JIMMA UNIVERSITY
SCHOOL OF POST GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDRAULIC AND HYDROLOGY CHAIR
MASTER OF SCEINCE IN HYDRAULIC ENGINEERING

Simulation of Rainfall-Runoff Process Using Hydrologic Engineering Center Hydrological Modeling System in Gojeb watershed

By: Saron Tekuame

A Thesis Submitted to Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering, Hydraulic Engineering Chair in Partial Fulfillment of the Requirements for the Degree of Master of Science in Hydraulic Engineering.

January, 2020
Jimma, Ethiopia

JIMMA UNIVERSITY
SCHOOL OF POST GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDRAULIC AND HYDROLOGY CHAIR
MASTER OF SCEINCE IN HYDRAULIC ENGINEERING

Simulation of Rainfall-Runoff Process Using Hydrologic Engineering Center Hydrological Modeling System in Gojeb watershed

By: Saron Tekuame

A Thesis Submitted to Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering, Hydraulic Engineering Chair in Partial Fulfillment of the Requirements for the Degree of Master of Science in Hydraulic Engineering.

Advisor: Dr.Ing-Tamene Adugna (PHD.)

Co- Advisor: Sewmehon Sisay (MSC.)

January, 2020
Jimma, Ethiopia

DECLARATION

I hereby declare that the Thesis entitled “Simulation of Rainfall-Runoff Process Using Hydrologic Engineering center Hydrological modeling system in Gojeb watershed” is my original work, which I submit for partial fulfillment of the degree of Master of Science in Hydraulic Engineering to school of graduate studies, Hydrology and Hydraulic Engineering Chair, Jimma Institute of Technology, Jimma University.

Saron Tekuame ________________ ______________

Signature Date

APPROVAL SHEET

We certify that the Thesis entitled “Simulation of Rainfall-Runoff Process Using Hydrologic Engineering center Hydrological modeling system in Gojeb watershed” is the work of Saron Tekuame and we here by recommend for the examination by Jimma Institute of Technology in partial fulfillment of the requirements for degree of Masters of Science in Hydraulic Engineering.

Dr.-Ing. Tamene Adugna ________________ ______________
Main-advisor Signature Date

Mr. Sewmehon Sisay __________________ ______________
Co-advisor

As a member of Board of Examiners of the MSc. Thesis open Defense Examination, We certify that we have read, evaluated the Thesis prepared by Saron Tekuame and examined the candidate. We recommended that the Thesis could be accepted as fulfilling the Thesis requirements for the Degree of Masters of Science in Hydraulic Engineering.

_____________________ _______________
External Examiner Signature Date

_____________________ _______________
Internal Examiner Signature Date

_____________________ _______________
Chair holder Signature Date

_____________________ _______________
Chair Person Signature Date

ACKNOWLEDGEMENT

First, I would like to thank the Almighty God for giving me the chance to study this program. My deepest gratitude goes to my advisor Dr.Ing. Tamene Adugna and my co-advisor Mr. Sewmehon Sisay for all their limitless efforts in guiding me through out my work and for providing me useful reference materials.

Without the support of my family especially my husband, friends and my senior staff members, this work is not realized; I would like to pass my acknowledgement for those who give me direction and support.

Finally, my deepest appreciation goes to Jimma University, Jimma Institute of Technology, Civil and Environmental Engineering Faculty, Hydraulics and Hydrology chair for allowing me to attend this post graduate program.

ABSTRACT

Rainfall was the main source for generation of runoff, which flows through Rivers and streams. The study was conducted in Gojeb River. In this area, there is lack of planning and inadequate water resources management. Therefore, the main objective of this study was simulation of rainfall runoff processes using Hydrologic Engineering Center Hydrological Modeling System (HEC-HMS) model. The data used were meteorological data from (2002-2014), Stream flow data from (2002-2014), Digital Elevation Model (DEM), Soil and Land use/land cover. The data were collected from National Meteorological Agency of Ethiopia and Ministry of Water, Irrigation and Electricity. After data collection, the missing data were filled by using Arithmetic Mean method and the consistency of data was checked by using double mass curve. The point rainfall data was changed to areal rainfall using Thiessen polygon. By using Hydrological Engineering Center Geospatial Hydrologic Modeling System (HEC-GeoHMS), basin model was generated which is imported to HEC-HMS. Using DEM, soil data and land cover data curve number for each sub basin was also computed using HEC-GeoHMS and the methods for determination of loss, transformation, channel routing and base flow SCS loss, SCS unit hydrograph. Muskingum and monthly constant methods was selected respectively. For this study, there are five watershed parameters available these are curve number, initial abstraction, lag time, time of passing of a wave (k) and Muskingum coefficient(x). By using these initial values of parameter, the first run was conducted and there is a variation between simulated and observed flow. Therefore, calibration was done using optimization. The result indicates that the wave travel time and channel storage coefficient are the most sensitive parameters. After calibration, there was an agreement between the simulated and observed flow. The model performance evaluation was conducted using percentage error in simulated volume (PEV), percentage error in simulated peak (PEP), Nash-sutcliffe efficiency (NSE) and coefficient of determination (R^2). In calibration (PEV=16%, PEP=10.3%, NSE=0.810, R2=0.866 and PBIAS=16.44%) and for validation (PEV=23%, PEP=3.9%, NSE=0.55, R2=0.728 and PBIAS=22.9%). These values were in the range of very good, good and satisfactory therefore, the model was adopted for runoff simulation on Gojeb watershed. In the watershed, the peak flow during calibration and validation was116.5m3/sand 85.9m3/s respectively. The total runoff volume of the watershed was 1700.8mm. Determination of stream flow from the watershed is required for policy makers to make decisions on water planning and management. This study can be used as reference or benchmark for any other future studies that will be conducted.

Key words: *Gojeb River, HEC-HMS, Model Calibration, Model Validation, Rainfall- Runoff*

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
HBV	Hydrologiska Byråns Vattenbalansavdelning
HSPF	Hydrological Simulation Program Fortran
HEC-GeoHMS	Hydrological Engineering Center's Geospatial Hydrologic
HEC HMS	Hydrological Engineering Center Hydrological Modeling System
HEC RAS	Hydrological Engineering Center River Analysis System
HSG	Hydrological Soil Group
MIKE11/SHE	MIKE System Hydrologique European
MARE	Mean Absolute Relative Error
MoWIE	Ministry of Water, Irrigation and Electricity
NMAE	National Meteorological Agency of Ethiopia
NWSRFS	National Weather Service River Forecast System
NSE	Nash Sutcliff Efficiency
PEV	Percentage Error in Simulated Volume
PEP	Percentage Error in Simulated Peak
PWRMSE	Peak Weighted Root Mean Standard Error
REP	Relative Error in peak
REV	Relative Error volume
R^2	Coefficient of Determination
SCS CN	Soil Conservation Service Curve Number
SCS UH	Soil Conservation Service unit Hydrograph
SMA	Soil Moisture Accounting
SWAT	Soil and water Assessment Tool
TOPMODEL	Topography Based Hydrological Model

USACE	United States Army Corps of Engineers
WMS	Watershed Model System
WATBAL	Water Balance Model
WATFLOOD	Waterloo and Flood Forecasting

1. INTRODUCTION

1.1 General Background

Runoff is the portion of rainfall, which runs across the land surface into surface waters like streams, rivers, lakes or other reservoirs. There are factors that affect the runoff such as type of precipitation, Rainfall intensity, Duration of rainfall, Rainfall distribution, Direction of prevailing wind, other climatic factors, Physiographic factors, Orientation of watershed and Topographic Characteristics of the area. Runoff is one of the important hydrologic parameter used in the watershed management. The surface runoff generated from the catchment was estimated based on the rainfall intensity and major characteristics of the catchment area; Watershed management is really an important subject, which is helpful in future planning of Hydro projects and natural resources management (Praveen et *al*., 2015).

Assessment of the surface runoff, which mainly depends on the meteorology, topography, geology, and soil and land use pattern, is required for proper planning of the hydraulic structures as well as mitigation of Natural hazards in the area (Kishanlal *et al*., 2019).

Adequate knowledge of rainfall-runoff processes is vital to estimate the amount of runoff produced within a given catchment. Knowing the amount of runoff within a given catchment is important for sustainable water resources project planning and management. The activities to estimate runoff volumes can be easily simplified by adopting a modeling concept and by understanding rainfall partitioning and the principal factors triggering runoff (Bitew *et al*., 2019).

There are range of methods available to estimate stream flow from catchments, using observed data wherever possible, or using empirical and statistical techniques to estimate river discharge, more commonly known as rainfall-runoff models (Jeevika & Jagritee, 2018).

A runoff model helps to visualize the response of water systems due to changes in the land-use and meteorological events. Physical processes that convert rainfall to runoff with set of equations by employing various parameters that describes the catchment. Modeling surface runoff is challenging as the calculation involves complexities with many interconnected variables (Jeevika & Jagritee, 2018).

Depending on input variables, Hydrologic models are classified into three part. This are lumped, semi distributed and distributed, parameter of lumped models do not vary spatially with in the basin and basin response is evaluated only at the out let. Distributed model parameters can easily vary in space at the desired resolution based on preference of the user and it requires large amount of input parameters. Semi distributed parameters are simplified distributed and partially allowed to vary in space by dividing the basin into a number of smaller sub basin. It requires less input data. Example of semi-distributed models are HEC-HMS, SWAT (Sitterson *et al*., 2017).

Hydrologic models also divided into event-driven (short-term) models and continuous-process models. Event models are designed to simulate individual precipitation-runoff events. Their emphasis is placed on infiltration and surface runoff. Typically, event models have no provision for moisture recovery between storm events and, dry event therefore, they are not suited for the simulation of dry-weather flows. Continuous-process models simulate instead a longer period, predicting watershed response both during and between precipitation events. They are suited for simulation of daily, monthly or seasonal stream flow, usually for long-term runoff-volume forecasting and for estimates of water yield (Cunderlik & Simonovic , 2007).

The measurement of all parameters that affect watershed's runoff is impossible therefore, choosing a suitable model with simple structure, minimum input data requirements and reasonable precision is essential (A. Majidi & K. Shahedi, 2012). Therefore, for this study HEC-HMS was selected to simulate rainfall –runoff in Gojeb River because the model requires minimum input data.

1.2 Statement of the Problem

Now a days, climate change in the world increases due to different factors like rapid urbanization, deforestation, mineral exploitation, industrialization, and Agricultural expansion. This condition would affect the distribution of precipitation and the intensity or frequencies of hydrologic event. In the study area, particularly, deforestation and expansion of Agricultural was adopted. Therefore, effective water resources management requires a proper estimation of availability of water, which can be achieved by using hydrological modeling of the basin (D. Roy *et al*., 2013). In the study area, lack of planning and inadequate water resources management (Misganaw & Aramde, 2019).

Therefore, adequate knowledge of runoff within a given catchment is important for the planning and designing of many water resources development and related projects (Melesse, 2018).

In many cases, poor land-use planning and land management practices during rapid development have adversely impacted on surface runoff quantities and quality through the reduction of land cover, loss of plant nutrients, deterioration of river water quality and an increase of impervious surface area (Kishor *et al*., 2014). Therefore, a major challenge remaining is the accurate prediction of catchment runoff responses to rainfall events (Udhavrao, 2014).

1.3 Objective

1.3.1 General Objective

The general objective of this study is to simulate rainfall-runoff processes and analysis by using HEC-HMS model in Gojeb watershed.

1.3.2 Specific Objective

In order to attain the general objective of the study, the following specific objectives were set out for major indicators of this study:-

- To evaluate the performance of HEC-HMS in runoff simulation of Gojeb watershed.
- To estimate the runoff potential of the watershed.
- To assess the spatial distribution of runoff in Gojeb watershed.

1.4 Research Question

- Does HEC HMS used to evaluate runoff simulation of Gojeb watershed?
- How much is the potential of runoff in the watershed?
- What is the distribution of runoff in Gojeb watershed?

1.5 Scope of the study

The study was conducted in Gojeb watershed, which is the part of upper omo gibe river basin. The study includes the determination of runoff volume and peak discharge by using HEC-HMS model. Showing the performance of the model with in Gojeb watershed and spatial distribution of runoff for each sub basin with in a watershed.

1.6 Significance of the study

The major significance of this study is to provide useful data about runoff in the watershed and peak flow of the river. Governmental and nongovernmental organizations, who plan to construct structures in the watershed, use this data for their design or construction in the future. Therefore, it is important to use hydrological model to assess and predict the water availability of watershed to develop the strategies. Hence, a proper understanding of the rainfall- runoff relation at different catchment level of the upper Omo River basin help to study water balance, water resources management, soil and water conservation measures, design of hydraulic structures (hydropower and irrigation projects) and flooding control of the basin. The research will also add its own value for researches of related topics being as a reference and indicator for further study.

1.7 Limitation

For conducting hydrologic study by using hydrological model, long recorded hydro metrological data was the basic input. For the study there was 31 years of metrological data was available which is important but, stream flow data of the watershed outlet at chida station have only 13 years of data. Therefore, the study was conducted by using these 13 years of both hydro-metrological data. In HEC-HMS for simulating rainfall-runoff using hourly recorded data was efficient than using daily time serious data but there is no data available which is recorded hourly.

2. LITERATURE REVIEW

2.1 Hydrologic cycle

Rainfall-runoff modeling requires a brief understanding of the hydrological cycle, since rainfall and runoff are the most important components in this process.

The cycle has no beginning or end, and its processes occur continuously. The general processes take place in the operation of hydrological cycle are water evaporates from the oceans and the land surface to become part of the atmosphere. Then water vapors was transported and lifted in the atmosphere until it condensed to precipitates on the land or on the ocean's surface.

The Precipitated water may intercepted by vegetation to become over land flow over the ground surface or Infiltrated into the ground, flow through the soil as subsurface flow, and discharge into streams as surface runoff. Much of the intercepted water and surface runoff returns to the atmosphere through evaporation. The infiltrated water may percolate deeper to recharge groundwater, later emerging in springs or seeping into streams to form surface runoff, and finally flowing out to the sea or evaporating into the atmosphere as the hydrologic cycle continue (Ven Te Chow *et al*., 1988).

2.2 Rainfall-Runoff Relationship

Determination of surface runoff in a watershed based on the rate of received precipitation and quantifying discharge at outlet is important in hydrologic studies. The relationship between rainfall and runoff is essential in a catchment for hydrologic analysis and design. After water-loss caused by interception, infiltration, evaporation and transpiration, the remaining rainfall will change to surface-runoff, interflow and base-flow (Chang & Chi-Wen, 2009).

Rainfall runoff process involves in many parameters either it may be physical features of the catchment or climatological parameter. In the real world, system rainfall -runoff process was influenced by each physical characteristics of catchment and to generalize all physical characteristics of the catchment is really a difficult task (Praveen *et al*., 2015). Input data are a major source of uncertainty for rainfall-runoff models because they rely heavily on input data and physically based parameters (Pechlivanidis *et al*., 2011).

Effective estimation of runoff values and groundwater recharges from a rainfall event helps in development of all water resources projects i.e. storage reservoirs of surface water, design of hydraulic structures and flood protection structures, hydropower and irrigation projects (Sonu & Kumar, 2017). However, improper estimation of runoff in basins causes some problems in optimum management of water resources and reservoir dams (Vidyapeeth, 2014)

2.3 Hydrological Models

Hydrological modeling is a commonly used tool to estimate the basin's hydrological response due to precipitation (Halwatura & Najim, 2013)**.** Hydrological models have been used in different River basins across the world for better understanding of the hydrological processes and the water resources availability. Currently it is important to use hydrological model to assess and predict the water availability of river basins due to climate change to develop a strategies in order to cope up with the changing environment (Gebre, 2015).

Hydrological modeling is a widely used technique to define the hydrological response of a watershed due to precipitation and other hydrological parameters (Sonu & Kumar, 2017). The hydrographs produced by program use directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation (Sardoii *et al*., 2012).

Hydrological modeling and its operations require a larger set of temporal and spatial data (topographic data, land use/cover, soil, and rainfall and flow data). Indeed, the accessibility and accuracy of this data usually becomes a concern to cope with and this puts a more considerable effect on the precision of model. Due to lack of data accuracy, efficiency of the model is compromised for hydrological model simulation and its operations like calibration and validation (Sonu & Kumar, 2017).

2.3.1 Types of Hydrological Models

Hydrological models are classified based on model input and parameters and the extent of physical principles applied in the model. The spatial structure of catchment processes in rainfall-runoff models can be categorized as lumped, semi-distributed, and fully distributed.

