115.1	172.9	13	133.3	97.433333
2003	69.6	11.7	74.7	94.7	74.4	185.3	77.1	117.5	198	36.6	41.6	36.4	84.8
2004	80.6	41.5	25.2	184.3	182.3	64.8	104.7	169.2	14.7	150.4	102.4	35.9	96.333333
2005	70.5	29.5	82.5	123.3	324.3	104.3	87.5	142.9	145.1	253.2	64.9	0	119
2006	0	76.4	56.5	161.1	131.8	136.8	112.7	133.1	44.4	177.5	86.8	60.7	98.15
2007	84.2	51.7	53.3	209.5	196.2	256.7	117.2	278.5	162.77608	84.7	69.999875	2	130.56466
2008	0.550375	23.3	47.4	109.4	159.7	168.5	90	158	212.3	143.6	114.4	5	102.6792
2009	91.9	36.3	30.6	126.6	179.6	69.9	46.6	249.2	72.9	142.8	29.6	77.3	96.108333
2010	25.9	181.6	200.7	263.1	329.9	111.1	96.3	130.6	193.2	214.5	3.6	6.1	146.38333
2011	2.4	2.1	24.5	264.7	368.4	150.2	143.3	154.5	150.2	199.4	259.7	62.879625	148.5233
2012	2.4	2.1	24.5	264.7	206.41188	66.827	12.878	78.8	43.268125	145.1	39.2	34.5	76.72375
2013	5.9	8	71.93725	322.4	197.79563	116.9	24.311	6.248375	36.5585	62.419	119.2	69.68025	86.779167
2014	0	11.97875	26.89175	57.787875	116.33275	262.3	6.636875	229.3	245.2	201.2	110.6	16.9	107.094
2015	30	22.6	35.7	244.1	244.9	113.8	58.5	135.8	122.1	116.4	136.35125	4.37375	105.38542
2016	29.5	10.5	75.3	199.8	283	179.6	133.5	182.2	159.6	176.8	47.8	5.78925	123.61577
2017	1	5.2	50.4	71.6	63.333	13.377875	218.8	206	365.1	70.900875	43.31475	0	92.418875
Mean	39.631665	41.936448	73.7043	173.9562	182.55267	123.4635	97.377529	146.34828	137.90342	162.964	66.732196	29.857429	106.36897
Max	102.7	181.6	200.7	322.4	368.4	262.3	218.8	278.5	365.1	442.4	259.7	133.3	148.5233
Min	0	0	8.3	39.5	51.5	13.377875	6.636875	6.248375	14.7	36.6	3.6	0	76.72375
STDEV.S	33.547943	46.377639	51.117049	68.101711	80.33587	60.852445	51.168892	60.096301	78.165552	92.131886	55.56642	31.511502	17.213245

B-2: Mean Monthly Rainfall at Worka (Nensebo) After Filling for Missing Data

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10	Column11	Column12	Column13	Column14
	Monthly Rainfall at Worka(Nensebo) After filling for missing data												
Year	January	February	March	April	May	June	July	August	Sebtember	October	November	December	Yearly Mean
1990	25.4	113.3	137.5	136.3	243.9	177.3	76.7	151.5	100.1	109.3	72.5	31.7	114.625
1991	35.7	37.8	124.2	97.2	177.5	124.2	96.7	140.4	151.2	66.6	19.6	23.9	91.25
1992	5.1	33.8	11.6	149.4	287.3	215.3	97.9	158.8	162.8	267.3	62.1	74.7	127.175
1993	94.5	106	15.2	147.2	239.7	158.4	86.2	125.1	113.5	215.5	21.9	43.6	113.9
1994	1.9	1	37.7	201.6	219.4	114.5	199.7	154.3	120.3	131.2	83.6	7.1	106.025
1995	10.7	21.4	221.6	244.8	137.6	116.6	137.3	114.8	206.4	164.7	58.8	27.4	121.84167
1996	29.1	8.5	186.1	196.2	325.4	231.1	217	172.7	190.3	148.9	34.1	23.9	146.94167
1997	30.3	0	53	237.4	174.1	144.2	122.9	63	100.6	270.9	268	85.6	129.16667
1998	161.3	137.4	12.5	139.3	140.5	119.9	91.1	188.7	59.2	135.9	20.5	31.8	103.175
1999	8.1	1.3	109.7	111.3	195.9	100.8	130.1	110.2	118.5	209.9	49.9	14.4	96.675
2000	4.2	14.8	197.3	201.1	108.3	153	125.7	130.7	387.7	89.4	95.640325	27.344225	127.93205
2001	72.9	88.3	203.6	381.4	144.2	136.6	226.2	230.7	336.2	29.4	17.1	5.052325	155.97103
2002	38.86905	11.152125	354.5	234.3	212.6	291.5	131.5	70	77.6	57.5	18.9	112.3	134.22676
2003	6.3	3.027375	193.8	150.3	78.5	186	105.6	184.7	82.8	54.7	26.5	91	96.935615
2004	21.5	127.5	37.8	30.8	19.3	64.3	70.3	92.5	70.8	56.3	156.884	7.5166667	62.958389
2005	3.0806452	5.6166667	91.583425	6.4774194	8.86	8.5387097	3.1633333	45.852175	65.512625	150.9699	58.532075	0	37.348915
Mean	34.309356	44.43101	124.23021	166.56734	169.56625	146.38992	119.87896	133.37201	146.46954	134.90437	66.534775	37.957076	110.38423
Max	161.3	137.4	354.5	381.4	325.4	291.5	226.2	230.7	387.7	270.9	268	112.3	155.97103
Min	1.9	0	11.6	6.4774194	8.86	8.5387097	3.1633333	45.852175	59.2	29.4	17.1	0	37.348915
STDEV.S	42.710173	50.929531	97.074836	89.330175	88.191122	66.689811	57.053099	49.955753	95.041251	75.993685	65.333715	34.298376	29.973981

B-3: Mean Monthly Rainfall at Wadera After Filling for Missing Data

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10	Column11	Column12	Column13	Column14
	Monthly Rainfall at Wadera After filling for missing data												
Year	January	February	March	April	May	June	July	August	Sebtember	October	November	December	Yearly Mean
1987	9.3	3.6	69.4	153.9	398.6	28.2	4.9	2.5	102.9	174.3	81.5	19.2	87.358333
1988	9.3	4.3	47.3	226.6	149.2	28.7	67.1	12.5	118.3	240.1	21	19.1	78.625
1989	4.2	10	32.9	297.6	128.3	8.4	18	1.5	158.7	220.9	194.1	85.8	96.7
1990	16.9	108.3	102.4	231.2	91.3	3.1	11.8	51.223375	46.5	121.2	195.5	77.8	88.101948
1991	27.584975	4.2	130.4	97.463225	244.1	81.51345	53.301575	19.8	70	224.2	17.8	12.581125	81.912029
1992	11.8	37.3	50.6	18.5	223	33.9	85.4	17.1	46.2	214.1	38.237475	39.6	67.978123
1993	64.6	38.9	11.5	293	385	7.4	30.87425	44.973425	20.5	224	8	16.431925	95.431633
1994	51.223375	51.223375	43	203.4	270.5	6.5	2.7	6.5	71.2	105.7	53.6	11.051925	73.04989
1995	2.5	40	165.7	336.1	152.6	28.4	9.1	9.8	135.6	263.1	86.3	32.1	105.10833
1996	16.1	14.1	146.1	315.6	312.8	70.9	3.7	27.5	74.1	188.5	104.6	8.492025	106.87434
1997	51.223375	51.223375	50.7	235	88.5	20.5	13	28.4	58.9	258.6	280.5	29.4	97.162229
1998	88.7	147.8	26.2	149.8	222	20.5	18.1	14.9	28.9	235.8	48.2	5.4	83.858333
1999	51.223375	4.2	91.7	161.4	86.2	46.0119	2.5	73.921175	41.1	172	21.7	14.9	63.904704
2000	51.223375	51.223375	48.051025	118.4	18.4	53.8283	1.4	28.4	39.7	241.9	147.7	10.9	67.59384
2001	32.089675	2.5	104.9	90	168.89063	15.6	3.4	45.9	114	180.4	92.7	51.223375	75.13364
2002	32.3	51.223375	141.3	87	145.0324	15.1	5.1	22.70485	102.3	263.7	5.4	137.7	84.071719
2003	28.50805	81.006475	81.006475	187.48808	157.25095	27.1	40.5	39.8	31	56.5	36.7	58.2	68.755002
2004	29.3	8.3	16.1	308.2	53.6	36.191275	45.806725	67.03995	68.56295	100.79303	51.223375	19.890796	67.084008
2005	42.892398	14.759371	85.4	150.7	247	152.30623	25.366424	51.223375	51.223375	51.223375	51.223375	51.223375	81.211775
2006	51.223375	24.168275	48.277525	92.52275	115.47903	74.40285	39.38605	52.501925	32.808775	124.49065	94.011175	56.5349	67.150606
2007	4.5	15.552725	97.5	128.6	157.5	56.2	63.567775	12.4	281.9	115.1	51.223375	51.223375	86.272271
2008	51.223375	51.223375	33.95855	112.7	50.3	96.214075	43.100475	48.678875	89.688	261.6	75.7	51.223375	80.467508
Mean	33.087061	37.050169	73.836072	181.59882	175.70695	41.40764	26.731967	30.87577	81.094686	183.55487	79.859944	39.089827	81.991148
Max	88.7	147.8	165.7	336.1	398.6	152.30623	85.4	73.921175	281.9	263.7	280.5	137.7	106.87434
Min	2.5	2.5	11.5	18.5	18.4	3.1	1.4	1.5	20.5	51.223375	5.4	5.4	63.904704
STDEV.S	22.829993	37.189496	44.228542	88.697805	102.8868	36.003521	24.721164	21.068095	58.37423	68.418135	69.513525	31.939509	12.654177