Lumped models treat the catchment area as a single homogenous unit with state variables, which represent averages over the catchment area such as average storage in the saturated zone (Rinsema *et al*., 2014). The model Parameters do not vary spatially within the basin & response is evaluated only at the outlet, without explicitly accounting for the response outlet and without explicitly accounting for the response of individual sub basins. Examples of lumped model are. SCS-CN based models, HAC RES and WATBAL.

Distributed runoff models are the most complex because they account for spatial heterogeneity in inputs and parameters. Fully distributed models separate the model process by small elements or grid cells (Sitterson *et al*., 2017).Examples of Distributed model are WMS, HYDROTEL, MIKE11/SHE and WATFLOOD.

Semi-distributed models' Sub-areas represent important features in a catchment and combine advantages of lumped and distributed model (Pechlivanidis *et al*., 2011). The semi-distributed model, which is partly permitted to change in space with a division of the catchment into a number of sub-basins. Examples of Semi-distributed model are HEC-HMS, SWAT, TOPMODEL, HBV and HSPF.

Semi-distributed models developed for a runoff estimation based on the data availability and complexity of the hydrological systems (Bitew *et al*., 2019). If the input include both lumped and distributed parameters, the model is semi-distributed. Most models are semi-distributed because of data availability, and range in the spectrum between lumped and distributed models (Sitterson *et al*., 2017).

Depending on the structure of model in-and output model divided in to Deterministic and stochastic models. Deterministic models permit only one outcome from a simulation with one set of inputs and parameter values. Stochastic models allow some randomness or uncertainty in the possible outcomes due to uncertainty in input variables, boundary conditions or model parameters (Rinsema *et al*., 2014)

Empirical models have allowed them to be applied relatively easily to ungauged catchments by regional analysis, relating (parsimonious) model properties (that is: unit hydrograph time to peak, percentage runoff) to physical and climatic descriptors of the catchment (Wheate *et al*., 2011).

These are observation-oriented models, which take only the information from the existing data without considering the features and processes of hydrological system, and hence these models are called data driven models. It involves mathematical equations derived from concurrent input and output time series and not from the physical processes of the catchment (Devia *et al*., 2015).

Conceptual based models have a conceptual idea of the behavior of the soil and runoff in a catchment. They have to be calibrated for a single catchment. Data driven models are employed if there is not enough data available. The behavior is estimated based on data collected from satellites and fieldwork on the ground (Rinsema *et al*., 2014). Conceptual models are best used when computation time is limited and catchment characteristics are not analyzed in detail. TOPMODEL, HBV, NWSRFS and HSPF are some examples of conceptual models (Sitterson *et al*., 2017).

Empirical and conceptual models are usually run spatially as lumped. Due to many assumptions and averaged conditions that lumped models incorporate, they do not represent large watersheds and catchments accurately (Sitterson *et al*., 2017).

Physically based models are based on the physical characteristics of the catchment. The physical characteristics focus on the more physical aspects of the catchment and try to estimate for each grid of the catchment (Rinsema *et al*., 2014). In this method huge amount of data such as soil moisture content, initial water depth, topography, topology and dimensions of river network are required. Physical model can overcome many defects of the other two models because of the use of parameters having physical interpretation (Devia *et al*., 2015).

The HEC-HMS model is physically based and semi-distributed model designed to simulate rainfall-runoff processes in a wide range of geographic areas, from large river basin water supplies and flood hydrology to small urban and natural watershed runoffs (Bitew *et al*., 2019).

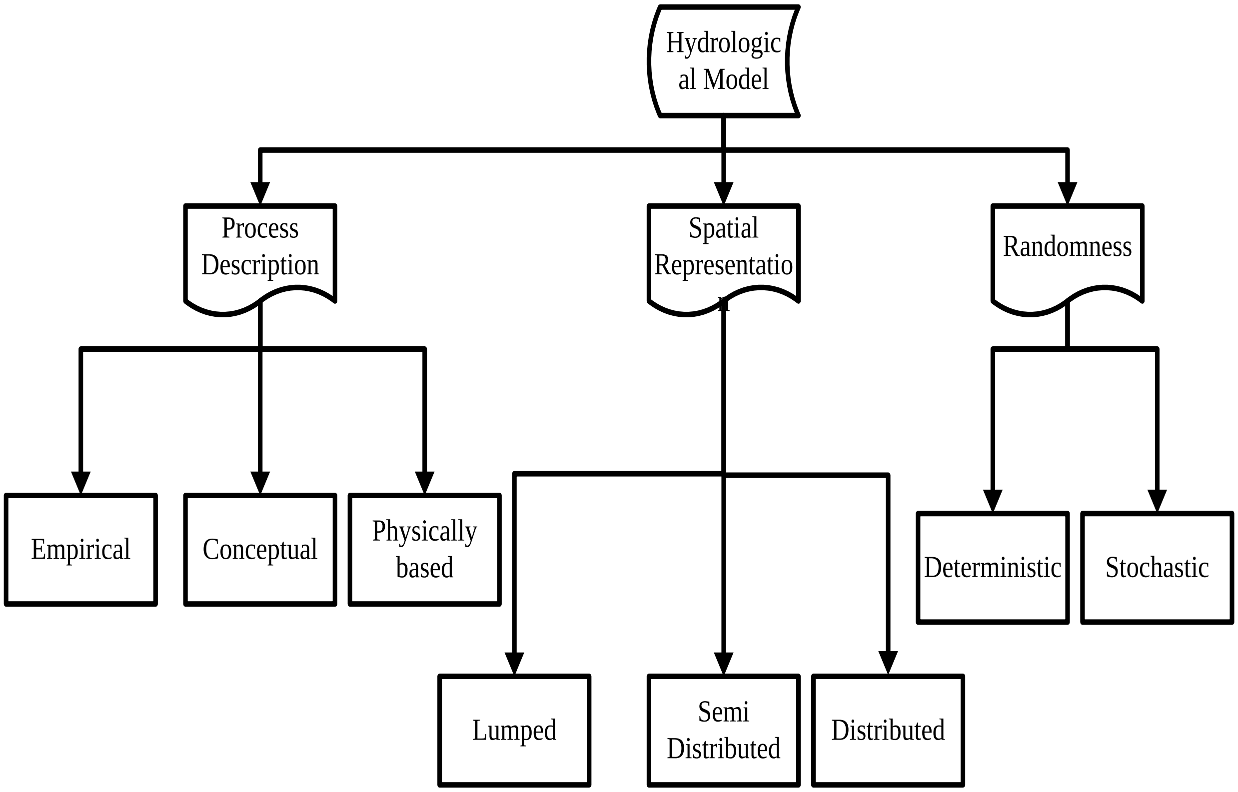


Figure 2.1: Classification of Hydrologic Model

2.3.2 Selection of hydrologic model

Selecting the best and appropriate model is an essential part in any research work. There are various criteria for choosing the most suitable model. According to (Cunderlik & Simonovic , 2007). The choice depends mainly on the requirement and needs of the research or project under interest. The criteria for choosing the most suitable model are required output of the model, availability of input data, prices and availability of the model, the model structures and Hydrologic processes that need to be modeled to estimate the desired output adequately.

2.4 HEC-HMS Model Setup

HEC-HMS model is a popularly used watershed model to simulate rainfall runoff process (Kishor *et al.*, 2014). It has been widely applied for humid, tropical, subtropical, and arid watersheds to simulate and forecast streamflow (Abushandi & Merkel, 2013).

HEC-HMS is widely used as a rainfall- runoff-modeling tool for various purposes, such as climate changing effects in catchment scale, land use effects on stream flow (Jaewon *et al.*, 2014).

HEC-HMS has designed based on simulation of rainfall-runoff in watersheds that can solve different problems using graphical interface (Sardoii *et al*., 2012). The HEC-HMS model's performance on a different storm event could negatively affect the results when applying the same values of physical parameters. These parameters cannot be taken as constant or identical for every kind of storm (Abushandi & Merkel, 2013).

The system encompasses losses, runoff transform, open channel routing, and analysis of meteorological data, rainfall-runoff simulation and parameter estimation. HEC-HMS uses separate models to represent each component of the runoff process, including models that compute runoff volume, models of direct runoff, and models of base flow. Each model run combines a basin model, meteorological model and control specifications with run options to obtain results (Choudhari *et al*., 2014).

2.4.1 Modeling Rainfall Losses

HEC–HMS offers a number of different methods to compute infiltration loss such as the deficit and constant method, the exponential method, the Green and Ampt method, the initial and constant method, the Soil Conservation Service curve number method, and the soil moisture accounting method (Halwatura & Najim, 2013). The deficit constant loss method uses a single soil layer to account for continuous changes in the moisture content. It can be used in combination with a meteorological model that computes evapotranspiration (Halwatura & Najim, 2013).

Gridded Loss Methods and Soil Moisture Accounting Loss Methods are not preferred for the simulation studies because they require a high number of parameters (Halwatura & Najim, 2013). The simplest one "Initial and Constant Loss" method is selected for the event based simulation studies. Green & Ampt infiltration model is a conceptual model in HEC-HMS that calculates precipitation loss in permissible surfaces in specific period. (Sardoii *et al*., 2012). The Green and Ampt method assumes that the initial soil moisture content is uniform and accounts for ponding on the surface.

The implementation of the Green and Ampt method requires knowledge of the soil type of the sub basin. Thus, the Green and Ampt method was utilized in the event-based modeling (Silva *et al*., 2014).

2.4.2 Modeling Direct Runoff

With respect to the transform options of excess rainfall into runoff, HEC–HMS includes several unit hydrograph methods, such as the Clark unit hydrograph method, the kinematic wave method, the SCS unit hydrograph method, and the Snyder unit hydrograph method (Silva *et al*., 2014). The Clark unit hydrograph method requires a small number of parameters, namely, time of concentration and storage coefficient. It was selected for both event-based and continuous simulations (Silva *et al*., 2014). SCS unit hydrograph method is more reliable in calculating the rate of runoff regarding the importance of peak flows in the design of watershed structures, dams and in planning related to soil and water conservation measures (Majidi & Shahedi, 2012).

2.4.3 Modeling Base Flow

Three alternative base flow methods are available in HEC–HMS there are the constant monthly base flow the linear reservoir method, and the recession base flow method. Among these methods, the recession base flow method was employed for both event-based and continuous simulations because the recession method produced the best fit against observations. The recession base flow method is designed to approximate the typical behavior observed in watersheds when the channel flow recedes exponentially after an event (Silva *et al.,* 2014).

2.5 HEC-GeoHMS

The hydrologic models was generated with the help of HEC-GeoHMS using Digital Elevation Model of the study areas. The DEM was a fundamental dataset used for development of the basin model component in the HEC HMS model (Martin, 2012). By Using DEM and terrain, data HEC-Geo HMS produces a stream network, sub-basin boundaries, and connectivity of various hydrologic elements in Arc GIS.

2.6 Previous Studies

Ayenew (2008) Developed rainfall runoff model for sustainable water resource management as a case study of Gumara watershed. The main objective of the research was developing rainfall runoff model in order to predict and forecast storm events so that water resources are managed properly. HEC-HMS hydrological model was used by integrating GIS and remote sensing techniques for rainfall-runoff estimation from the watershed. The runoff volume was determined using SCS-CN method and model was found to be most sensitive to rainfall input and curve number. However, the result indicated unsatisfactory correlation coefficient between observed and simulated flow (R^2 =0.498). The authors finalized the research by concluding data scarcity (2001-2005) made calibration difficult to fit the model with observed value.

Gebre (2015) Developed runoff simulation for upper Blue Nile River basin by using HEC-HMS Model. According to the author, deficit and constant loss method, synder unit hydrograph method and exponential recession method, are the best-fit performed methods of the hydrological processes of infiltration loss, direct runoff transformation and base flow part respectively. The model performance was tested for each catchment in simulation. The runoff flow during calibration and validation period, The ENS and R^2 used to evaluate the performance of the model. The author has concluded that, the results obtained are satisfactory and accepted for simulation of runoff.

Assefa *et al.,* (2008) developed flood forecasting and early warning model for Lake Tana sub basin. The study was aimed to set up flood forecasting model for Gumara and Rib catchments and verify the accuracy. The rainfall-runoff model was integrated with HEC-HMS for Gumara and Rib using soil moisture accounting model-to-model soil loss, Clark unit hydrograph for direct runoff, linear reservoir model for base flow and Muskingum–Cunge routing model components. Model validation showed good model performance. It noted that simulated stream flow were higher than observed value for validation period and seasonality, spatial variability of rainfall soil/land use heterogeneity were identified to be possible source of error in the hydrological modeling. The authors concluded that HEC-HMS continuous hydrologic simulation has good performance for hydrological modeling in Gumara watershed.

Bitew (2019) studied by using HEC-HMS Simulate Flow in the Lake Tana Basin. This study demonstrated that the HEC-HMS hydrological model is adaptable to tropical conditions. The rainfall-runoff simulation was conducted using extreme rainfall events and for knowing the loss, runoff estimation, and flow routing, SCS-CN, SCS-UH and Muskingum methods were used respectively. Overall performance of the HEC-HMS model was very good in terms the model validation results showed a reasonable difference in peak flow (REP = 1.49%) and total volume (REV = 2.38%). based on the result the author concluded that the model is appropriate for hydrological simulations in the Gilgel Abay Catchment.

Melesse (2018) studied the applicability of Semi-Distributed Hydrological Model for watershed scale runoff estimation in Northwest Ethiopia at one of the catchments in Abbay River (upper Blue Nile River) basin. In this study, two loss methods such as SCS and initial and constant methods with two transform methods including SCS and Clark unit hydrographs were considered in the study for selecting the best combinations applicable in the area. The authors concluded that results were obtained by using initial and constant loss method and SCS unit hydrograph better than initial and constant with Clark's unit hydrograph, and it can be used for similar ungagged watersheds.

Arega (2018) studied the evaluation of impacts of climate change on surface water potential of Borkena River. The study used high-resolution dynamical downscaled climate data and new climate scenarios. HEC-HMS used to examine the effect of climate change on stream flow. The hydrological model calibrated from 2003 to 2010 and validated from 2011 to 2015. The performance of the model assessed by Nash-Scatilffe, coefficient of determination and relative volume error (RVE = 4.0% & -13%) during calibration and validation process respectively. The authors concluded that impact of climate change analysis was controlled on surface water potential (runoff volume) in hydrological model.

Previous studies on HECHMS proved its ability to simulate and forecast streamflow based on different datasets and catchment types in Ethiopia. In Gojeb watershed different studies was undertaken, like impact of land use/land cover change on the stream flow and sediment of Gojeb watershed using SWAT (Misganaw & Aramde, 2019). Despite the different modelling activities that are practiced in the watershed, the HEC-HMS model was not tested, calibrated, and validated in Gojeb wateshed.

3 MATERIALS AND METHODS

3.1 Description of the study area

This study was conducted in south western part of Ethiopia in Gojeb River, which is one of sub basin of Omo- Gibe river basin. Omo-Gibe river basin is located between 4°0’0”N to 9°0’0’’ N latitude and 35°0’0’’E to 39°0’0’’E longitude in south western part of the country which covers the total area of about 79,000 km^2 including the selected study area of Gojeb river catchment. The geographical location of Gojeb river catchment is in between 7°0′0’’N to 8°0′0’’N latitude and 35°50′0’’E to 37°30′0’’E longitude and covers the total area about 6667.32km^2.