B-4: Mean Monthly Rainfall at Kibre-Mengist After Filling for Missing Data

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10	Column11	Column12	Column13	Column14
	Monthly Rainfall at Kibre Mengist After filling for missing data												
Year	January	February	March	April	May	June	July	August	Sebtember	October	November	December	Yearly Mean
1987			129.8	180.1	334.8	137.8	11.2	15.6	105.6	321.7	61.6	0.851	129.9051
1988	14.5	15.793875	29.2	197.4	175.4	61.1	48.4	28.1	92	207.5	20.7	9	74.92449
1989	15.8	4.4	213.8	251.5	181.8	34.5	60.4	58.6	201.3	280.9	144.4	97.5	128.74167
1990	2.8	147.2	166.2	315	166.5	19.2	54.4	18.2	65.4	120.9	136.9	29.8	103.54167
1991	37	36.5	110.2	118	166.1	56.8	23.4	46.1	70.3	40.8	24.6	25.8	62.966667
1992	29.3	4.4	21.5	366.3	251.3	61.6	19.4	27.1	130.9	301.4	46	24.7	106.99167
1993	64.9	32	5.3	203.2	383.9	44.1	2.4	6.2	34.2	206.7	10.34545	9.1	83.528788
1994	1.8797	2.992525	68.3	227.6	457.1	16.8	10.7	20.8	80.5	128.4	44	32.6	90.972685
1995	7.44425	16.3	145.9	223.5	83.9	11.1	31.5	29.1	156.1	260.2	152	0.9	93.162021
1996	2.1	3.4	129	292.2	320.1	211	56.6	9.4	70.4	151.3	78	1.8	110.44167
1997	21.906325	0	39.6	223.9	47.5	19.3	80.1	21.3	55.7	213.3	184.2	18.4	77.100527
1998	90.6	75.3	35.4	182.8	173.7	26.5	54.5	22.2	70	226.9	35.5	10.853575	83.687798
1999	8.149225	7.524475	140	161.1	59.7	18.9	15.8	32.5	32.3	164.8	12.4	30.8	56.997808
2000	15.793875	15.793875	15.4	197.9	264.4	15.9	7.4	56.9	28.1	210.9	71.3	11.4	75.932313
2001	10	12.8	66.8	308.5	193.9	49.5	17.8	53.6	91.5	191	73	4.3	89.391667
2002	15.2	15.793875	115	87.4	167	5.4	11.7	3.1	83.2	247.8	27.1	108.6	73.941156
2003	43.6	15.793875	67.5	246.3	276.2	52	27.4	53.7	13.8	66.3	30.4	52.2	78.766156
2004	65.7	16.9	48.5	174.6	11.8	13.6	21.1	11.6	101.6	117.6	252.5	17.9	71.116667
2005	100.8	31.7	142.2	320.8	358.3	24	28.5	29.2	92	281.1	137.3	15.793875	130.14116
2006	0	30.3	107.9	152.1	111.1	43.6	2.5	94.2	28.4	279.2	64.3	33.7	78.941667
2007	7.3	18.4	85.5	252.3	125.4	124.2	57	59.7	128.8	156.8	19.3	0.4255	86.260458
2008	1.7	5.588325	101	132.9	147.3	18	63	49.6	160	155.1	42	46.76625	76.912881
2009	56.5	21.938575	18.3	31.98415	82.37215	61.760475	13.0199	53.1688	18.514225	62.6	48.8184	27	41.33139
2010	5.6	79.5	194	289	269.6	1.7	12.8	82.3	30.3	120.6	51.8	15.690275	96.07419
2011	0.5106	0.446775	5.464875	56.314925	85.72485	45.6	61.1	28.1	31.95505	65.4756	99.135675	15.793875	41.301852
2012	0.5106	0.446775	0.5	287.8	260	10.9	37.3	43.3	103.7	260.1	106.3	3.2	92.838115
2013	21.3	9.9335	222.2	283.8	283.8	96.8	48.7	19.3	61	192.8	107.2	15.793875	113.55228
2014	15.793875	37	76.6	15.793875	198.5	110	20.5	66.4	38	42.8053	23.53015	24.098475	55.751806
2015	6.3825	4.80815	26.3	200.9	185.3	50.1	37.5	20.4	30.5	154.6	56.2	6.4	64.949221
2016	6.553875	2.233875	19.858075	134.97295	126.035	7.9	139.9	9.8	39.63615	111.0917	26.98595	15.793875	53.396788
2017	0.21275	2.49505	15.7726	15.2329	15.793875	18.7	53.08945	50.8	123.47853	15.793875	15.793875	15.793875	28.579731
Mean	22.327919	22.256118	82.677276	197.78061	192.39761	47.366467	36.422882	36.140929	76.425289	172.78924	71.084177	23.31466	82.327163
Max	100.8	147.2	222.2	366.3	457.1	211	139.9	94.2	201.3	321.7	252.5	108.6	130.14116
Min	0	0	0.5	15.2329	11.8	1.7	2.4	3.1	13.8	15.793875	10.34545	0.4255	28.579731
STDEV.S	27.414398	30.659219	64.695204	92.719738	110.06973	46.299549	28.643493	22.806148	46.708523	84.277872	57.675978	24.913555	25.543977

B-5: Mean Monthly Rainfall at Dello Menna After Filling for Missing Data

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10	Column11	Column12	Column13	Column14
	Monthly Rainfall at Dello Menna After filling for missing data												
Year	January	February	March	April	May	June	July	August	Sebtember	October	November	December	Yearly Mean
1987	2.3	16	80.9	93.3	354.4	19.1	1.8	14.9	75.7	255.1	36.1761	1.3	79.248008
1988	2.8	18.1	74.4	204.9	142.3	43.4	44.5	57.3	84.5	181.9	16.5	34.6	75.433333
1989	2.9	2.7	160.4	259.5	94.82725	34.194875	11.9	45.549825	122.5784	158.1608	95.657575	61.968275	87.528083
1990	0.7	71.9	116.3606	206.8659	120.4	4.7	12	36.1761	65.075725	98.7726	10.2	35.80305	64.912831
1991	36.1761	29.11935	191.3	171.9	78.9	22	22.4	0.9	12.6	53.5	26.7931	36.1761	56.813721
1992	15.563441	24.107607	29.0247	166.56033	196.2	82.5	75.194575	21	18	217.3	6.8	57.4	75.804221
1993	77.1	0.9	12.2	130.6	84.1	7.3	36.1761	7.2	30.6	212.2	4.8	36.1761	53.27935
1994	36.1761	36.1761	35.9	270.4	309.7	10.4	9.2	7.8	79.7	113.4	47.3	2	79.846017
1995	36.1761	48	193.4	387.4	114.7	81	19.9	13.2	65.7	226.2	111.8	47.4	112.07301
1996	32.164175	12.078975	109.01285	36.1761	36.1761	168.78928	76.312025	75.54685	96.447925	132.68505	61.44545	36.1761	72.750906
1997	36.1761	36.1761	64.436925	159.9	90.3	10.9	25	35.5	101.1	293	273.7	31.5	96.474094
1998	148.4	199.1	26.5	174.7	159.7	12	8.4	50.3	15.4	472.3	19.5	36.1761	110.20634
1999	1.5	3.1	122.6	226.6	109.6	13.3	24.3	14.4	32.7	133.8	27.2	16.158525	60.43821
2000	6.8	36.1761	6.8	173.6	370.6	10.5	3.5	6.9	146.41065	226.8	36.8	41.2	88.840563
2001	0.4	21.4	64.6	232.6	249.8	30.1	4.7	42.8	132.3	270.1	136.6	5.7	99.258333
2002	49.8	36.1761	115	145.1	121	11.5	15.2	0.5	132.5	249.1	28.5	72	81.364675
2003	10.5	36.1761	46	325.7	247.3	38.1	21.2	26.9	80.1	78.1	104.6	84.1	91.564675
2004	32	4.5	7.5	162	64.1	28.6	22.3	46.7	111.6	126	174.4	27.8	67.291667
2005	15	36.1761	36.1761	86.9	252	507.8	36.1761	36.1761	36.1761	36.1761	36.1761	36.1761	95.925733
2006	36.1761	5.2	44.4	94.7	254.2	147.8	64.7	10.9	69.5	86.8	250	148.1	101.03968
2007	22.7	2.3	6.4	138.8	145.5	172.2	106.5	21.3	38.6	151.5	182.8	36.1761	85.398008
2008	36.1761	2.5	36.1761	0.8	128.5	236.1	39.3	18.3	32.2	68.6	214.3	181	82.82935
2009	33.2916	56.3	10.958325	20	174.9	185.7	12.3	0.6	11.9	158.2	168.4	47.2	73.312494
2010	79.4	50.4	115.9	350.7	91.7	397.3	7.3	34.3	64.8	109.7	101.4	57	121.65833
2011	36.1761	36.1761	1	36.1761	29.1	42.85415	34.8	30.2	36.1761	91.3	173.8	180.3	60.671546
2012	36.1761	36.1761	5.27475	17.2	350.5	181.5	2.3	8.1	27.8	89.7	157.2	154.6	88.877246
2013	15.7	32.6	36.1761	252.3	303.7	169.5	24.5	36.1761	48.2	36.1761	191.4	199.8	112.18569
2014	36.1761	36.1761	6	165.7	149.3	82.346075	36.1761	14	36.1	36.1761	36.1761	81.2	59.627215
2015	36.1761	36.1761	14.0086	1.7	159.7	244.7	63.3	18.5	1.2	57.2	338.8	6.6	81.505067
2016	1.1	36.1761	15.2	366.2	260.7	38.6	14	63	22.5	291	66.6	16.6	99.306342
2017	36.1761	5.5	20	36.1761	181.6	21	25.9	41.2	181.4	203.3	124.2	36.1761	76.052358
Mean	30.582462	32.378807	58.193711	164.35982	175.01624	98.57369	29.072094	26.978225	64.824674	158.52409	105.16208	59.502018	83.597326
Max	148.4	199.1	193.4	387.4	370.6	507.8	106.5	75.54685	181.4	472.3	338.8	199.8	121.65833
Min	0.4	0.9	1	0.8	29.1	4.7	1.8	0.5	1.2	36.1761	4.8	1.3	53.27935
STDEV.S	29.850344	35.826533	56.099534	108.71927	96.046941	120.84598	25.113379	19.517676	45.560756	97.93408	88.471305	54.984332	17.677819

Appendix C: Mean Monthly Streamflow From 1990 – 2005 (m^3/Sec)

C – 1: Mean Monthly Streamflow at GD-3 Dam Site After transposing

Year	Januar	February	March	April	May	June	July	Augus	Sebtembe	October	Novembe	Decembe	Yearly Mea
1990	70.4	51.7	99.22	165.99	115.28	123.75	111.43	200.97	155.43	131.01	60.83	25.96	109.3308333
1991	7.81	4.84	19.47	57.09	63.25	50.38	108.02	190.3	161.92	92.95	66.44	58.63	73.425
1992	50.49	45.21	36.74	27.5	19.8	48.4	122.87	160.05	195.58	404.91	152.24	86.9	112.5575
1993	78.54	143.22	97.68	98.01	261.91	102.63	83.38	146.41	129.69	229.57	137.06	47.96	129.6716667
1994	31.68	24.53	29.37	52.36	160.16	156.64	218.46	268.73	185.35	189.53	134.75	66	126.4633333
1995	37.73	33	51.7	156.31	114.51	69.52	105.71	184.14	241.78	214.39	91.63	27.83	110.6875
1996	22.99	17.82	13.31	60.83	153.78	297.22	165.44	213.18	252.12	136.4	42.68	21.56	116.4441667
1997	15.51	9.9	5.94	50.71	51.26	46.64	132.99	111.54	72.38	290.62	515.46	166.87	122.485
1998	196.35	125.07	54.56	62.26	154.88	76.67	146.08	208.23	198.33	379.94	118.91	32.12	146.1166667
1999	18.59	9.79	18.04	20.9	41.91	43.01	110.22	141.13	123.75	266.53	92.84	25.19	75.99166667
2000	9.68	4.73	2.97	9.9	133.21	34.32	71.28	156.2	158.18	289.3	208.12	44.22	93.50916667
2001	18.81	15.07	21.12	52.36	126.28	166.98	139.92	193.93	192.28	183.48	120.78	46.2	106.4341667
2002	22.44	9.9	21.01	43.78	64.02	49.72	81.95	123.64	107.36	121.66	48.84	54.34	62.38833333
2003	36.85	10.67	8.25	58.63	101.97	86.02	93.17	125.4	131.56	127.82	50.27	60.61	74.26833333
2004	36.08	26.73	11	47.08	72.16	58.52	78.32	160.82	200.09	182.27	99.33	41.47	84.48916667
2005	18.59	11	26.07	56.65	318.78	114.51	131.89	189.75	261.91	247.94	192.06	47.19	134.695
Mean	42.0338	33.94875	32.2781	63.7725	122.073	95.3081	118.821	173.401	172.981875	218.02	133.265	53.315625	104.9348438
Max	196.35	143.22	99.22	165.99	318.78	297.22	218.46	268.73	261.91	404.91	515.46	166.87	146.1166667
Min	7.81	4.73	2.97	9.9	19.8	34.32	71.28	111.54	72.38	92.95	42.68	21.56	62.38833333
STDEV.S	45.8382	41.596	29.7322	42.8035	79.0154	67.5626	37.6551	40.6137	53.1713644	91.45916	113.232734	34.8830037	24.95332819
CV	1.09051	1.2252587	0.92112	0.67119	0.64728	0.70889	0.31691	0.23422	0.30738113	0.419499	0.84968097	0.65427356	0.237798307

C – 2: Generated Flow from "Increment to GD-3 Sub-basin" (Ungauged Part)