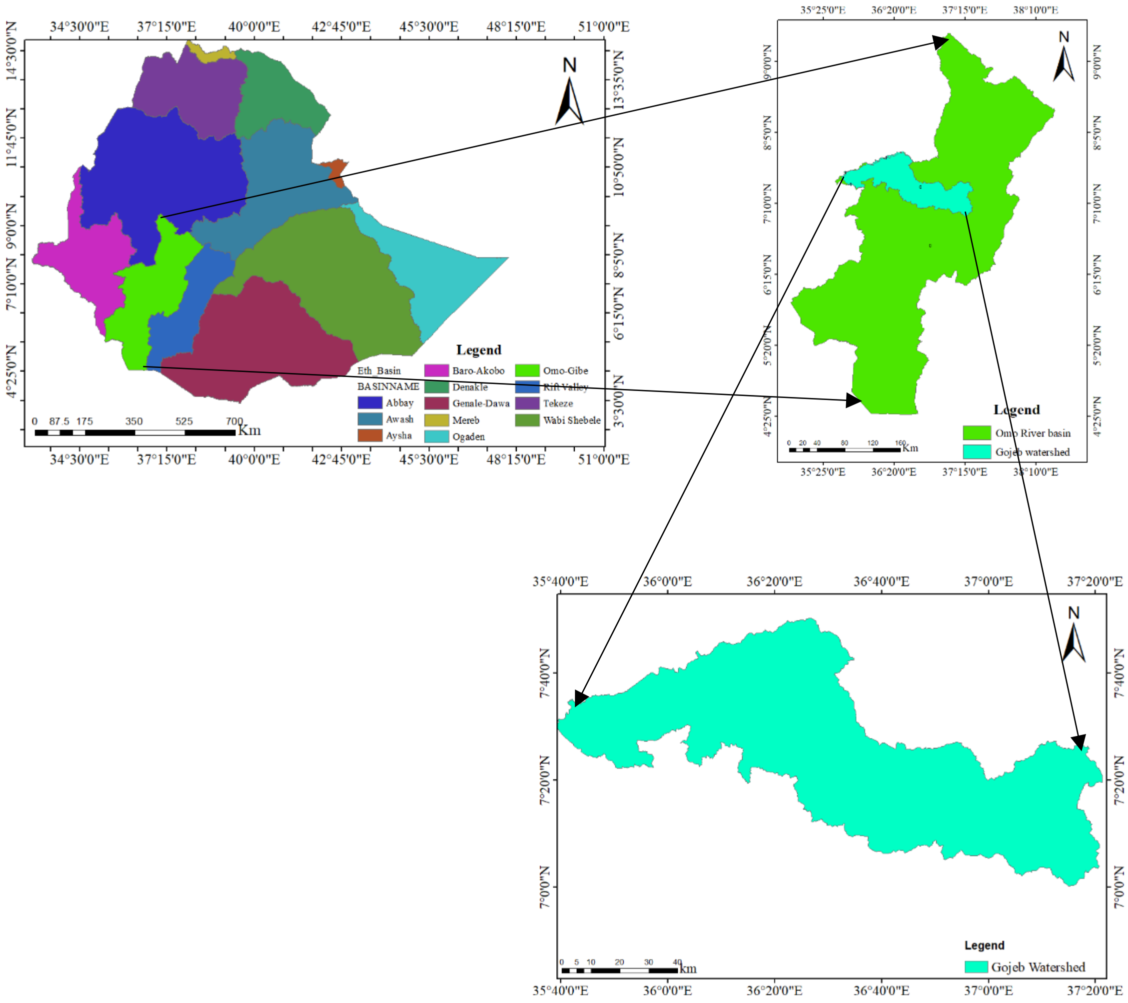


Figure 3.1: Geographic location map of study area

The climate condition in the area varies from a hot arid climate in the southern part of the flood plain to a tropical humid climate in the highlands that include the extreme north and northwestern part of the basin. The basin lies with an elevation range between 697 m.a.s.l to 3851 m.a.s.l. The mean annual temperature in Gojeb watershed varies from 16°C in the high lands at the northern part of the watershed to over 29°C in the low land at the southern part of the watershed (MisganawChoto & AramdeFetene, 2019).

The soils properties of the upper and middle area of the basin are mainly permeable and well drained while the valley bottoms have less permeable with impeded drainage. In the area, dystric nitisols is dominant which have clay texture. The dominant land use/land cover in the area is agricultural.

3.2 Materials / Tools

The tools used for this study are ARC-HYDRO and HEC-GeoHMS of version 10.1, which is an extension tool of Arc GIS version 10.1 and HEC-HMS version 4.2. Environmental Systems Research Institute (ESRI) developed geographic information system (GIS) technology. ARC-HYDRO, which is a tool of GIS, was used for catchment delineation, terrain pre-processing using a Digital Elevation Model (DEM).

The hydrologic Engineering Centers Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) is a public domain extension to ESRI’s ArcGIS software and the spatial analyst extension. It is hydrology toolkit for engineers and hydrologists. The user can visualize information about watershed characteristics, perform spatial analysis, and delineate sub basins and streams, calculates physical characteristics used for computation of hydrologic parameters and construct inputs hydrologic models, which used directly by HEC-HMS. HEC-HMS model was developed by US army corps of engineers. This model can simulate many hydrological issues such as urban floods, flood frequency, water compounds, spillways capacity and sediment and water quality and rainfall-runoff simulation. For this study, HEC-HMS model uses to simulate rainfall-runoff in the Gojeb watershed.

3.3 Study Design

The study was conducted by using spatial and hydro-meteorological data. After analyzing the data basin model and curve, number was prepared by using HEC-GeoHMS. The basin model was imported to HEC-HMS to simulate runoff.

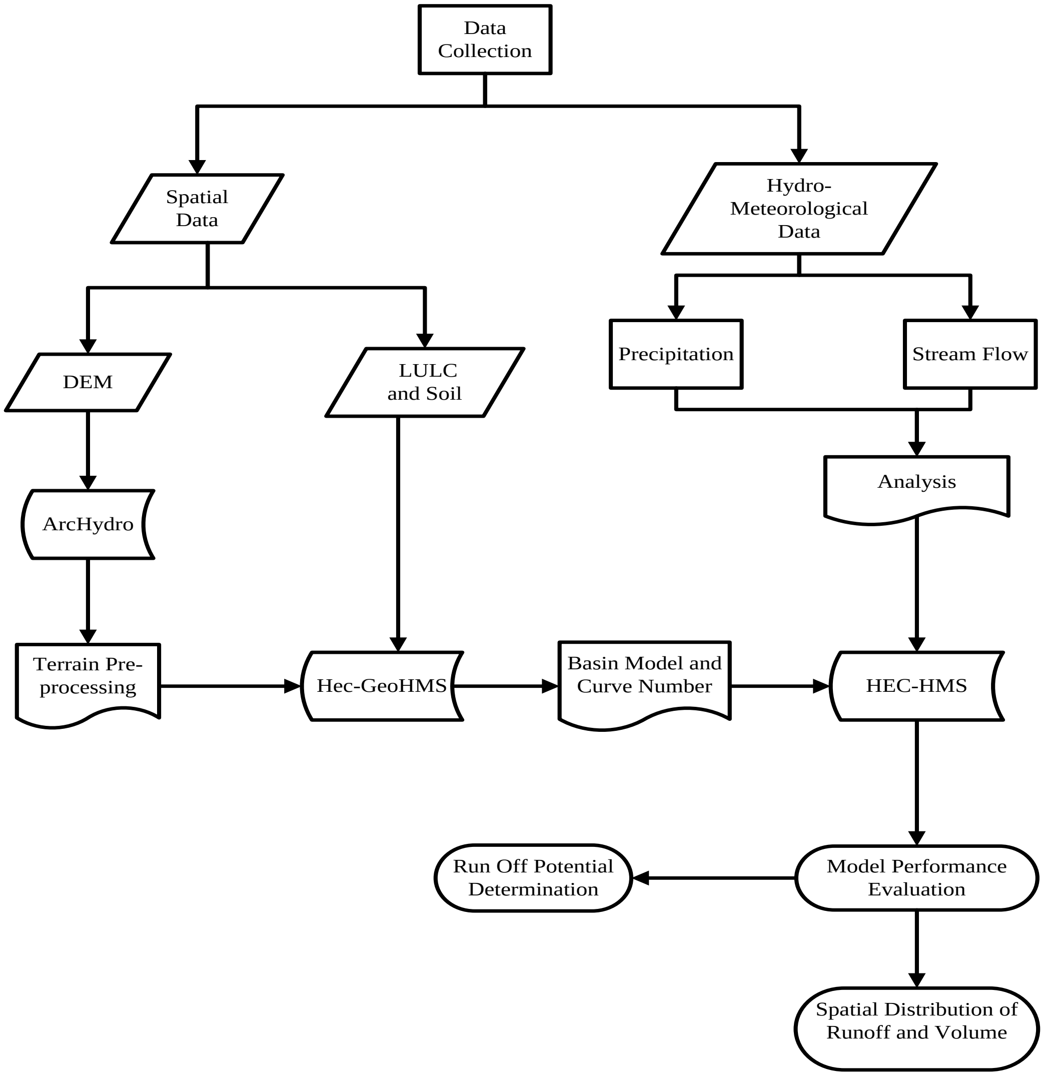


Figure 3.2: Study design of the study

3.4 Data Collection and analysis

The data, which are important for rainfall-runoff modeling, were classified into hydro-metrological data that includes rainfall and runoff data and physiographic data such as DEM, land use/land cover and soil data.

3.4.1 Land use and land cover

Land use/Land cover also has a fundamental role for knowing surface runoff. This surface runoff was affected by changing the land cover and the soil type. Woodland, grassland, wetlands and other types of land surfaces could change the dominant runoff processes at catchment scale. The land use data for the year of 2013 was collected from mapping agency of Ethiopia (EMA). For this study area the dominant type of land use/land cover are cultivation (58.5%), forest (24.46%), moderate cultivation (7.45%), open water (6.38%) and woodland (3.19%). The land use/ land cover data of the basin, along with the soil information helps for producing the curve number for the entire sub-basin by using HEC-Geo HMS.

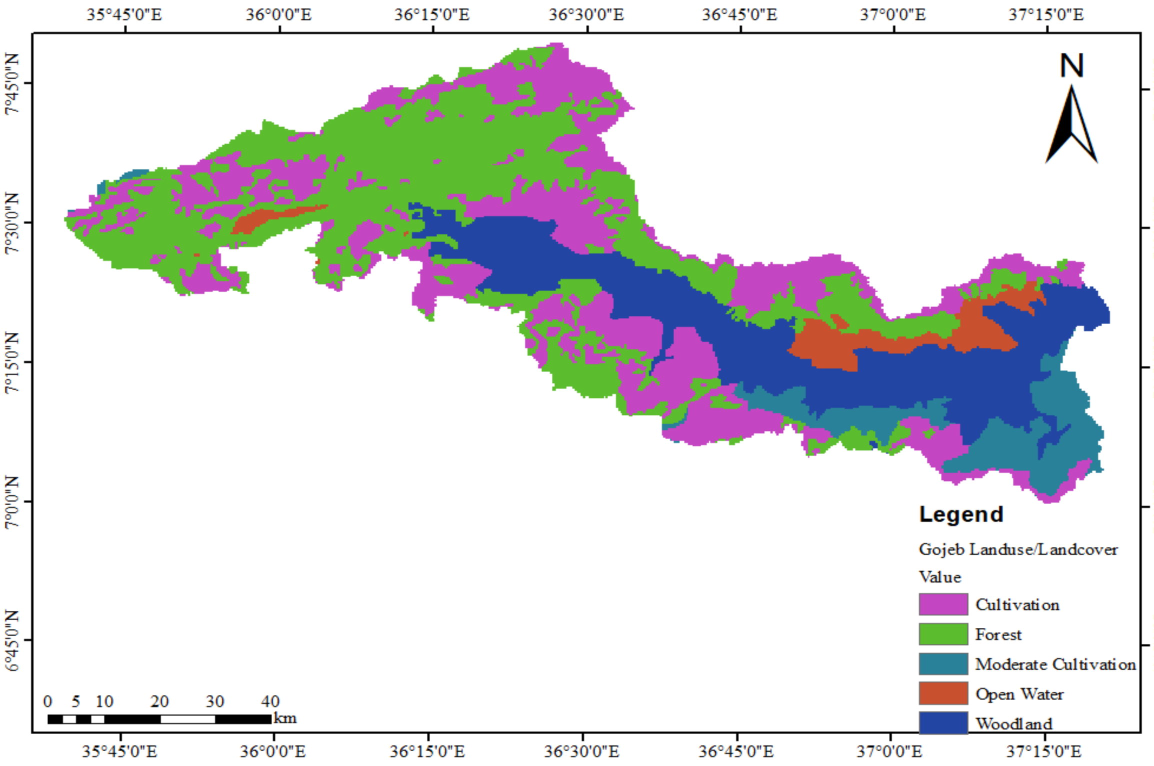


Figure 3.3: Land use/land cover type of Gojeb watershed

3.4.2 Soil type

Soil is the major physical catchment characteristic that governs runoff generation. Soil properties greatly influence the amount of runoff from rainfall (Aydagne, 2007). The main dominant soil in the basin are dystric nitisols (52.5%), eutric cambisols (14.9%) and dystric fluvisols (7.53%). The rest are in minor proportion like, cambisols, chromic vertisols, dystric gleysols, eutric nitisols, gypsic yermosols, leptosols, orthic acrisols and orthic solonchaks.

The infiltration capacity of the soil depends on the porosity of the soil, which determines its storage capacity and affect the resistance of the water to flow in to deep layers. Since the soil infiltration capacity depend on the soil texture, the highest infiltration rates are observed in sandy soil, but in Gojeb sub basin the wide area is covered with dystric nitisols which have clay texture this shows that surface runoff is high in this area.

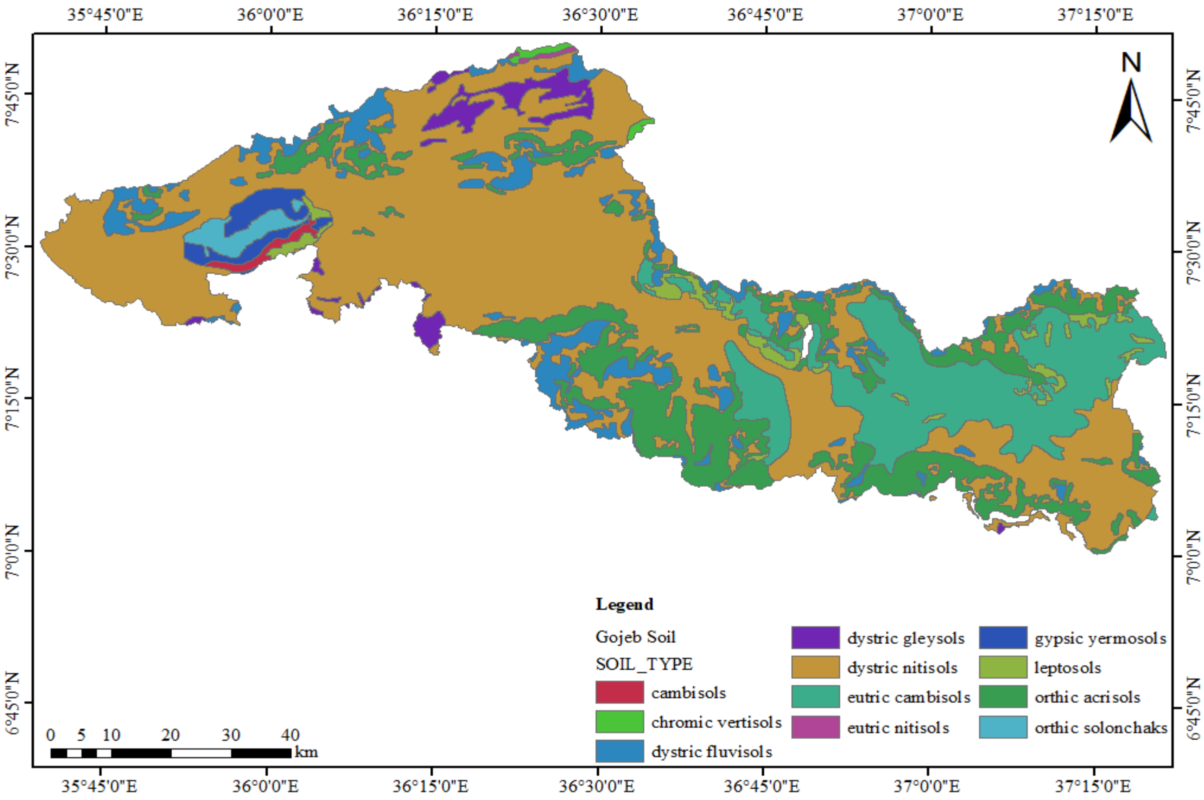


Figure 3.4: Soil classification of the study area

3.4.3 Meteorological Data

For this research, rainfall data has been used for simulating runoff of the Gojeb watershed. Meteorological stations, which are considered for this study, are located inside and outside of the study area. From nine meteorological stations, five stations exist inside and other four stations exist outside of the watershed. The data were collected from National Meteorological Agency of Ethiopia (from2002to2014) years.