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10	Column11	Column12	Column13	Column14
Year	January	February	March	April	May	June	July	August	Sebtember	October	November	December	Yearly Mean
1990	0	0	6.6903226	123.08667	14.551613	0.4433333	0	0	0	0	0	0	12.064328
1991	0	0	0	0	5.0870968	2.08	0	0	0	0	0	0	0.59725806
1992	0	0	0	122.24	104.82903	22.826667	0	0	0	85.4258065	35.0033333	0	30.8604032
1993	0	0	0	26.643333	145.10323	55.07	0	0	0	29.1483871	11.9433333	0	22.32569
1994	0	0	0	41.053333	194.29677	72.853333	0	0	0	0	0	0	25.6836201
1995	0	0	0	38.583333	15.503226	0	0	0	0	60.8612903	24.9366667	0	11.657043
1996	0	0	0	78.853333	128.13548	70.753333	12.551613	0	0	0	0	0	24.191147
1997	0	0	0	38.79	15.587097	0	0	0	0	33.0806452	29.17	6.27096774	10.2415591
1998	0	0	0	14.7	15.496774	3.93	0	0	0	41.1	16.84	0	7.67223118
1999	0	0	0	2.05	0.8225806	0	0	0	0	4.22580645	1.73	0	0.73569892
2000	0	0	0	23.67	72.816129	25.936667	0	0	0	31.6483871	12.97	0	13.9200986
2001	0	0	0	88.326667	56.974194	8.8033333	0	0	0	19.9064516	8.15666667	0	15.1806093
2002	0	0	0	0	7.4354839	0.4733333	0	0	0	70.4483871	4.49333333	0	6.90421147
2003	0	0	0	69.09	96.951613	5.91	0	0	0	0	0	0	14.3293011
2004	0	0	0	13.253333	0.8193548	0	0	0	0	0	74.0633333	4.58064516	7.72638889
2005	0	0	0	127.07667	164.49032	9.9866667	0	0	0	96.4419355	6.14666667	0	33.6785215
Mean	0	0	0.4181452	50.463542	64.93125	17.441667	0.7844758	0	0	29.5179435	14.0908333	0.67822581	14.8605068
Max	0	0	6.6903226	127.07667	194.29677	72.853333	12.551613	0	0	96.4419355	74.0633333	6.27096774	33.6785215
Min	0	0	0	0	0.8193548	0	0	0	0	0	0	0	0.59725806
STDEV.S	0	0	1.6725806	45.191437	65.716352	25.697054	3.1379032	0	0	33.039023	19.5421885	1.87878511	9.93159429
CV			4	0.8955265	1.0120913	1.4733142	4			1.11928607	1.38687245	2.7701469	0.66832137

C – 3: Generated Flow from “Increment to GD-5 Sub-basin” (Ungauged Part)

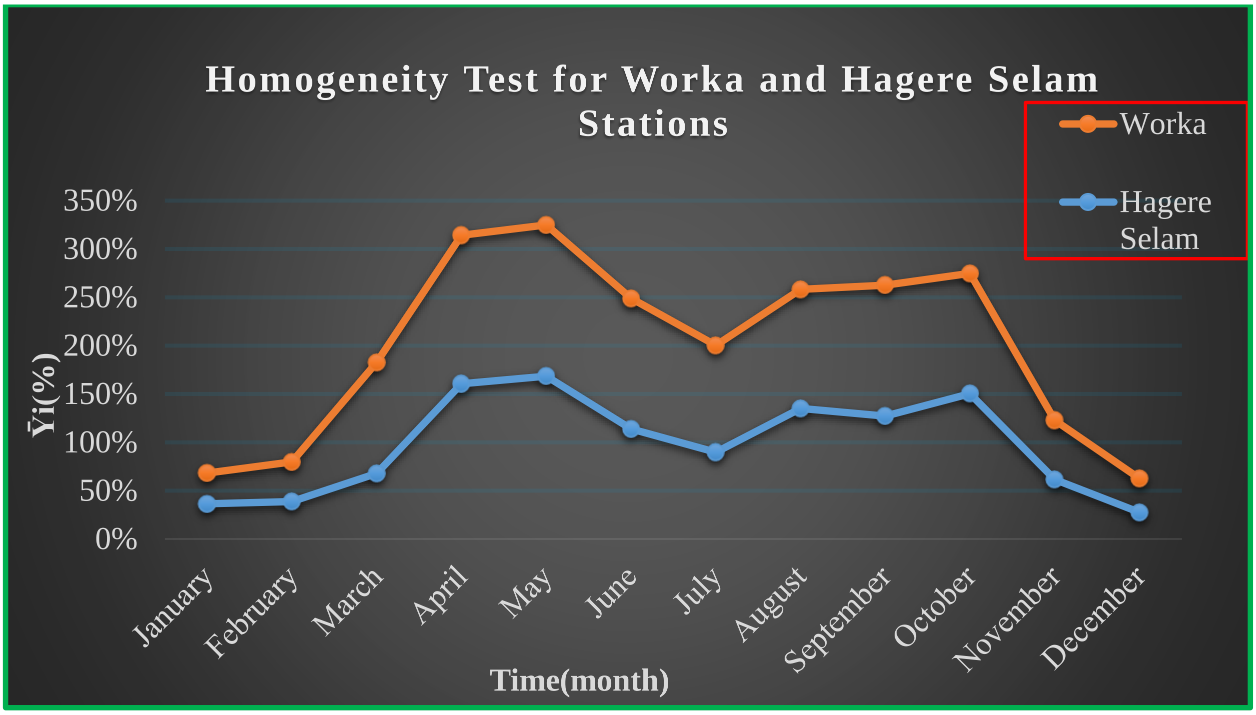
Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10	Column11	Column12	Column13	Column14
Year	January	February	March	April	May	June	July	August	Sebtember	October	November	December	Yearly Mean
1990	0	0	0	58.016667	3.083871	0	0	0	0	0	29.9533333	8.72580645	8.31497312
1991	0	0	0	0	52.045161	20.516667	0	0	0	39.9580645	15.7533333	0	10.6894355
1992	0	0	0	0	39.303226	15.496667	0	0	0	34.0225806	13.4133333	0	8.51965054
1993	0	0	0	80.466667	167.75484	53.876667	0	0	0	39.9580645	15.7533333	0	29.8174642
1994	0	0	0	27.226667	78.487097	26.796667	0	0	0	0	0	0	11.0425358
1995	0	0	4.8483871	107.82	40.925806	0	0	0	0	63.4096774	24.9966667	0	20.1667115
1996	0	0	0	93.763333	129.60968	36.813333	0	0	0	18.5290323	7.30666667	0	23.8351703
1997	0	0	0	45.88	17.729032	0	0	0	0	60.7290323	96.9066667	28.1967742	20.7867921
1998	0	0	0	0	38.725806	15.27	0	0	0	47.0483871	18.5466667	0	9.96590502
1999	0	0	0	2.2866667	0.883871	0	0	0	0	8.61290323	3.39666667	0	1.26500896
2000	0	0	0	0	0	0	0	0	0	50.6677419	19.9766667	0	5.88703405
2001	0	0	0	0	0	0	0	0	0	13.6806452	5.39333333	0	1.58949821
2002	0	0	0	0	0	0	0	0	0	83.6645161	4.58333333	0	7.35398746
2003	0	0	0	23.126667	1.2290323	0	0	0	0	0	0	0	2.02964158
2004	0	0	0	118.5	6.2967742	0	0	0	0	0	0	0	10.3997312
2005	0	0	0	0	70.464516	3.86	0	0	0	0	0	0	6.19370968
Mean	0	0	0.3030242	34.817917	40.408669	10.789375	0	0	0	28.7675403	15.99875	2.30766129	11.1160781
Max	0	0	4.8483871	118.5	167.75484	53.876667	0	0	0	83.6645161	96.9066667	28.1967742	29.8174642
Min	0	0	0	0	0	0	0	0	0	0	0	0	1.26500896
STDEV.S	0	0	1.2120968	43.427736	50.155678	16.375919	0	0	0	27.3296903	23.5964628	7.23875202	8.3252767
CV			4	1.2472813	1.2412108	1.517782				0.95001832	1.47489415	3.13683471	0.74894011

C – 4: Generated Flow from “Increment to GD-6 Sub-basin” (Ungauged Part)