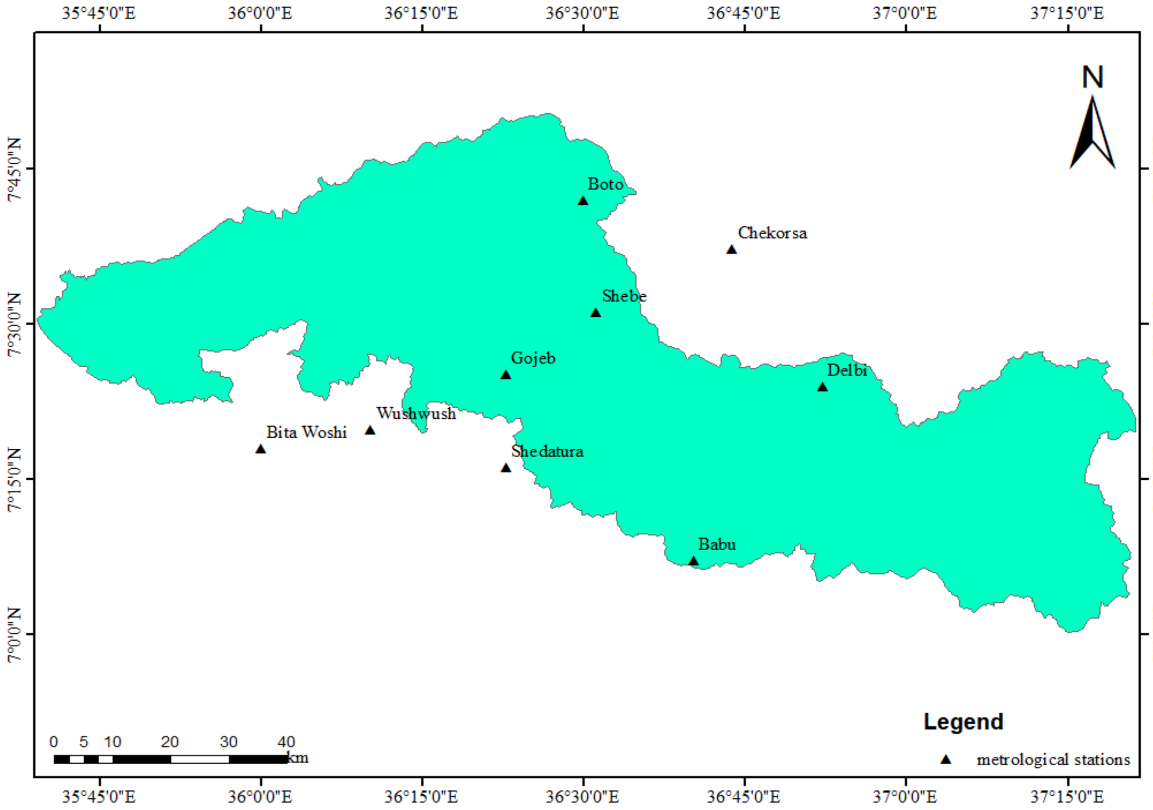


Figure 3.5: Selected meteorological stations of Gojeb watershed

3.4.4 Hydrological data

The hydrological data is required for performance sensitivity analysis, calibration and validation of the model. Daily stream flow data for selected watershed was used for (HEC-HMS) model to simulate runoff. The data covers from 2002 to 2014 were collected from ministry of water, irrigation and electricity (MoWIE). There is only one stream flow gauging station in the study area, which is Chida gaging station.

3.4.5 DEM

Topography was defined by DEM, which describes the elevation of any point in a given area at a specific spatial resolution. DEM was used to analyze the drainage pattern of the watershed, slope, stream length, width of channel within the watershed and it was a basic dataset used for development of the basin model component in HEC-HMS model. The digital elevation model for this study was obtained from (https://earthexplorer.usgs.gov/) website with a resolution of 12.5m*12.5m.

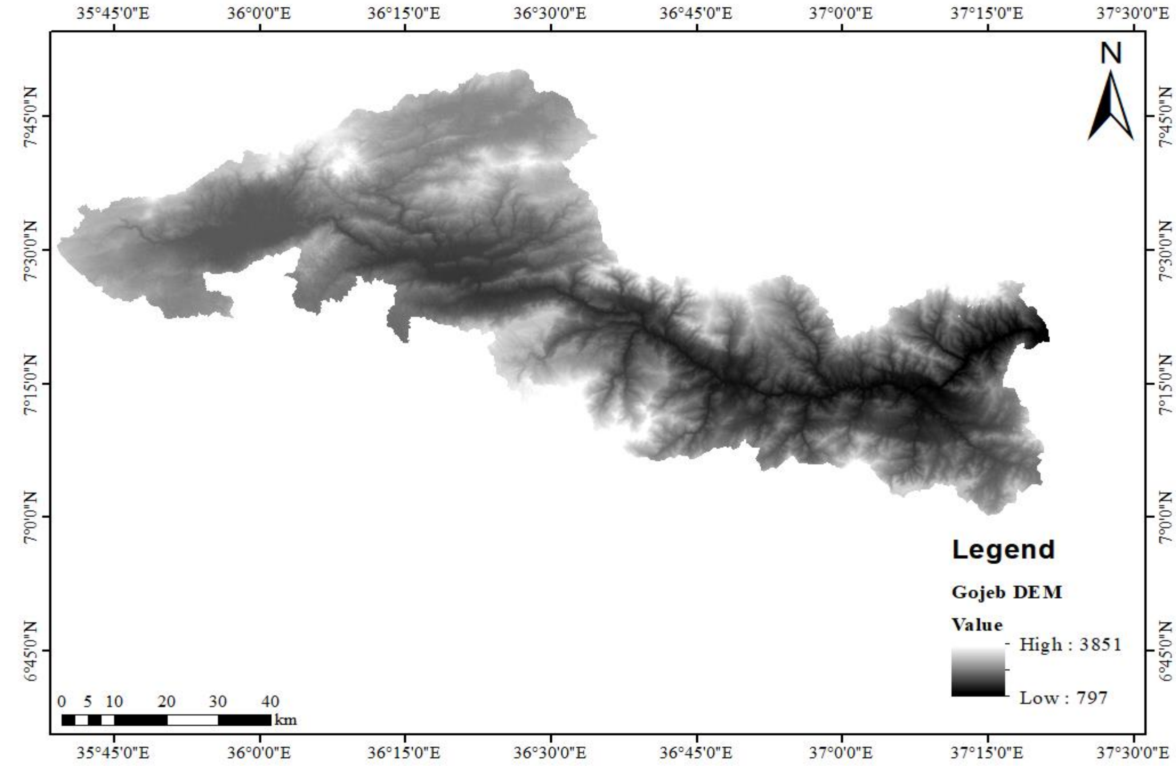


Figure 3.6: Map of Gojeb watershed DEM

3.5 Data Processing

3.5.1 Rainfall data gap-filling

The availability of a long and complete rainfall record is very important for carrying out a hydrological study successful. Precipitation data was taken from National Meteorological Agency of Ethiopian. These data includes missing therefore, the missing data was filled by using Arithmetic Mean method. This method was selected because the normal annual rainfalls at surrounding gauges are within the range 10% of the normal annual precipitation at the station X (Ven Te Chow, et al., 1988).

$p_x = \frac{1}{m}\sum_{i=1}^{m} p_i$ --3.1

Where: p_x is estimate for the concerned station, Pi is rainfall values of rain gauges used for estimation and m is a number of surrounding stations.

3.5.2 Checking the Consistency of Data

After the missing data was filled, then the consistency of the data for each station was checked. A small change may occur in and around a rain gage station; such a change occurring in a particular year was start affecting the rain gauge data, which is reported from that particular station. After several years, it may be felt that the data of station is not giving consistent rainfall values.

In order to detect such inconsistency, and to adjust the reported rainfall values a technique, called double mass curve method was used. It check the consistency of rainfall record by plotting the cumulative annual rainfall for individual station against the current cumulative values of mean annual rainfall for a group of surrounding station. The result shows that all metrological stations are consistent.

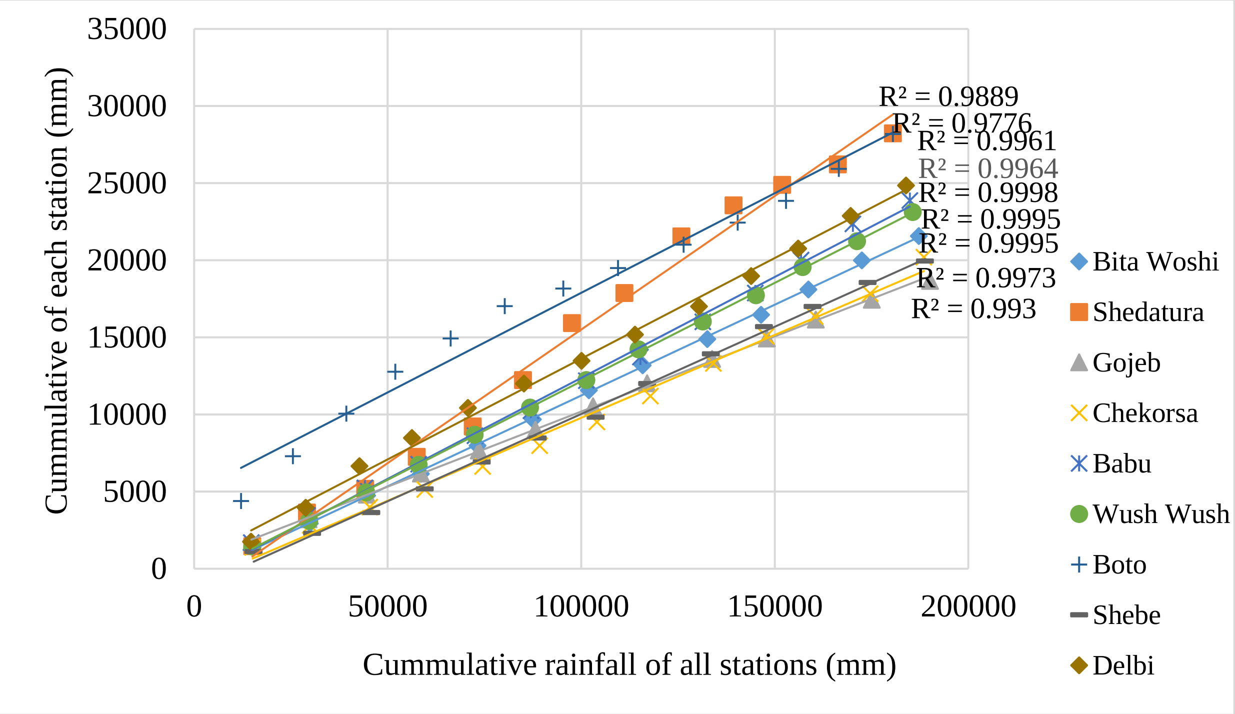


Figure 3.7: Double Mass Curve of the stations

3.5.3 Estimation of Areal rainfall

The rain catch at one station may be different from that of a second station in the same basin. For this study for changing point, rainfall in to aerial rainfall Thiessen polygon mean method was used. Thiessen polygon was created by using ARC GIS tool. The data used to create Thiessen polygon was meteorological stations for Gojeb River watershed and each sub basin in basin model, which is generated by HEC-GeoHMS. The Thiessen polygon method is the most popular method used in practical engineering problems. The Thiessen polygon technique was used to determine the gauge weights. The ratio of the area of a polygon to the area of its corresponding sub-basin polygon represents the weight of the gage for each sub-basin.

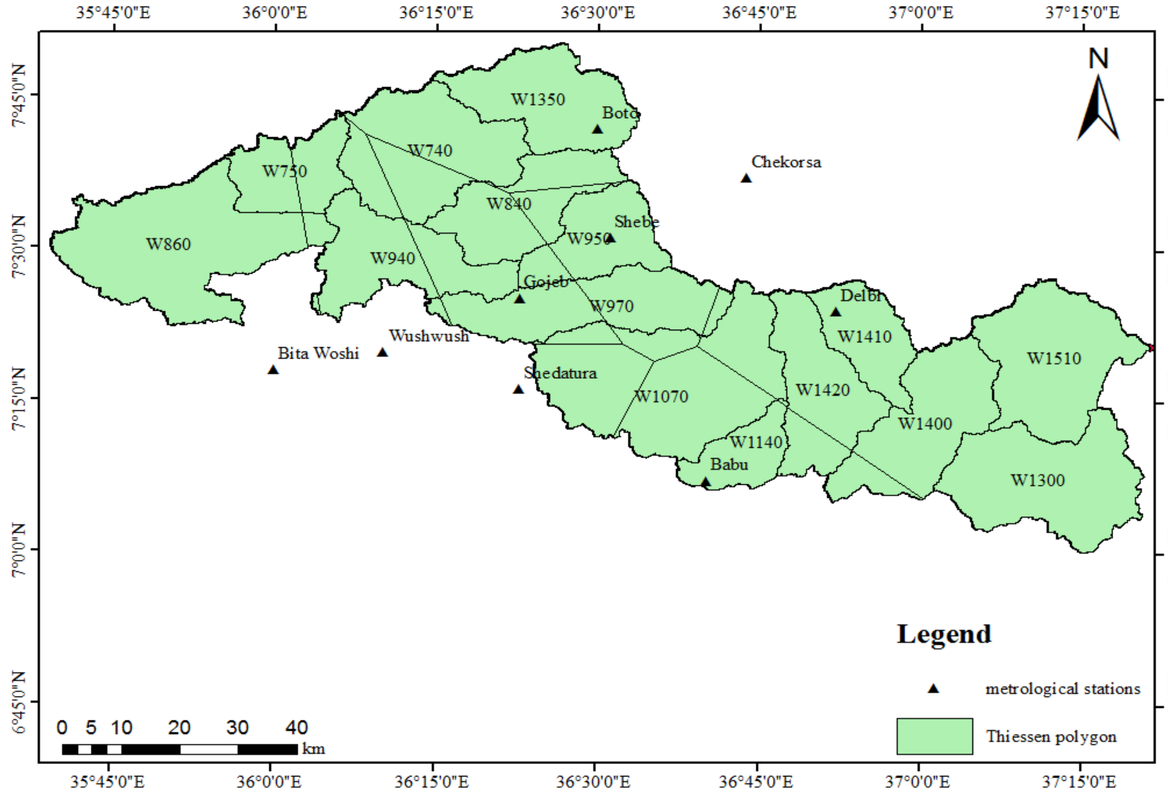


Figure 3.8: Thiessen polygon for the selected meteorological station

As the map indicates different sub basin can get rainfall from different stations. Table 3.1shows the contributing gage weight value for each sub basin from each meteorological station.

Table 3.1: Contributing Rainfall Station for Each Sub Basin

Sub Basin	Contributing station	Weight	Sub Basin	Contributing station	Weight	Sub basin	Contributing station	Weight
W740	Wush Wush	0.0136	W750	Boto	0.000001	W840	Boto	0.01693
	Boto	0.0484		Bita wosh	0.020127		Gojeb	0.02779
	Gojeb	0.0204		Wush Wush	0.017974		Shebe	0.01077
W950	Boto	0.00000528	W860	Wush Wush	0.00406	W1140	Delbi	0.00021
	Gojeb	0.0073		Bita Woshi	0.10721		Babu	0.02563
	Shebe	0.0364	W1300	Delbi	0.084990	W1510	Delbi	0.07963
W1400	Delbi	0.0592	W1420	Delbi	0.04404	W1350	Boto	0.06122
	Babu	0.0101		Babu	0.01357	W1410	Delbi	0.03548
W970	Wush Wush	0.0014	W1070	Delbi	0.02573	W940	Gojeb	0.02005
	Shedatura	0.0000002451		Shedatura	0.03656			
	Chekorsa	0.00000086		Gojeb	0.00543		Wush Wush	0.04009
	Gojeb	0.0305		Shebe	0.00859		Bita Woshi	0.00045
	Delbi	0.0029		Babu	0.05095			
	Shebe	0.0323						

3.6 Basin Model Preparation

Basin model was created with the help of HEC-GeoHMS, by using a series steps called terrain pre-processing and basin processing. Terrain Pre-processing have steps which includes fill sinks, flow direction, flow accumulation, stream definition, stream segmentation, catchment grid delineation, catchment polygon processing, drainage line processing, adjoint catchment processing and watershed slope. This process was done by using ArcHydro tool of Arc-GIS.

Following this terrain pre-processing hydrologic processing was done by using HEC-Geo HMS it includes basin marge and basin characteristics, which includes (River length, River slope, basin slope, longest flow path, basin centroid, and centroid elevation and centroid longest flow path). HEC-GeoHMS was also used to Select HMS, processing methods for calculating loss, transformation, base flow and channel route. By integrating Arc GIs tool, DEM, land use/cover, soil and HEC-GeoHMS curve number was generated which is a parameter for determination of loss in SCS method.