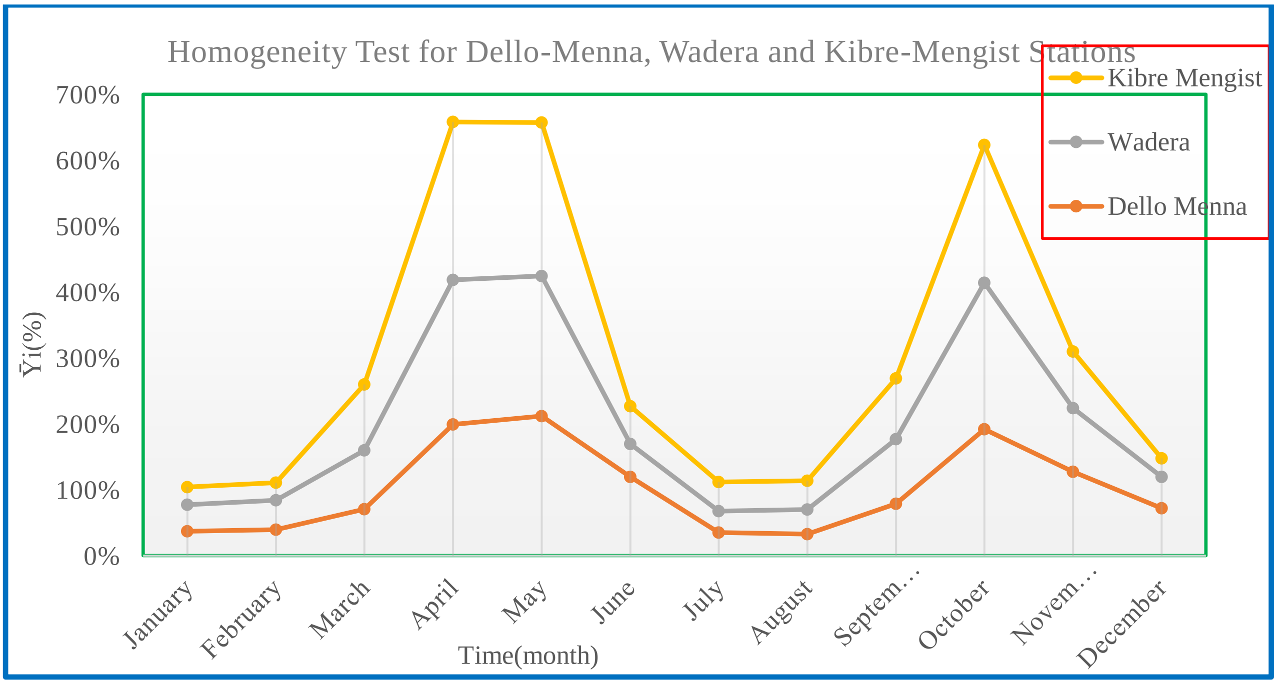
Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10	Column11	Column12	Column13	Column14
Year	January	February	March	April	May	June	July	August	Sebtember	October	November	December	Yearly Mean
1990	0	0	0	16.813333	0.8548387	0	0	0	0	0	9.40666667	2.71612903	2.48258065
1991	0	0	0	0	14.877419	5.8066667	0	0	0	11.683871	4.56	0	3.07732975
1992	0	0	0	0	11.467742	4.4766667	0	0	0	10.0903226	3.94	0	2.49789427
1993	0	0	0	22.286667	45.541935	14.45	0	0	0	11.683871	4.56	0	8.21020609
1994	0	0	0	8.3133333	22.196774	7.4233333	0	0	0	0	0	0	3.16112007
1995	0	0	2.4677419	29.916667	11.512903	0.17	0	0	0	17.8548387	6.97	0	5.74101254
1996	0	0	0	25.8	35.564516	10.03	0	0	0	6.02580645	2.35333333	0	6.64780466
1997	0	0	0	13.186667	5.0451613	0	0	0	0	17.1290323	26.97	7.76129032	5.84101254
1998	0	0	0	0	11.322581	4.42	0	0	0	13.5	5.27	0	2.87604839
1999	0	0	0	1.79	0.683871	0	0	0	0	3.48387097	1.36	0	0.60981183
2000	0	0	0	0	0	0	0	0	0	14.4451613	5.64	0	1.67376344
2001	0	0	0	0	0	0	0	0	0	4.79032258	1.87	0	0.55502688
2002	0	0	0	0	0	0	0	0	0	23.5032258	1.23333333	0	2.06137993
2003	0	0	0	7.6	1.816129	0.0766667	0	0	0	0	0	0	0.79106631
2004	0	0	0	32.586667	1.6612903	0	0	0	0	0	0	0	2.85399642
2005	0	0	0	0.0966667	19.990323	1.5266667	0.0225806	0	0	0	0	0	1.80301971
Mean	0	0	0.1542339	9.899375	11.408468	3.02375	0.0014113	0	0	8.38689516	4.63333333	0.65483871	3.18019209
Max	0	0	2.4677419	32.586667	45.541935	14.45	0.0225806	0	0	23.5032258	26.97	7.76129032	8.21020609
Min	0	0	0	0	0	0	0	0	0	0	0	0	0.55502688
STDEV.S	0	0	0.6169355	11.938544	13.650561	4.4262856	0.0056452	0	0	7.64333406	6.58311893	2.01252685	2.26199217
CV			4	1.2059897	1.1965288	1.4638398	4			0.91134251	1.42081703	3.07331686	0.71127533

Appendix D: Homogeneity Test Graph for Rainfall

D-1: Homogeneity Test for Worka and Hagere Selam



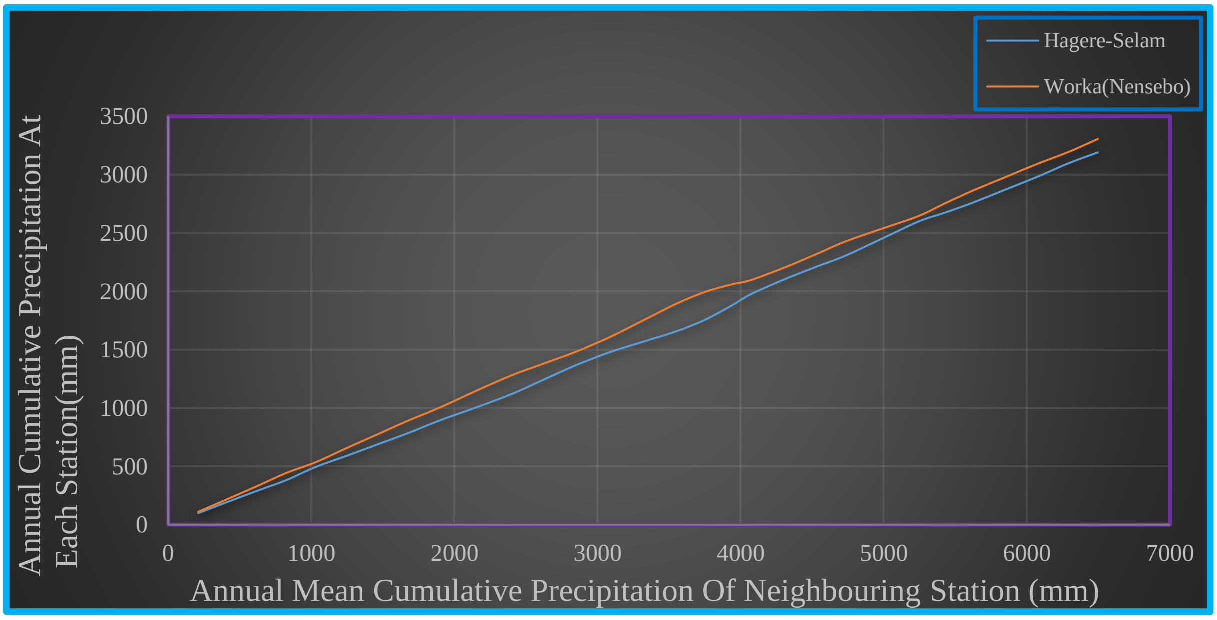
D-2: Homogeneity Test for Kibre-Mengist, Wadera and Dello-Menna.