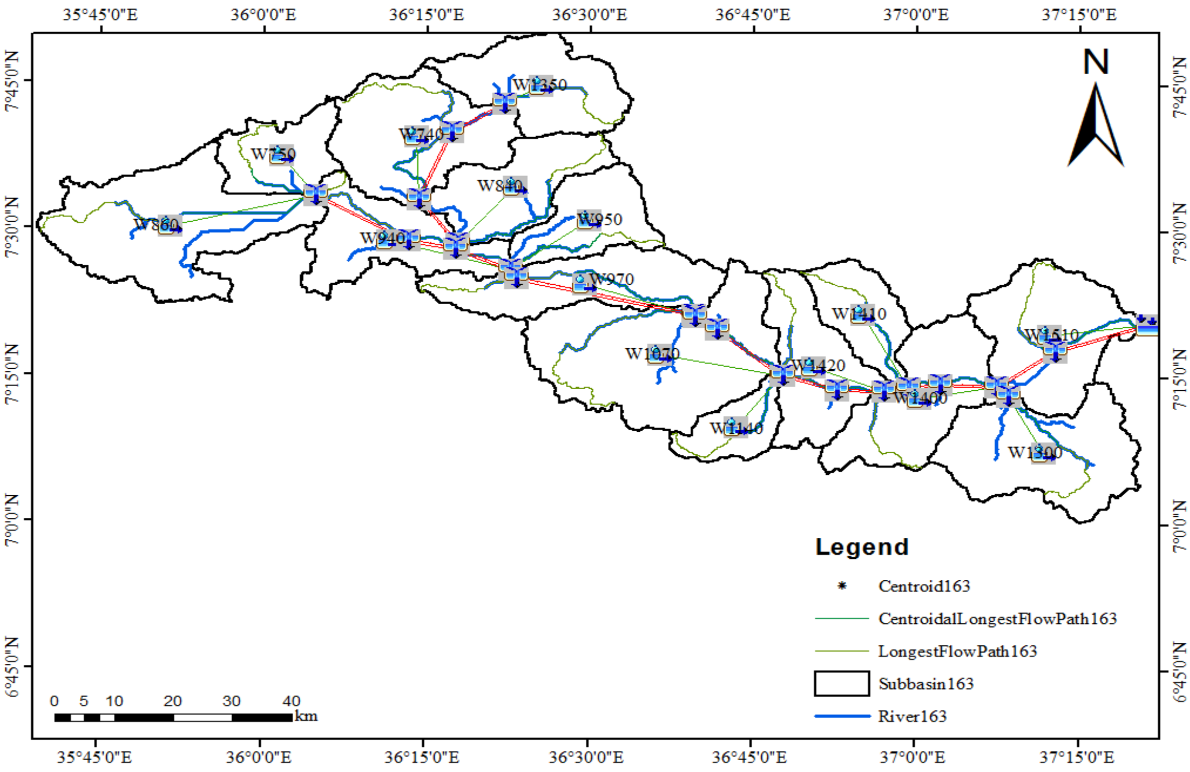


Figure 3.9: Basin model prepared by using HEC-GeoHMS

3.7 Curve Number Generation

One of the important parameters of HEC-HMS model is the curve number parameter. This parameter analyses runoff production in the basin. The curve number varies between 0 and 100. It becomes 100 when all rainfall is converted to runoff, and it becomes zero when all rainfall gets stored on surface of the basin (Refahi, 2004).

The data that was used for generate curve number are land use, soil and DEM. Land use classification was performed using classification functions of ArcGIS. Land use/cover classification was done by assigning a grid code for each class. Accordingly, after reclassification three types of land use was identified out of five-land use/cover in the study area, namely agriculture, water body and forest. After classification, the raster form was converted to land use shape file maps using raster to polygon function in conversion tool, which exist, in Arc toolbox. The Soil data also classified into four hydrologic groups namely A, B, C and D. From this four hydrologic soil groups soil type A has high infiltration rate; soil type B has moderate infiltration rates; soil type C has slow infiltration rate and D soil type has very slow infiltration rate. Table 3.2 shows the classification of soil type in to four hydrologic soil groups. In the area type C and D hydrologic soil group are more dominant.

Table 3.2: Hydrological Soil Group for each soil type

Soil Type	Soil Texture	Hydrologic Soil Group
Dystric Nitisols	Clay	D
Eutric Cambisols	Clay Loam	D
Dystric Fluvisols	Sandy Clay	C
Cambisols	Sandy Loam	C
Chromic Vertisols	Sandy Loam	B
Dystric Gleysols	Loam	C
Eutric Nitisols	Clay	D
Gypsic Yermosols	Loam	C
Leptosols	Loam	C
Orthic Acrisols	Sandy	A
Orthic Solonchaks	Clay	D

Then the land use data was merge with soil data by using union function of Arc GIS. The CN Look-up table was Created by using create table function of Arc GIS and assigned Hydrological Soil Group (HSG) for each land use type. Then curve number was generated by using generated grid function in HEC- GeoHMS with integration of merged land use and soil data, sink filled DEM and CN lookup table.

Table 3.3: Curve Number look up table

Description of land use/land cover type	Hydrologic soil group			
	A	B	C	D
Agricultural	67	76	83	86
Forest	35	61	74	80
Water Body	98	98	98	98

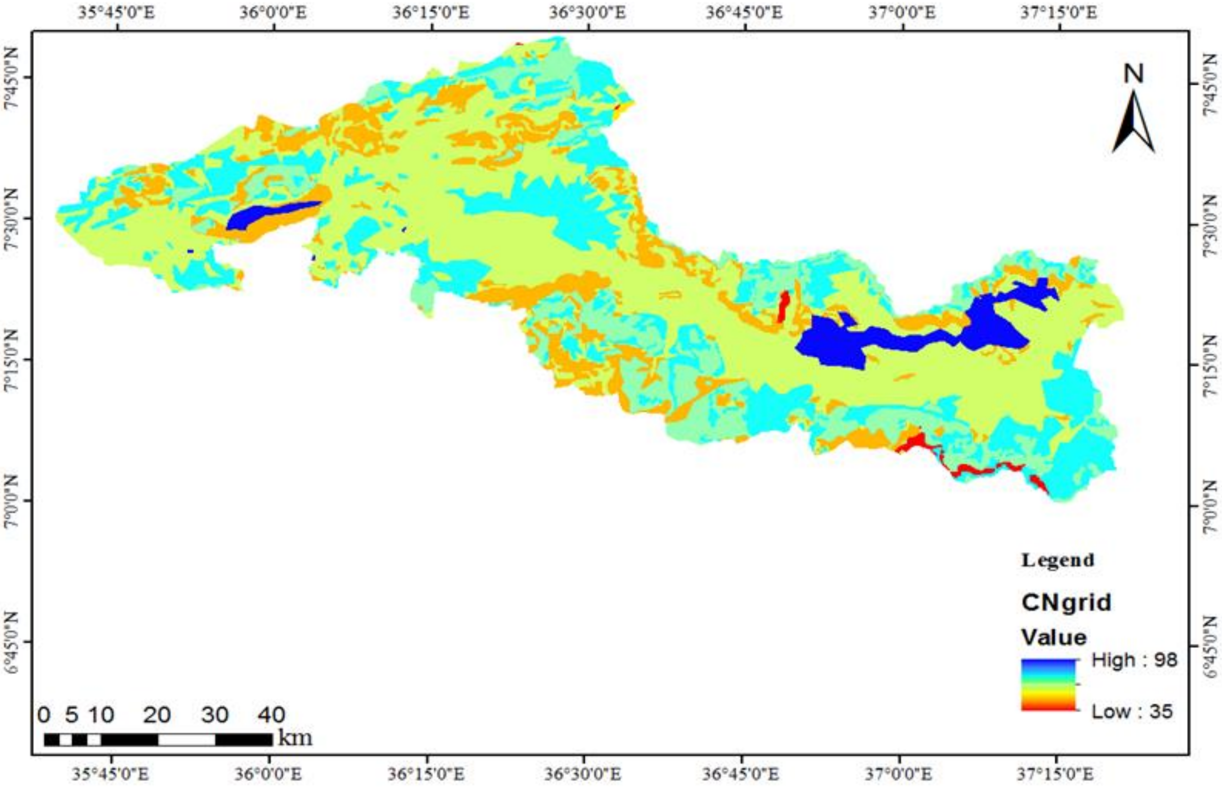


Figure 3.10: Generated curve number Grid

The weighted curve number value for each sub basin was calculated by using HEC-GeoHMS and the values of CN of the Gojeb Watershed are between 79 and 84.

Table 3.4: Weighted curve number from HEC-GeoHMS

Sub Basin	Basin CN	Basin Lag Time (hr)	Sub Basin	Basin CN	Basin Lag Time (hr)
W740	79.0063	7.63037	W1140	82.7591	4.05901
W750	79.9064	4.6699	W1300	82.8641	4.59642
W840	81.5615	6.18144	W1350	82.2296	4.4916
W860	81.6482	8.28298	W1400	81.4438	5.45981
W940	80.9869	6.95065	W1410	84.3352	4.062
W950	82.0369	5.0282	W1420	83.2346	5.49737
W970	79.1711	7.27327	W1510	83.5898	4.78856
W1070	80.4672	8.51623			

3.8 HEC-HMS Model

The HEC-HMS model was used for surface runoff simulation in a watershed. Data required for hydrologic modeling are basin model, weighted precipitation data from theissen polygon, runoff flow data and physiographic data such as (Curve number, lag time, initial abstraction and Area). Several components was combined to simulate the basin processes and convert precipitation to runoff within a part of the model. HEC-HMS model includes four components these are basin model, meteorological model, control specification, and time series data.

3.8.1 Basin Model

Basin model was created using HEC-GeoHMS in the form of a background map file with all its hydrologic elements then imported into HEC-HMS model. The hydrologic elements include sub basin, junction, reach, and reservoir and drainage network. Basin model is the most important input to run the model and simulate rainfall-runoff over entire watershed (Majidi & Shahedi, 2012).

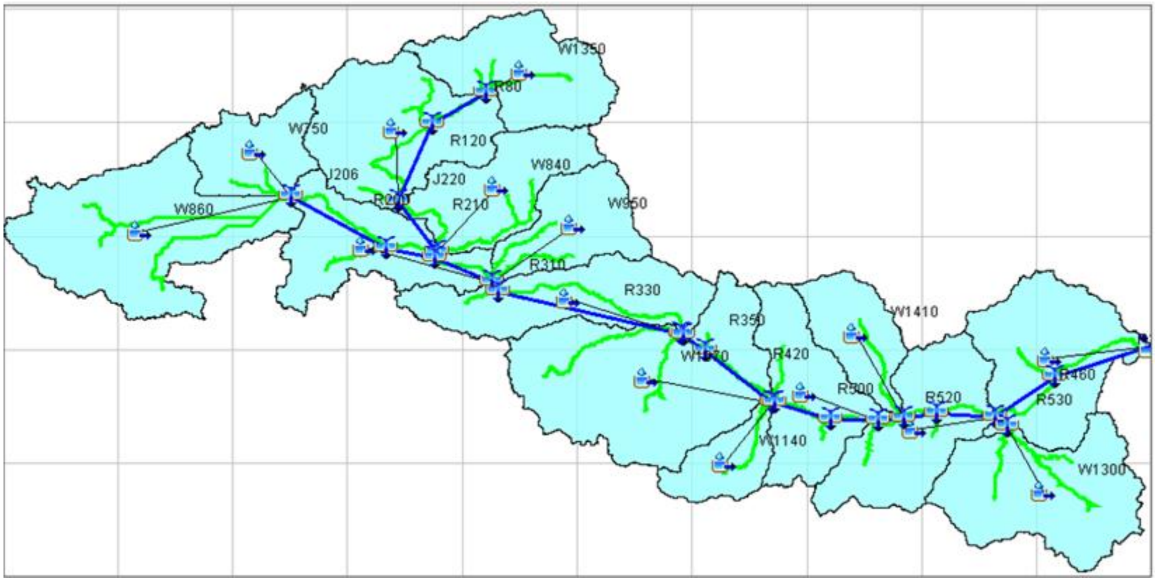


Figure 3.11: Basin model of Gojeb watershed

In HEC-HMS, the basin model comprises four vital processes; loss, transform, base flow and routing.

3.8.1.1 Modeling Rainfall Losses

Among different loss methods, SCS CN Method was selected to calculate rainfall losses. The reason for selecting this method is it is simple, predictable and stable method used for estimating precipitation excess. In SCS-CN method curve number, initial abstraction and percent, impervious area in the basin was the basic parameters. CN was generated by using HEC-GeoHMS and I_a was calculated by using the formula above. Percent impervious area was taken as “0 %”, since no urban settlements are present inside the sub basin.

$P_e = \frac{(p-I_a)^2}{(p-I_a)+s}$ --3.2

Where: p_e is Accumulated precipitation excess at time t (mm), P is Accumulated rainfall depth at time t (mm), I_a is the initial abstraction (mm) and S is Potential maximum (mm)

I_a = 0.2S --3.3

$S = \frac{25400}{CN} - 254$ --3.4

3.8.1.2 Modeling Direct Runoff

With respect to the transform options of excess rainfall into runoff, HEC–HMS includes several unit hydrograph methods. Among the methods SCS unit hydrograph was used because of data availability, researcher recommendation and it is adoptable in the country at different place and it gives a good result. The transform method requires a lag time as an input. There are several methods available for calculating t_{lag} one of them is the SCS method (USACE, 2000).

$t_{lag} = \frac{l^{0.8}(s+1)^{0.7}}{1900Y^{0.5}}$ --3.5

$t_c = 1.67t_L$ ---3.6

Where: t_{lag}denotes basin lag time measured in (hr), L denotes length from sub basin outlet to divide along longest drainage path in fit, Y denotes sub basin slope (in percentage) and S denotes saturated moisture measured in inch expressed in terms of average curve number as (in)

$S = \frac{1000}{CN} - 10$ ---3.7

CN is average curve number for each sub watershed

3.8.1.3 Modeling Base Flow

A Base flow model represents the subsurface model, which is interacted with infiltration and surface runoff process. For this study for computation of base flow among different methods in HEC-HMS model monthly constant method was selected.

Table 3.5: Base flow for each month

Month	Jun	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Base Flow (m^3/s)	4.06	12.7	12.6	18.2	27.29	32.7	39.3	43.23	45.27	23.54	10.9	9.2

3.8.1.4 Routing Model

For this study Muskingum, method was chosen because this method is adoptable in natural channel. In this method X and K, parameters must be evaluated. Theoretically, K parameter is time of passing of a wave in reach length and X parameter is constant coefficient that its value varies in between 0 to 0.5.

$K = \frac{l}{2v}$ ---*3.8*

Where: l is length of reach (m) and V is Mean velocity ($^{m}/_{s}$)

3.8.2 Meteorological Model

The meteorological model calculates the precipitation input required by a sub-basin element. This model is one of the main Components of the study, which create metrological boundary conditions for the basin. The precipitation data necessary to simulate watershed processes are stored in the meteorological model. Results computed by the metrological model were matched with the sub-basin and Gauge weight method was used for creating this model.

3.8.3 Control Specification Model

The control specification was set the time span of a simulation run. Information in the control specifications includes a starting date and time, ending date and time, and computation time interval.

3.8.4 Time Series Data

In time-series data, we needed to set up the precipitation gage and the discharge gage in the simulation. The observed runoff data was inputted in the discharge Gage to compare with the simulated runoff data after the rainfall–runoff model was done. For the precipitation data, there are weight for each rainfall station in the Gojeb sub basin was inserted in precipitation gage. Thiessen's Polygon method was chosen to divide the represented.

After using the Thiessen's Polygon Method, we obtained the average rainfall for each sub basin and input in the precipitation gage.

3.9 Model Calibration and Model Validation

The available hydrological data from 2002-2014 was splatted in two parts for model calibration (2002-2008) and model validation (2009-2014). The sensitive parameters was identified depending on the change on peak discharge and volume. These parameters were optimized using the optimization tools available in HEC-HMS. The sensitivity analysis of the model was performed to determine the important parameters, to make accurate prediction of basin yield. This sensitivity analysis is done by changing each input parameter within prescribed range and keeping the others constant and running the model (D. Roy *et al*., 2013). The sensitivity parameters were then selected based on their effect on peak discharge and total volume by viewing the output the more sensitive parameter was identified.

The model was optimized for the identified sensitive parameters to improve the agreement between the simulated and observed data.

During optimization from the objective functions peak weighted root mean square error (PWRMSE) was selected because, it is a measure of the comparison of the magnitudes of peak, volume and time of peak of the simulated and measured hydrograph. To aid in parameter value adjustment, the Univariate Gradient searching algorithm was used to minimize the PWRSME by identifying the most reasonable parameter values that will yield the best fit of computed to the reference hydrograph (USACE, 2000).

Model validation was a process of using the calibrated model parameters to simulate runoff over an independent period outside the calibration period (if enough data is available) to determine the suitability of (USACE, 2000)the calibrated model for predicting runoff over any period outside the calibrated period. If there is no enough data available the validation may performed by testing short period was taken.

3.10 Model Performance Evaluation

The HEC-HMS model performance evaluation involved assessing the goodness of fit in the observed and simulated stream flow using Percentage Error in simulated Volume (PEV), Percentage error in simulated peak (PEP), Nash-Sutcliffe efficiency (NSE), coefficient of determination (R^2) and PBIAS.

The PEV (Percentage error in simulated volume) value measures the deviation between the simulated and the observed volume of stream flow.

$$PEV = \frac{(vol_o - vol_c)}{vol_o} x100 \text{ ---3.9}$$

Where: $\mathrm{Vol_o}$ is the observed runoff volume (m^3) and $\mathrm{Vol_c}$ is the computed runoff volume (m^3)

The PEP (Percentage error in simulated peak) values measure the percent deviation between the simulated and observed peak flows, considers the magnitude of computed peak flow, and does not account for total volume or timing of the peak:

$$\mathrm{PEP} = \frac{(\mathrm{Q_{po}} - \mathrm{Q_{pc}})}{\mathrm{Q_{po}}} * 100 \text{ ---3.10}$$

Where: Q_{po} is the observed peak discharge (m^3/s) and Q_{pc} is the computed peak discharge (m^3/s)

The Nash-Sutcliffe efficiency (NSE) was used to evaluate the overall agreement of the shape of the simulated and observed hydrograph. NSE measures the efficiency of the model by relating the goodness of fit of the simulated data to the variance of the measured data. It can be defined according to the following equation: Nash-Sutcliffe efficiencies can range from -∞ to 1. An efficiency of NSE = 1 corresponds to a perfect match of modelled discharge to the observed data. An efficiency of NSE = 0 indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($-\infty < NSE < 0$) occurs when the observed mean is a better predictor than the model (Nash & Sutcliff, 1970)

$ENS = 1 + \frac{\sum(Q_{obs} - Q_{sim})^2}{\sum(Q_{obs} - Q_{mobs})} * 100$---3.11

Correlation coefficient (coefficient of determination) describes the proportion of the total variance in the observed data that can be explained by the model. The closer the model efficiency is to 1, the more accurate the model is. R2 is indicates how the simulated data correlates to the observed values of data. The range of R2 is extends from 0 unacceptable to 1 the best (Gebre, 2015).

$R^2 = \left(\frac{\sum(Q_{obs} - \bar{Q}_{obs})^2 - \sum(Q_{sim} - \bar{Q}_{sim})^2}{\sum(Q_{obs} - \bar{Q}_{obs})^2}\right)$ ---3.12

Where: Q_{obs} is observed discharge (m^3/s), Q_{sim} is simulated discharge (m^3/s), $\bar{Q}_{obs}$ is mean of observed discharge (m^3/s) and $\bar{Q}_{sim}$ is mean of simulated discharge (m^3/s).

PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed counterparts do. This statistic has the ability to clearly indicate poor model performance optimal value is zero, with low magnitude values indicating accurate model simulation; positive values indicate model underestimation bias, and negative values indicate model overestimation (Jojene *et al.*,).

$\mathrm{PBIAS} = \frac{\sum_{i=1}^{n}(Q_{obs} - Q_{sim})}{\sum_{i=1}^{n} Q_{obs}} * 100$ ---3.13

Where: Q_{obs} is observed discharge (m^3/s) and Q_{sim} is simulated discharge (m^3/s)

4. RESULTS AND DISCUSSION

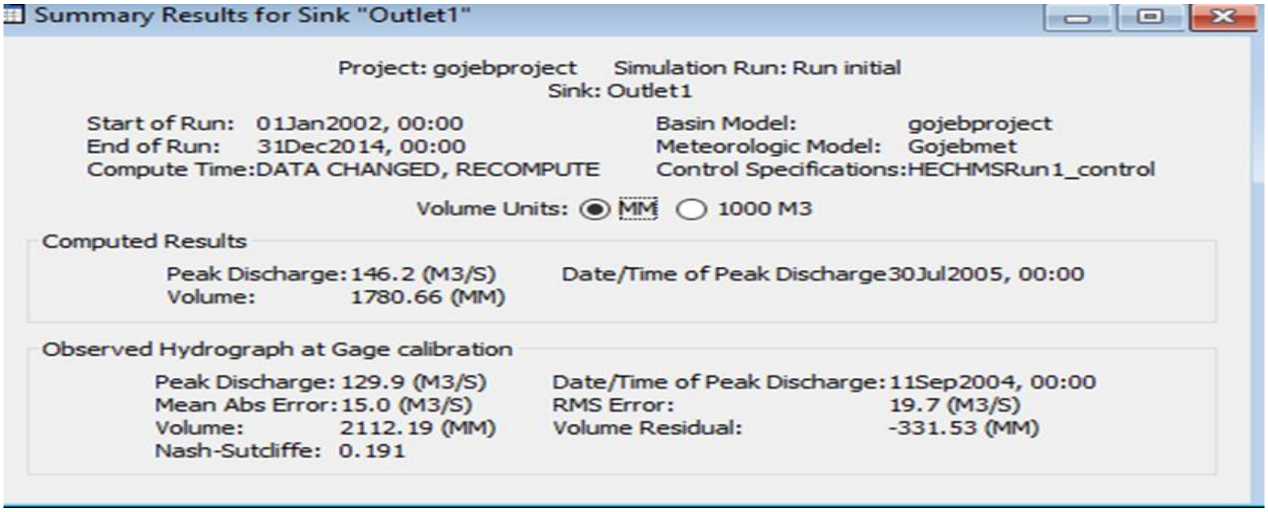
4.1 Input parameters

For HEC-HMS processing, the basin model of Gojeb watershed and parameters of each sub-basin were imported from HEC-GEOHMS. Sub-basin parameters include curve number, Area, lag time and initial abstractions, from which curve number and initial abstraction were used to determine loss by SCS - CN method while for transformation and for channel routing lag time and X and K value were used respectively. SCS Unit Hydrograph method was applied for transforming rainfall to runoff and Muskingum method was used for channel routing. There are 15-sub basin, 21 junction and 18-reach in basin model. In HEC-HMS under time series command, precipitation data and observed stream flow for each sub basin from 2002 to 2014 were entered to precipitation gage and discharge gage respectively.

Table 4.1: Initial parameter for each sub basin

Sub Basin	Area (km^2)	CN	Ia (mm)	Lag time (hr)	Sub Basin	Area (km^2)	CN	Ia (mm)	Lag time (hr)
W740	549.97	79	13.49	7.63	W1350	407.9	82.23	10.98	4.49
W750	254.14	79.9	12.77	4.66	W1140	172.3	82.75	10.58	4.059
W970	448	79.17	13.36	7.27	W1300	566.5	82.86	10.5	4.59
W950	290.7	82	11.123	5.028	W1070	848.6	80.46	12.33	8.516
W940	404.2	80.98	11.926	6.75	W860	742.6	81.648	11.418	8.28
W1400	461.5	81.44	11.57	5.45	W840	369.9	81.56	11.484	6.18
W1410	236.46	84.335	9.435	4.06	W1510	530.5	83.59	9.97	4.78
W1420	384.05	83.23	10.235	5.49					

By using initial parameters as listed above in table, the HEC-HMS simulation run was computed and the result showed that there was a variation between simulated and observed flow. The simulated discharge was 146 m^3/s and observed discharge was 129.9 m^3/s. The value of model efficiency measures, Nash-Sutcliffe, was 0.19 and this shows that the simulation was Unsatisfactory. Therefore, to correlate the variation between observed and simulated flow model calibration was executed.



Project: gojebproject Simulation Run: Run initial
Sink: Outlet1

Start of Run: 01Jan2002, 00:00
End of Run: 31Dec2014, 00:00
Compute Time: DATA CHANGED, RECOMPUTE

Basin Model: gojebproject
Meteorologic Model: Gojebmet
Control Specifications: HECHMSRun1_control

Volume Units: ● MM ○ 1000 M3

Computed Results
Peak Discharge: 146.2 (M3/S)
Date/Time of Peak Discharge 30Jul2005, 00:00
Volume: 1780.66 (MM)

Observed Hydrograph at Gage calibration
Peak Discharge: 129.9 (M3/S)
Date/Time of Peak Discharge: 11Sep2004, 00:00
Mean Abs Error: 15.0 (M3/S)
RMS Error: 19.7 (M3/S)
Volume: 2112.19 (MM)
Volume Residual: -331.53 (MM)
Nash-Sutcliffe: 0.191

Figure 4.1: Summary result for simulated Run

4.2 Model Calibration

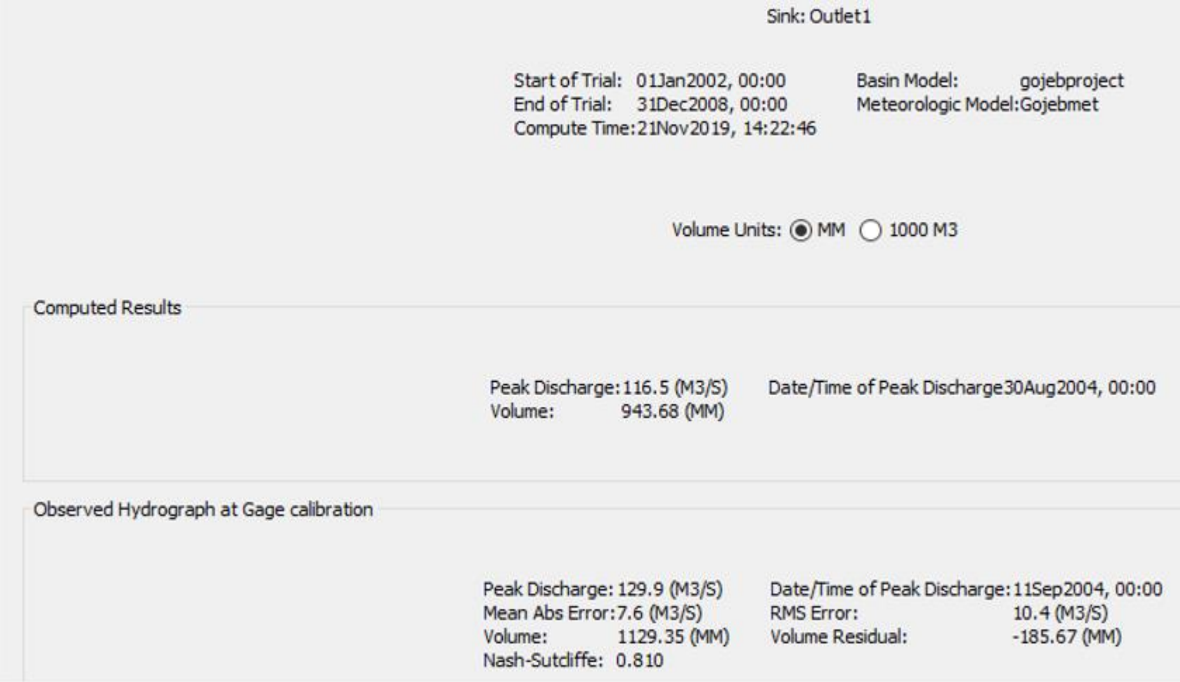
After the first run was conducted, sensitivity analysis test was done by varying each input parameter within prescribed range and keeping the others constant then by running the model. The output values were analyzed based on their variations with respect to peak discharge and runoff volume. A sensitivity analysis was done to identify the most sensitive parameter from the loss, transform, and channel routing methods. It was found that from five parameters K, X parameter shows a big variation on peak discharge and volume of observed and simulated. Therefore, K, X are the most sensitive parameters, CN and initial abstraction is sensitive and lag time is less sensitive. The rank of sensitivity of the parameters was depend on the variation in discharge and volume due to each parameter.

Table 4.2: Ranking Model Parameters Based on Sensitivity Analysis

Model Parameter	Minimum Optimized value	Maximum Optimized value	Ranking
K	19.012	150	1
X	0.0043	0.5	2
Curve Number	80.35	99	3
Initial Abstraction	8.88	12.705	4
Lag Time(min)	243.5	510.97	5

For calibration, purpose data from 2002 to 2008 was used. Due to the variation of observed and simulated flow in simulated run calibration uses observed stream flow data in a systematic search for parameters that yield the best fit of the computed results to the observed runoff. This search referred as optimization. Optimization begins from initial parameter estimates and adjusts by using different trail until the simulated results match the observed stream flow as closely as possible. The HEC-HMS built-in automatic optimization procedure was used to authenticate the acceptability and suitability of the parameter values and their ranges as applicable to their uses in HEC-HMS.

The most sensitive parameters identified above was optimized X and K values until the simulated value resembles with the observed data. For this study, both manual and automated calibration methods were used. Finally, as shown in figure below the simulated value was correlated with the observed data.



Sink: Outlet1

Start of Trial: 01Jan2002, 00:00
End of Trial: 31Dec2008, 00:00
Compute Time: 21Nov2019, 14:22:46
Basin Model: gojebproject
Meteorologic Model: Gojebmet

Volume Units: ● MM ○ 1000 M3

Computed Results

Peak Discharge: 116.5 (M3/S)
Volume: 943.68 (MM)
Date/Time of Peak Discharge 30Aug2004, 00:00

Observed Hydrograph at Gage calibration

Peak Discharge: 129.9 (M3/S)
Mean Abs Error: 7.6 (M3/S)
Volume: 1129.35 (MM)
Nash-Sutcliffe: 0.810
Date/Time of Peak Discharge: 11Sep2004, 00:00
RMS Error: 10.4 (M3/S)
Volume Residual: -185.67 (MM)