Appendix E: Double Mass Curve Test for Rainfall Data Consistency

E-1: Checking Consistency of Dello Menna, Kibre-Mengist and Wadera

E-2: Checking Consistency of Worka (Nensebo) and Hagere Selam

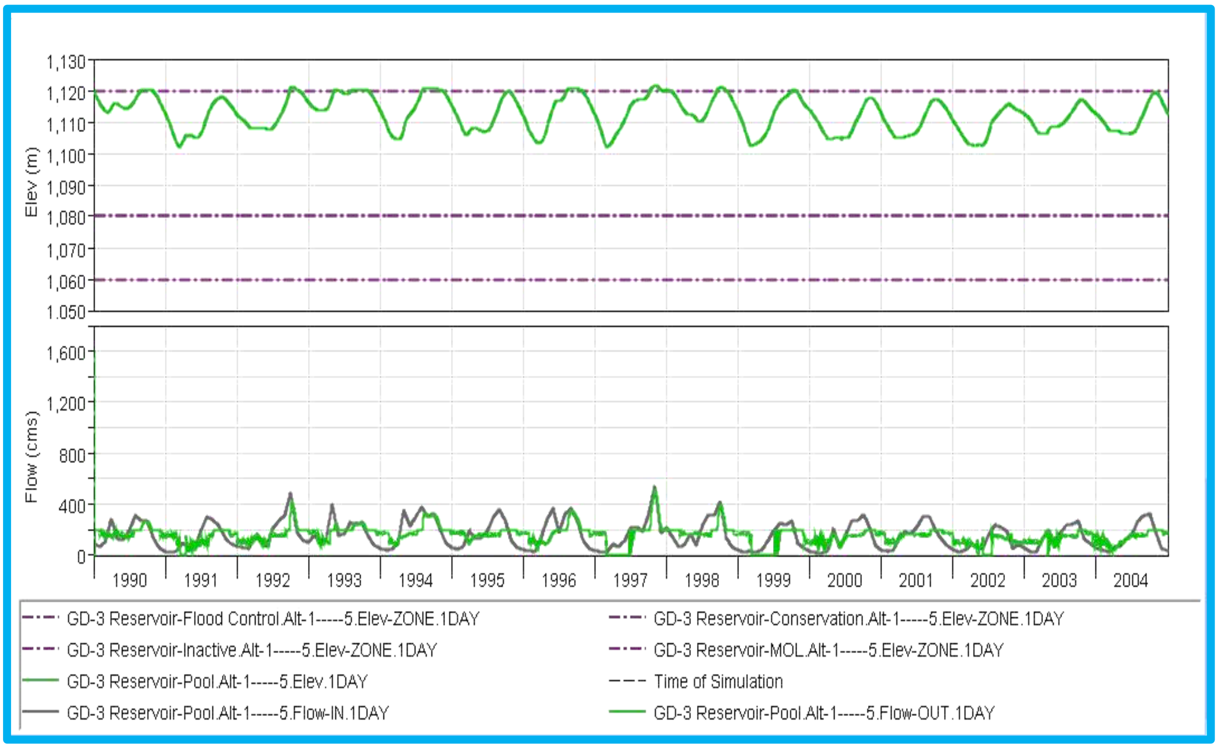


Appendix F: Reservoir and Dam Sailent Features for Proposed Cascade Dam

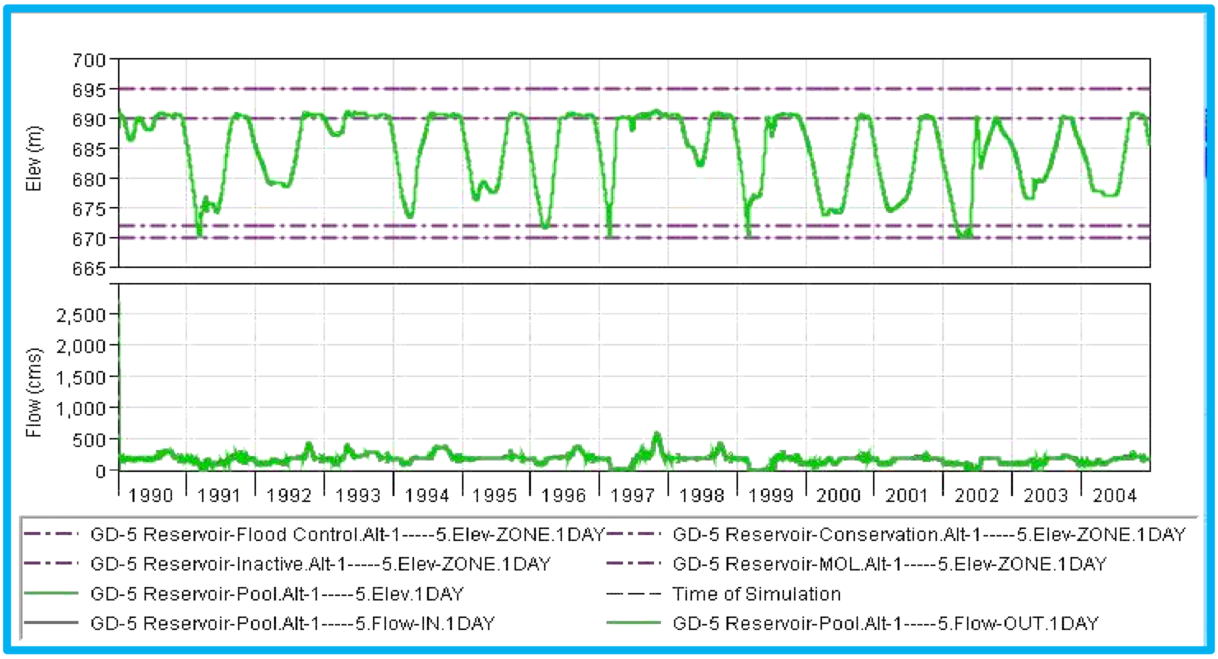
Parameter	Dimension	GD-3	GD-5	GD-6
Main Dam Type	-	**RCC Gravity**	**RCC Gravity**	**RCC Gravity**
Full Supply Level	**Masl**	**1120**	**690**	**585**
Reservoir Area at FSL	**Ha**	**9800**	**706.52**	**810**
Reservoir Volume	**Mm^3**	**2570**	**138.86**	**183.6**
Dam Height	**M**	**110**	**59**	**60**
Crest Length	**M**	**450**	**400**	**650**
Length of Headrace Tunnel	**Km**	**12.402**	**4.65**	**4.7**
Tail Water Level	**M**	**831.9**	**585**	**351**
Average Flow	**m^3/Sec.**	**92.6**	**97**	**102**
Installed Capacity	**MW**	**254**	**146**	**246**
Rated Head	**M**	**254.5**	**83**	**182**
Number of gates	-	**2**	**1**	**1**
Hydraulic Loss	**M**	**12.5**	**2**	**6**
Average Energy	**GWh/year**	**1640**	**715**	**1575**
Primary Energy	**GWh/year**	**1600**	**620**	**1540**