Figure 4.2: Summary result for Calibration

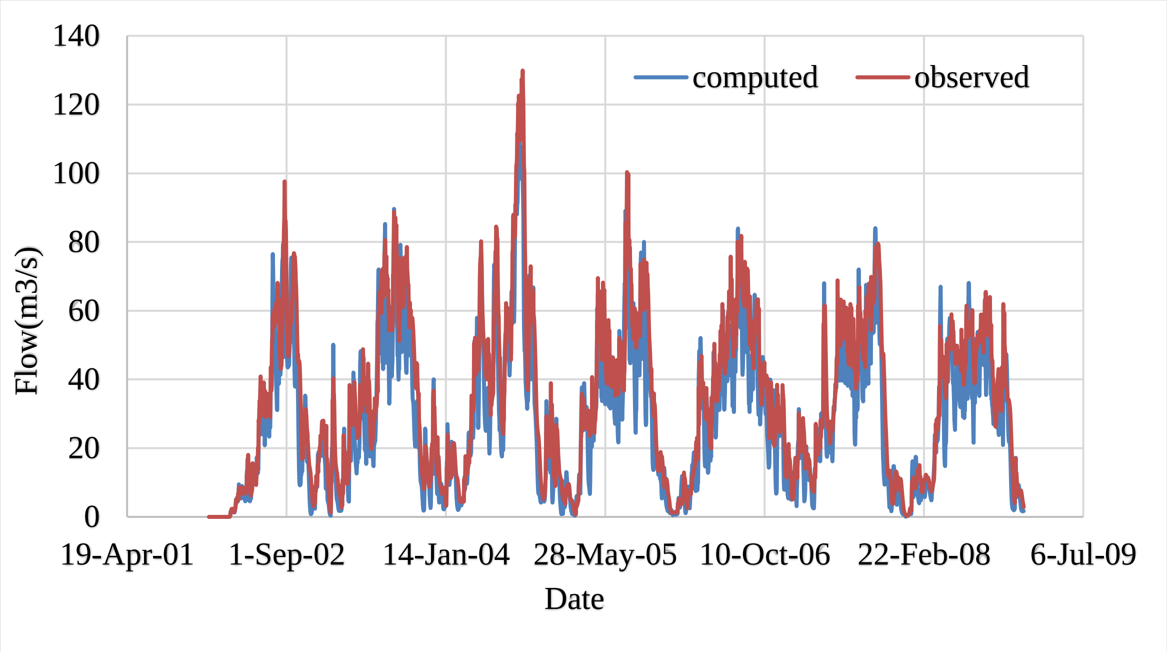


Figure 4.3: Daily computed and observed flow hydrograph for calibration

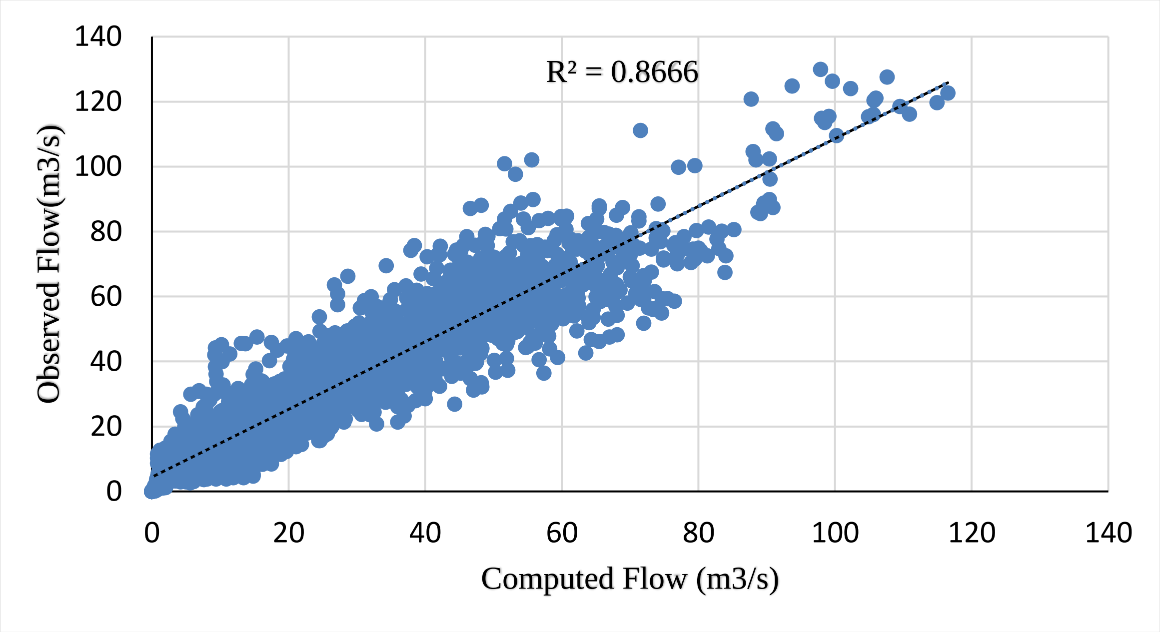
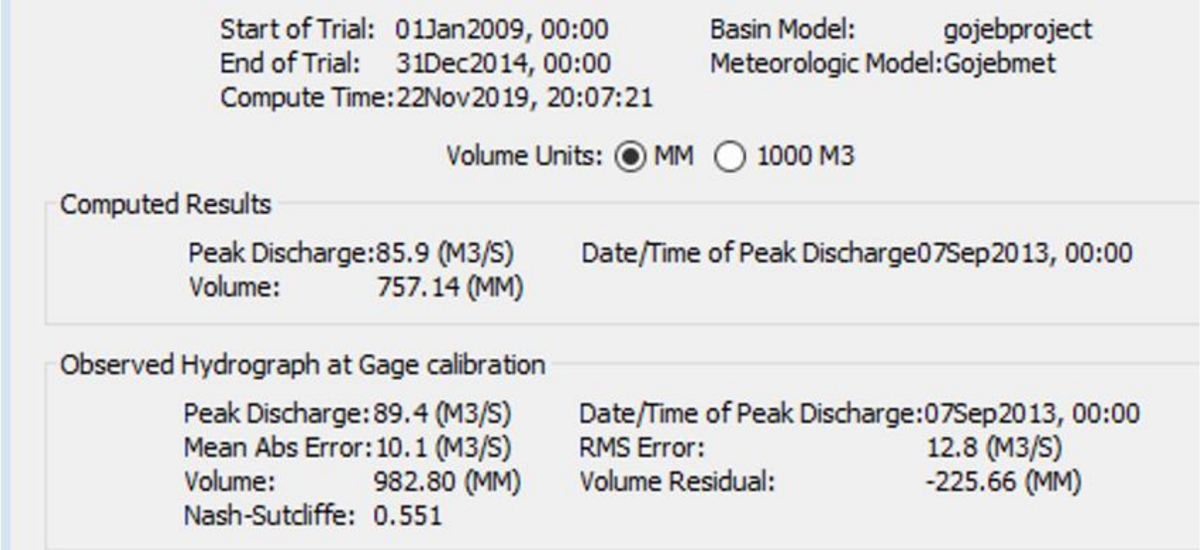


Figure 4.4: Coefficient of determination during calibration Model

4.3 Validation

Validation was conducted by using the parameter which is adjusted during calibration to simulate runoff over an independent period outside the calibration period from 2009-2014. For validation, the simulated data as predicted by the model was computed and compared with the observed data by using figure. As shown in figure below the two data were correlated in a good range.



Start of Trial: 01Jan2009, 00:00
End of Trial: 31Dec2014, 00:00
Compute Time: 22Nov2019, 20:07:21

Basin Model: gojebproject
Meteorologic Model: Gojebmet

Volume Units: ● MM ○ 1000 M3

Computed Results

Peak Discharge: 85.9 (M3/S)
Volume: 757.14 (MM)
Date/Time of Peak Discharge 07Sep2013, 00:00

Observed Hydrograph at Gage calibration

Peak Discharge: 89.4 (M3/S)
Mean Abs Error: 10.1 (M3/S)
Volume: 982.80 (MM)
Nash-Sutcliffe: 0.551
Date/Time of Peak Discharge: 07Sep2013, 00:00
RMS Error: 12.8 (M3/S)
Volume Residual: -225.66 (MM)

Figure 4.5: Summary result for Validation

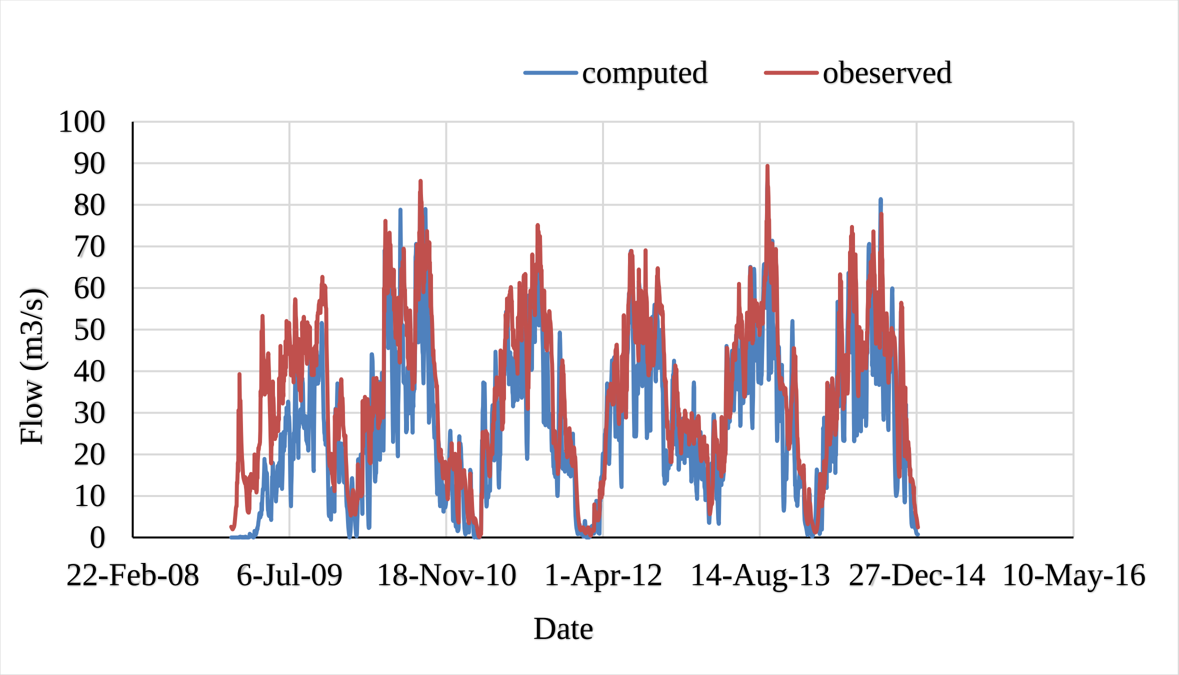


Figure 4.6: Daily Simulated and observed hydrograph for validation

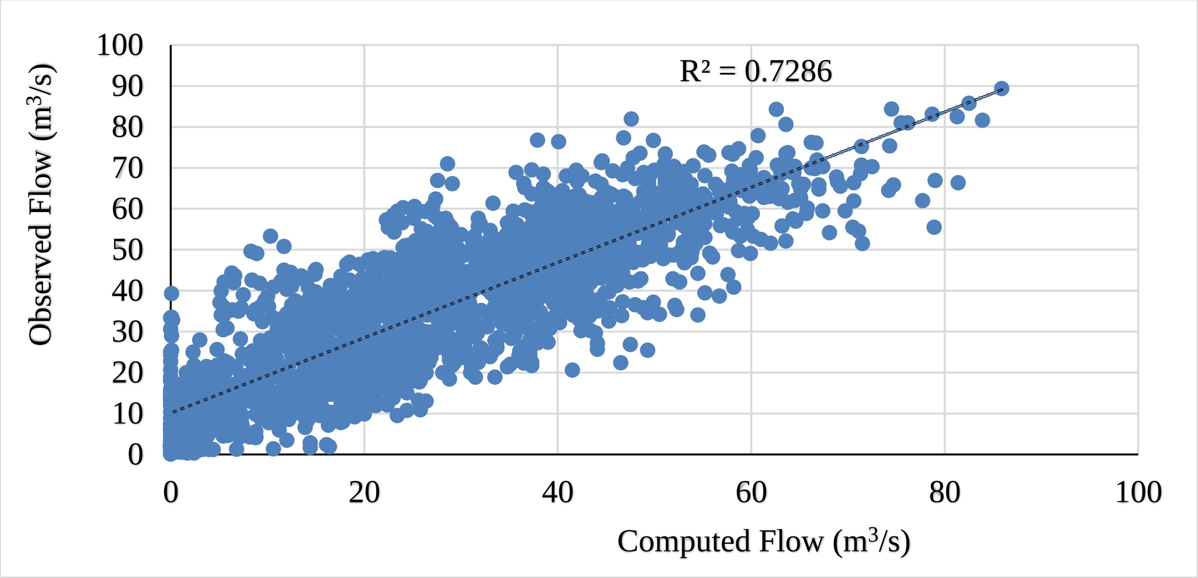


Figure 4.7: Coefficient of determination during validation

4.4 Performance of the Model

After calibration and validation, the performance of HEC-HMS model was checked by using various standard statistical test of error function.

In calibration, this standard statistical test of error functions was PEV (percentage error in simulated volume), PEP (percentage error in simulated peak), NSE (Nash-Sutcliffe model efficiency), coefficient of determination (R^2) and PBIAS the result for each show 16.44%, 10.3%, 0.810, 0.86 and 16.44% respectively. Depend on the standard in calibration the value of R^2, PEP and NSE shows in very good range of performance. The other standard test PEV and PBIAS exist in the range of satisfactory.

For validation, the result of PVE, PEP, NSE, R^2 and PBIAS shows that 22.9%, 3.9%, 0.551, 0.73 and 22.9 respectively. Depend on the standard of model performance PEV. NSE and PBIAS shows in satisfactory range. The remaining PEP exist in very good range and R^2 is in good range. Depending on the general performance rating standard shown in table 4.4 the result shows that HEC-HMS model performs well for Gojeb watershed. The result from HEC-HMS shows that the runoff generated from precipitation was matched with the observed stream flow.

Table 4.3: General Performance rating

No	Performance Rating	PEV (%)	PEP (%)	NSE	R^2	PBIAS (%)
1	Very Good	<±10	<15%	0.75-1	0.75-1	<±10
2	Good	±10 - ±15	15% - 30%	0.65-0.75	0.65-0.75	±10 - ±15
3	Satisfactory	±15 - ±25	30% - 40%	0.50-0.65	0.50-0.65	±15 - ±25
4	Un Satisfactory	>±25	>40%	<0.50	<0.50	≥±25

(Source: Oeurng, 2017).

4.5 Runoff potential of the catchment

The relation between precipitation and simulated surface runoff was depends on many factors like watershed and meteorology. This relation was shown in formula in Figure 4.8. By using this formula for the watershed the discharge is calculated by using different rainfall events.

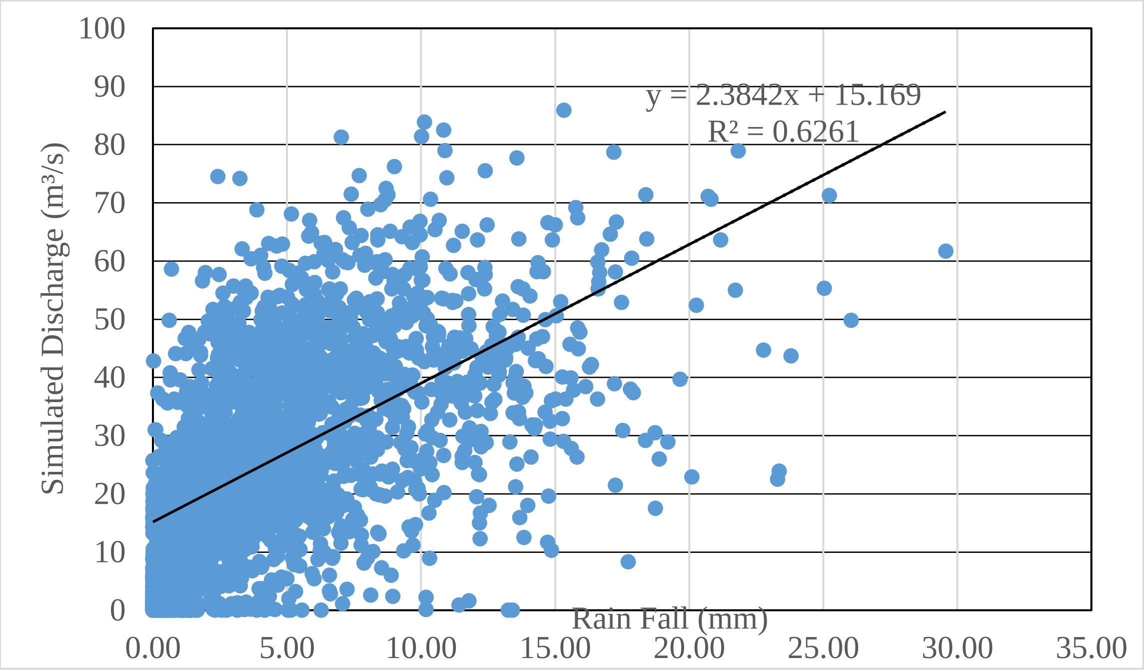


Figure 4.8: Relationship between simulated discharge and rainfall

The runoff potential was used for different purpose in study area. From HEC-HMS, the result total runoff volume of the river was 1700.8mm. The peak discharge during calibration was 116.5m^3/s and for validation the peak discharge was 85.9m^3/s.

4.6 Spatial distribution of runoff and volume

The distribution of runoff volume and peak discharge for each sub basin within the watershed shows different result. These indicates that the soil data, land use/land cover data and the distribution of rainfall were affect the distribution of runoff and discharge in each sub basin. For sub basin W1070 both peak, discharge and runoff volume were maximum since in this sub watershed, the dominant soil type was orthic aerisols eutric cambisols and dystric fluvisols, which have clay and clay loam texture in this type of soil texture runoff is high. In sub basin W1140, the discharge and runoff volume show minimum value because in this sub basin the dominant land use/land cover type was forest and cultivation therefore, the infiltration is high. The area of the sub-basin and the precipitation distribution also affect the runoff. The area of W1070 sub basin was 848.6km^2 which is higher than other sub basins and the area of W1140 was 172.3km^2 therefore, at W1140 both runoff and peak discharge have minimum value.