Appendix G: Standard Graphic Plot of HEC-ResSim Model

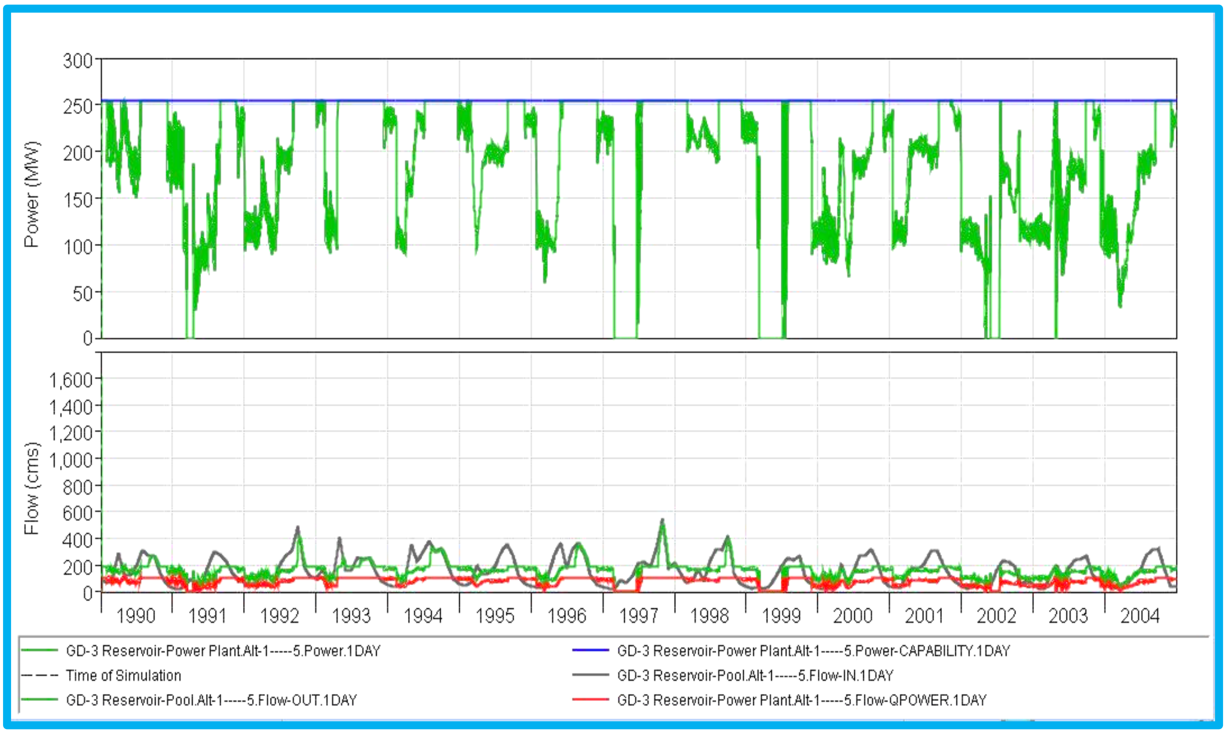
G-1: HEC-ResSim Simulated GD-3 Pool Level, Inflow and Outflow



G-2: HEC-ResSim Simulated GD-5 Pool Level, Inflow and Outflow

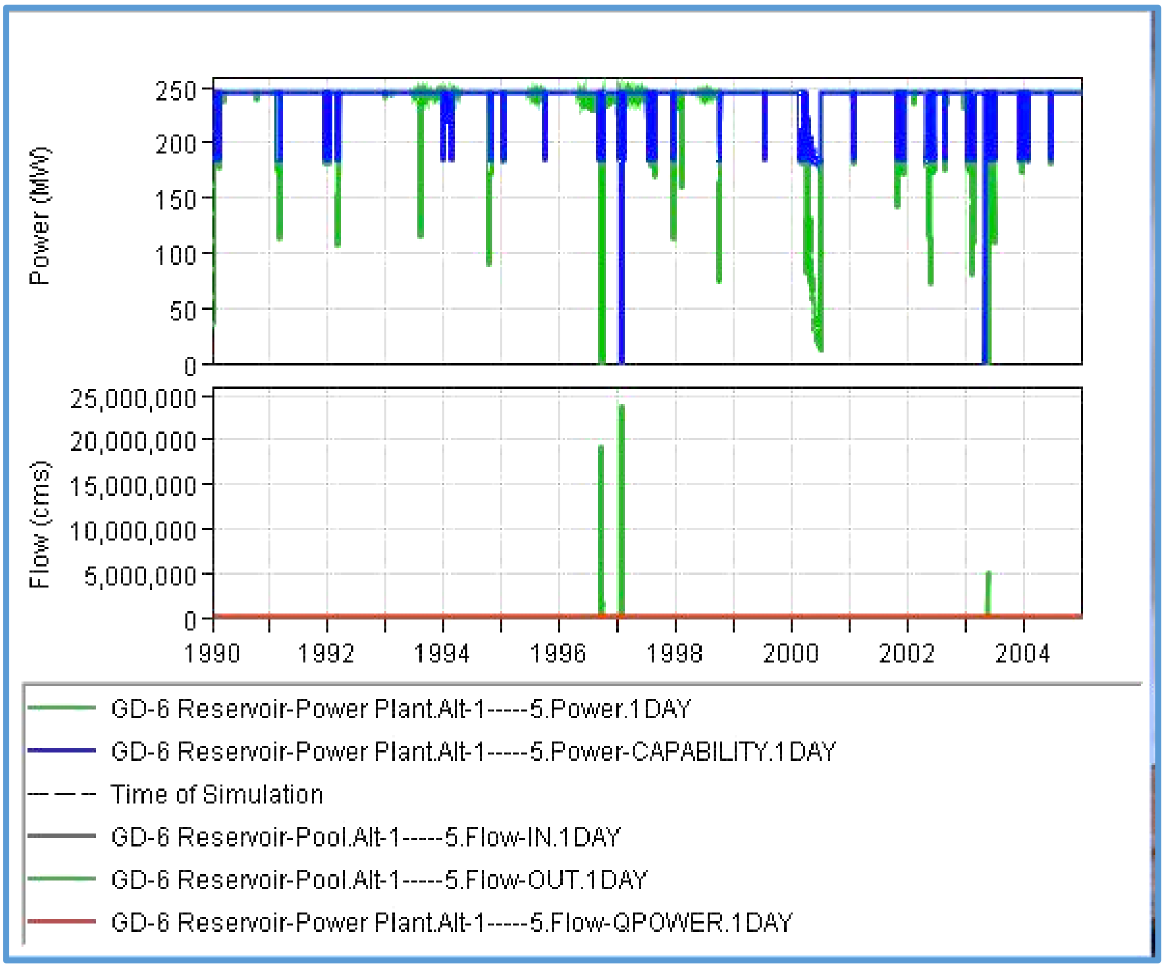


G-3: HEC-ResSim Simulated GD-3 Power Plant Operation



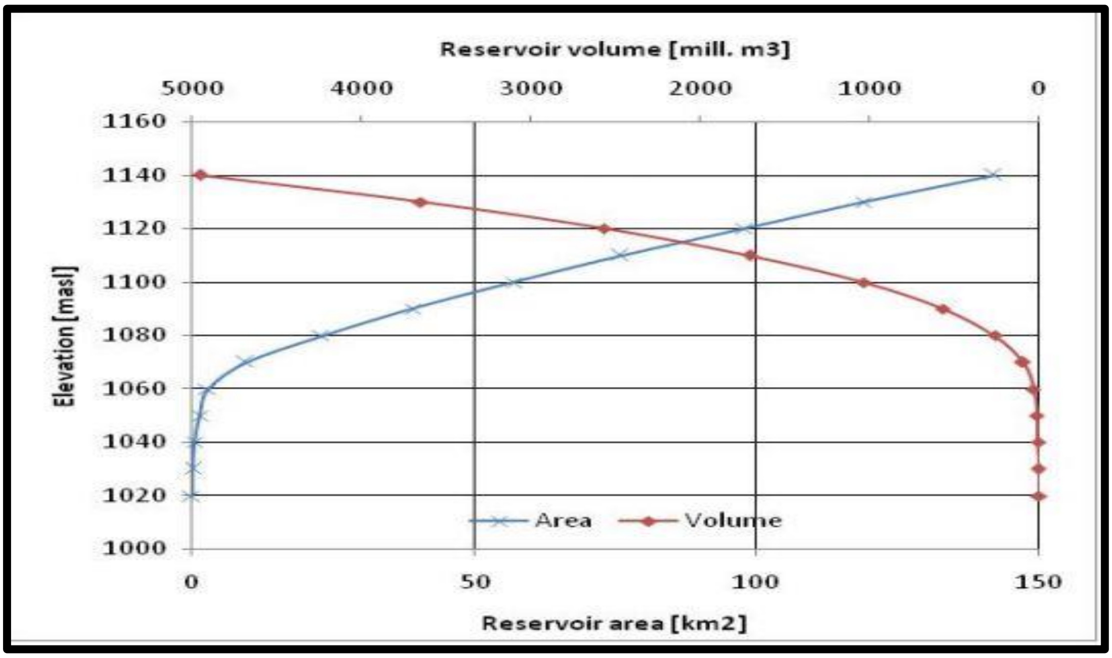
G-4: HEC-ResSim Simulated GD-5 Power Plant Operation

G-5: HEC-ResSim Simulated GD-6 Power Plant Operation



Appendix H: Elevation-Area-Storage Curves for Genale-Dawa Cascade Dams

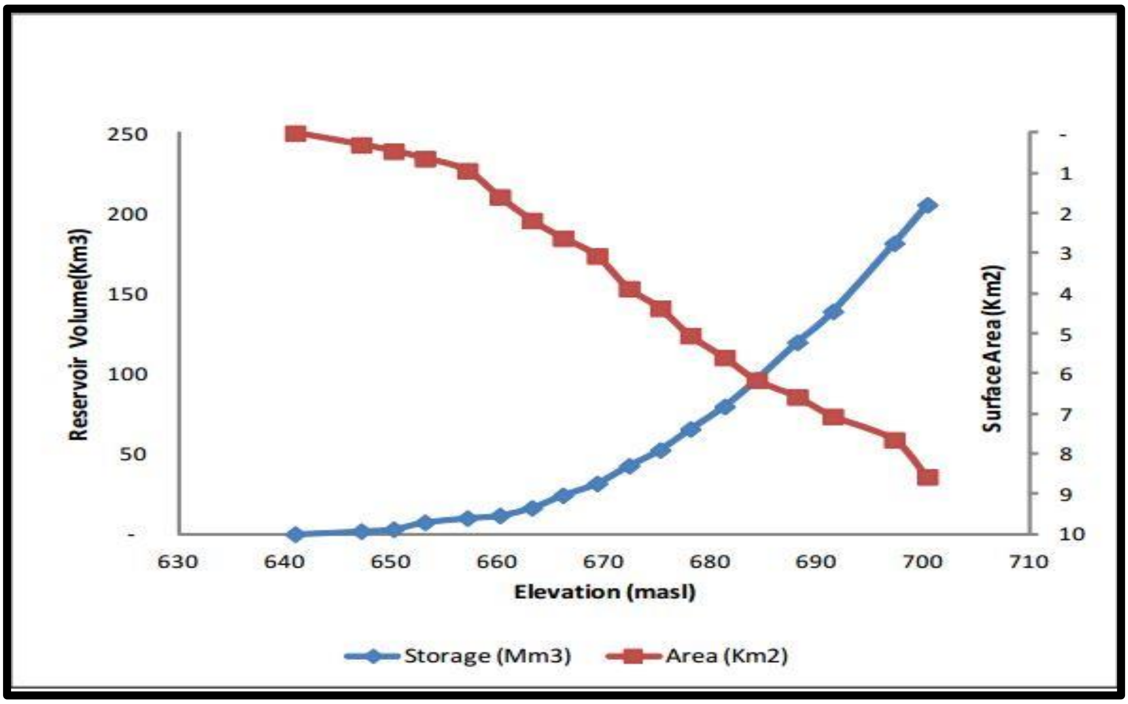
H-1: Elevation-Area-Storage for GD-3



Column1	Column2	Column3
Elevation (masl)	Area (ha)	Storage (Million m3)
522	0	0
525	10	0.3
530	30	1.2
535	50	3.3
540	100	7.1
545	130	12.8
550	170	20.4
555	240	30.7
560	310	44.3
565	390	61.7
570	490	83.6
575	590	110.5
580	720	143.6
585	810	183.6
590	930	227.1
595	1020	275.9
600	1140	330

Sources (GDMP-FS August, 2007)

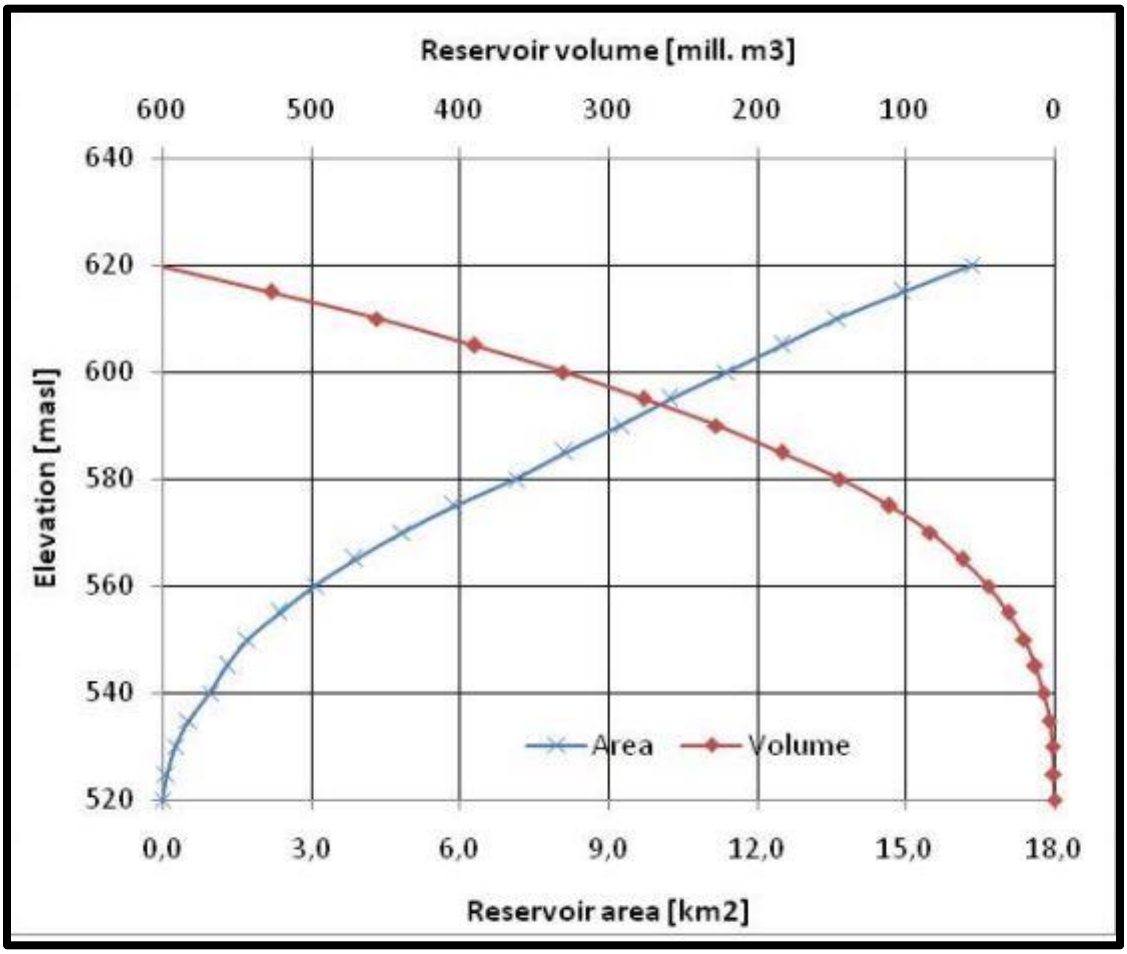
H-2: Elevation-Area-Storage Curves for GD-5



Column1	Column2	Column3
Elevation (masl)	Area (ha)	Storage (Million m3)
640.92	0	0
647.12	29.46	1.86
650.18	45.24	3.05
653.12	63.63	7.36
657.11	93.74	10.02
660.17	159.15	11.68
663.18	217.86	16.35
666.1	262.13	24.24
669.31	306.39	31.59
672.33	388.09	42.64
675.25	436.81	52.44
678.08	505.23	65.56
681.3	559.55	79.54
684.33	616.34	96.4
688.14	658.02	119.61
691.49	706.52	138.86
697.25	765	181.34
700.37	857.21	205.28

Sources (GDMP-FS August, 2007)

H-3: Elevation-Area-Storage Curves for GD-6



Column1	Column2	Column3
Elevation (masl)	Area (ha)	Storage (Million m3)
522	0	0
525	10	0.3
530	30	1.2
535	50	3.3
540	100	7.1
545	130	12.8
550	170	20.4
555	240	30.7
560	310	44.3
565	390	61.7
570	490	83.6
575	590	110.5
580	720	143.6
585	810	183.6
590	930	227.1
595	1020	275.9
600	1140	330

Sources (GDMP-FS August, 2007)