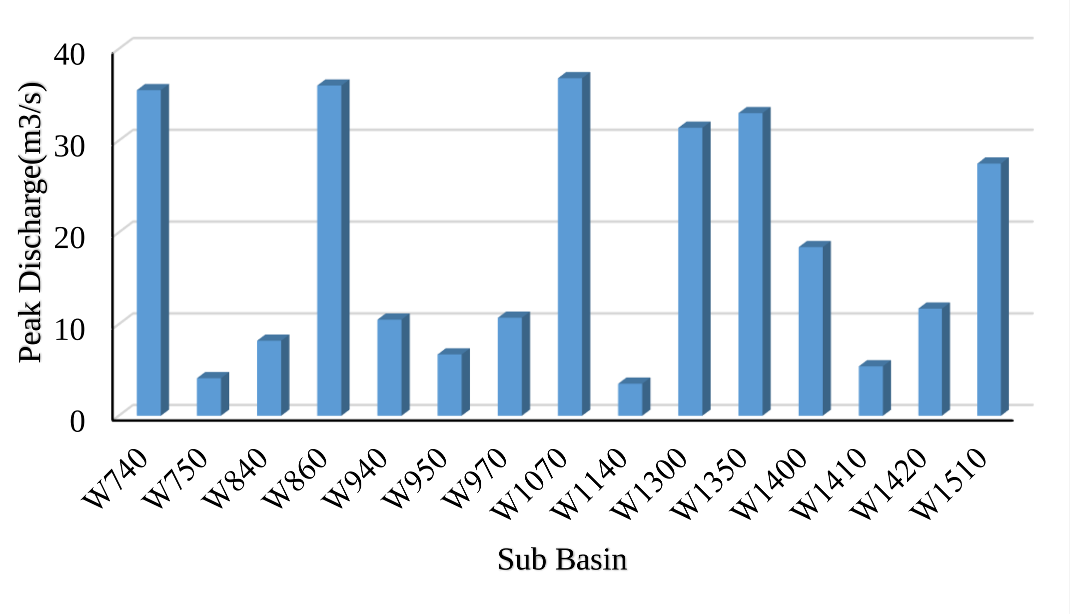


Figure 4.9: Peak discharge for each sub basin

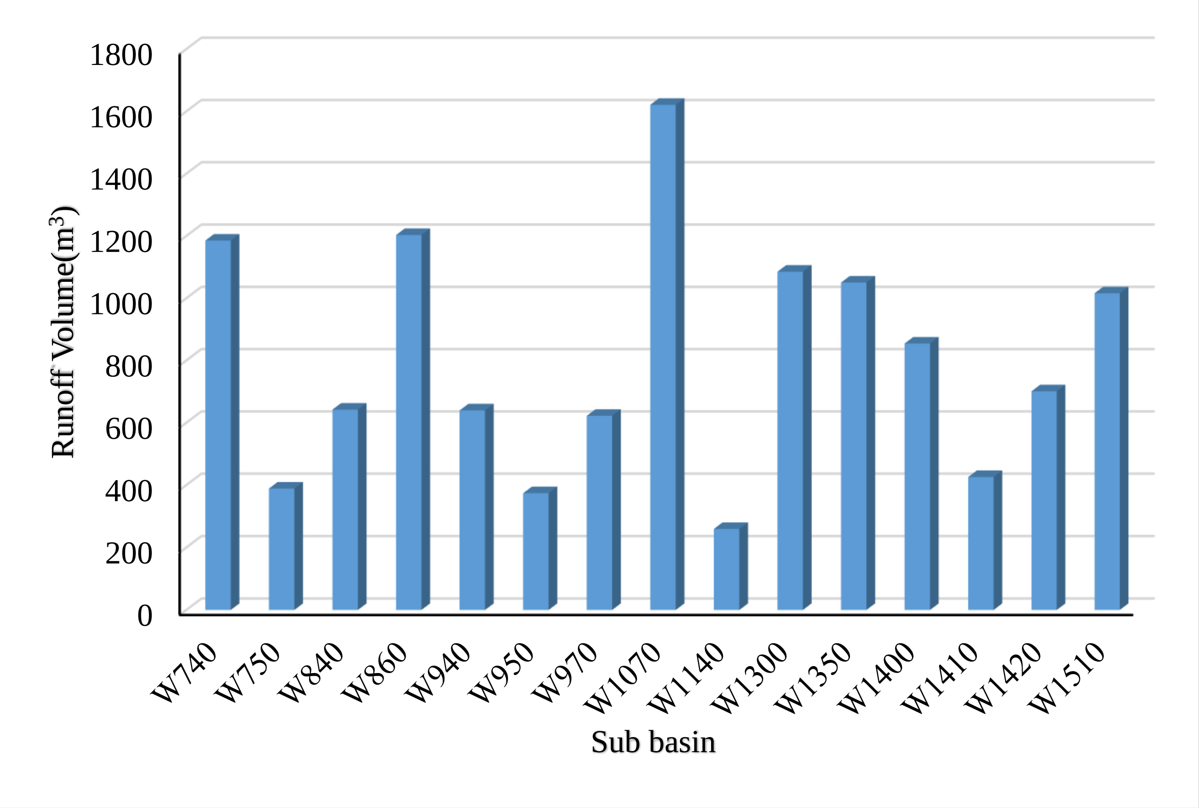


Figure 4.10: Runoff volume for each sub basin

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

By using GIS software and the extension tool HEC-GeoHMS and ArcHydro, the required intial parameters for the HEC-HMS model were provided. They consist of the hydrological data of basin, basin slope, rainfall, the river flow and route, sub-basins, soil hydrological groups, curve number, land use. HEC-HMS hydrological model for runoff simulation was calibrated and validated. To know the most influential parameter in simulation a sensitivity analysis was carried out. The result shows that Muskingum coefficient K and X parameters were identified as sensitive. Optimization was conducted for identified sensitive parameter after different trials the simulated and observed discharge was correlated. The performance of the model for the watershed was checked by using different statically test of error function like Nash-Sutcliffe Efficiency, coefficient of determination, percentage error in simulated volume, percentage error in simulated peak and PBIAS. The overall result shows the model is acceptable and satisfactory in the watershed. The selected methods in the model SCS loss, SCS unit hydrograph, Muskingum and monthly constant have good performance in the watershed. In the watershed, the runoff volume for both during calibrated and validated was 1700.8mm. The peak discharge during calibration and validation was 116.5m3/s and 85.9m3/s respectively. The spatial distribution of peak discharge and runoff volume for each sub basin in the watershed shows variation in sub basin w1070 both runoff volume and peak discharge.

5.2 Recommendation

The methodologies developed in this research can also be applied in other ungauged catchments and regions with similar hydro meteorological and land use characteristics. it is possible to suggest that the calibrated parameters can be further used to other studies in the watershed.

Depending on the result of this study, runoff volume and peak discharge value in the watershed used for further study like flood forecasting, impacts of climate changes on runoff and sediment and water quality.

Flow data of long time duration is necessary for the calibration and validation of hydrologic model. There is a shortage of data availably especially stream flow data, for the future MoWIE should correct such type of problems by taking different measurement. Due to this shortage of data the country may affected by natural hazard problems.

HEC-HMS hydrological model assumed that the land use has been unchanged during modeling period, in reality the land use may change. In the future, further studies, which incorporate the land use change of the watershed is important.

REFERENCES

Abushandi & Eyad, 2013. Modelling Rainfall Runoff Relations Using Hec-Hms and Ihacres for A Single Rain Event In An Arid Region of Jordan. Springer Science+Business Media Dordrecht, Volume 27, P. 2391–2409 .

Arega, S., 2018 . Impact of Climate Change on Surface Water Potential In Borkena Watershed , Jimma: Jimma University .

Ayenew, Y., 2008 . Rainfall-Runoff Modelling for Sustainable Water Resources Management: The Case of Gumara Watershed, Ethiopia , Addis Ababa : Addis Ababa University .

Bhaukajee, J. K. J., 2018 . Rainfall-Runoff Simulation and Modelling Using Hec-Hms and Hec-Ras Models: Case Studies from Nepal And Sweden , Sweden : Lund University .

Caldera, H., Piyathisse, V. & Nandalal, K., 2016. A Comparison of Methods of Estimating Missing Daily Rainfall Data. Engineer, 39(4), Pp. 1-8.

Chang & Chi-Wen, 2009. Application of SCS CN Method In HEC-HMS In Shihmen Watershed Simulation of Rainfall-Runoff Hydrologic Model, Taiwan: Florida State University Libraries.

Choto, M. & Fetene, A., 2019. Impacts of Land Use/Land Cover Change on Stream flow and Sediment Yield of Gojeb Watershed, Omo-Gibe Basin, Ethiopia. Remote Sensing Applications: Society and Environment, Volume 14, Pp. 84-99.

Choudhari, K., Panigrahi, B. & Paul, J. C., 2014. Simulation of Rainfall-Runoff Process Using HEC-HMS Model for Balijore Nala Watershed, Odisha, India. International Journal of Geomatics and Geosciences, 5(2), Pp. 253-265.

Devia, G. K., Pa, G. B. & Sa, D. G., 2015. A Review on Hydrological Models. Elsevier, Pp. 1001-1007.

Gebre, S. L., 2015. Application of The HEC-HMS Model for Runoff Simulation of Upper Blue Nile River Basin. Hydrology Current Research, Pp. 1-8.

Gebre, S. L., 2015. Application of The HEC-HMS Model for Runoff Simulation of Upper Blue Nile River Basin. Hydrology Current Research , Volume 6, Pp. 1-8.

Halwatura, D. & Najim, M., 2013. Application of The HEC-HMS Model for Runoff Simulation In A Tropical Catchment. Environmental Modelling & Software, Pp. 155-162.

Joo, J., Kjeldsen, T., Kim, H.-J. & Lee, H., 2014. A Comparison of Two Event-Based Flood Models (Refh-Rainfall Runoff Model and HEC-HMS) At Two Korean Catchments, Bukil and Jeungpyeong. Ksce Journal of Civil Engineering, Volume 18, Pp. 330-343.

Khadka, J. & Bhaukajee, J., 2018. Rainfall-Runoff Simulation and Modelling Using HEC-HMS and HEC-RAS Models: Case Studies from Nepal and Sweden, Lund: Lund University .

Majidi, A. & Shahedi, K., 2012. Simulation of Rainfall-Runoff Process Using Green-Ampt Method and HEC-HMS Model (Case Study: Abnama Watershed, Iran). International Journal of Hydraulic Engineering, 1(1), Pp. 5-9.

Melesse, D. G. Z. A. A. M., 2018. Applicability of A Spatially Semi-Distributed Hydrological Model for Watershed Scale Runoff Estimation In Northwest Ethiopia. Water, Volume 10, Pp. 1-16.

Oeurng, S. C. A. C., 2017. Flow Simulation In An Ungauged Catchment of Tonle Sap Lake Basin In Cambodia: Application of the HEC-HMS Model. Water Utility Journal , Volume 17, Pp. 3-17.

Okirya Martin1, A. R. &. J. O., 2012. Application of HEC- HMS/RAS and GIS Tools In Flood Modeling: A Case Study for River Sironko – Uganda. Global Institute for Reseach and Education, Pp. 19-31 .

Pechlivanidis, I., Jackson, B., Mclntyre, N. & Wheater, H., 2011. Catchment Scale Hydrological Modelling: A Review of Model Types, Calibration Approaches and Uncertainty Analysis Methods In The Context of Recent Developments In Technology and Applications. Global Nest Journal, Volume 13, Pp. 193-214.

Rathod, P., Borse, K. & V.L.Manekar, 2015. Simulation of Rainfall - Runoff Process Using HEC-HMS (Case Study: Tapi River, India). India, Praveen Rathod; Kalpesh Borse; V.L.Manekar, Pp. 17-19 .

Rinsema, Gert & Jan, 2014. Comparison of Rainfall Runoff Models for The Florentine Catchment, Australia: University of Tasmania:.

Roy, D., Begam, S., Ghosh, S. & Jana, S., 2013. Calibration and Validation of HEC-HMs Model for a River Basin In Eastern India. Arpn Journal of Engineering and Applied Sciences, Volume 8, Pp. 40-56.

Sardoii, E. R., Rostami, N., Sigaroudi, S. K. & Taheri, S., 2012. Calibration of Loss Estimation Methods In HEC-HMS for Simulation of Surface Runoff (Case Study: Amirkabir Dam Watershed, Iran). Advances In Environmental Biology, 6(1), Pp. 343-348.

Silva, M. M. G. T. D., Weerakoon, S. B. & Herath, S., 2014. Modeling of Event and Continuous flow Hydrographs with HEC–HMS:Case study in the kelani river basin,Srilanka. Journal of Hydrologic Engineering, 19(4), Pp. 800-806.

Silva, R. P. D., Dayawansa, N. & Ratnasiri, M. D., 2007. A Comparison of Methods Used in Estimating Missing Rainfall Data. The Journal of Agricultural Sciences, 3(2), Pp. 101-108.

Sitterson, J. Et Al., 2017. An Overview of Rainfall-Runoff Model Types, Athens: Office of Research and Development National Exposure Research Laboratory.

Sonu Duhan, M. K., 2017. Event and Continuous Hydrological Modeling with HEC-HMS: A Review Study. International Journal of Engineering Technology Science and Research, Pp. 61-66.

Tassew, B. G., Belete, M. A. & Miegel, K., 2019. Application of HEC-HMS Model for Flow Simulation In the Lake Tana Basin: The Case of Gilgel Abay Catchment, Upper Blue Nile Basin, Ethiopia. Hydrology, 6(21), Pp. 1-17.

Udhavrao, J. P., 2014 . Event Based Rainfall-Runoff Simulation Using HEC-HMS Model , Dapoli : Department of Soil and Water Conservation Engineering College of Agricultural Engineering and Technology .

Udhavrao, J. P., 2014. Event Based Rainfall-Runoff Simulation Using HEC-HMS Model , Dapoli : Master of Technology (Agricultural Engineering.

Vidyapeeth, D. B. S. K. K., 2014. Event Based Rainfall-Runoff Simulation Using HEC-HMS Model , Maharashtra, India. : Jaybhaye Pradeep Udhavrao .

Wheate, Pechlivanidis, I., Jackson, B. & Mcintyre H.S., N., 2011. Catchment Scale Hydrological Modelling: A Review of Model Types, Calibration Approaches and

Uncertainty Analysis Methods in The Context of Recent Developments In Technology and Applications. Global nest International Journal, Pp. 193-214.

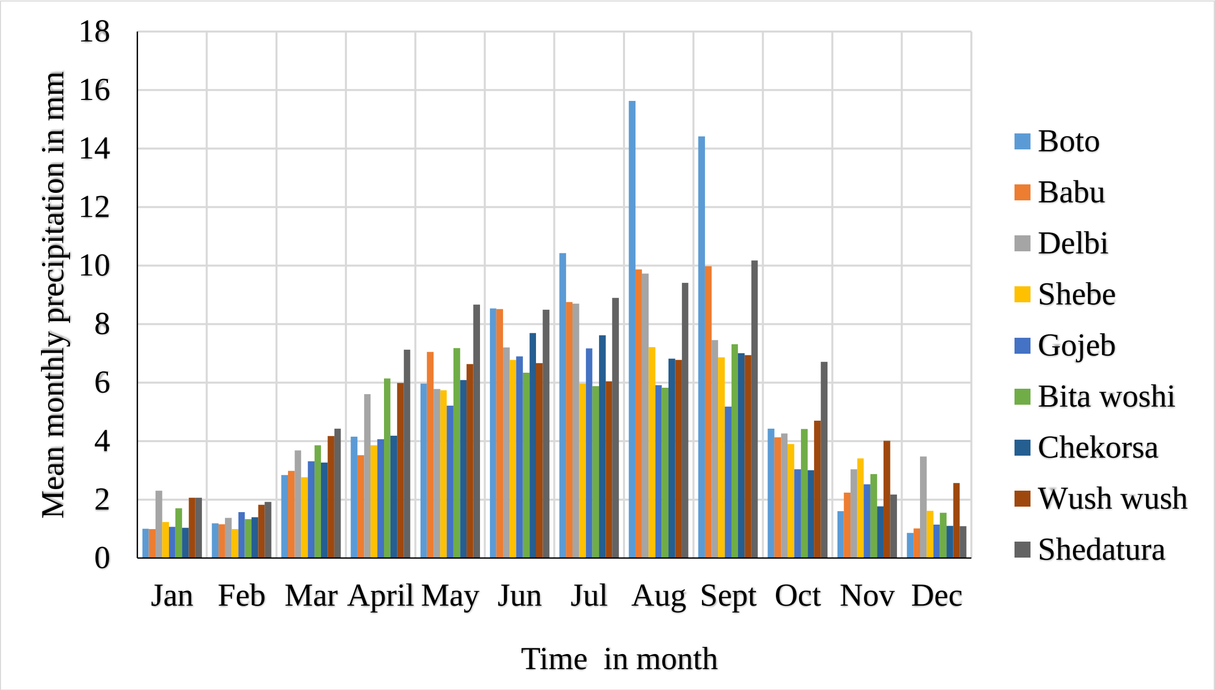
APPENDIX

Appendix A: The location of metrological station in the watershed.

S.No	Stations Name	Latitude	Longitude	Elevation	Year
1	Boto	7.7	36.5	1870	2002-2014
2	Babu	7.12	36.67	1880	2002-2014
3	Bita Woshi	7.3	36	1836	2002-2014
4	Chekorsa	7.62	36.73	1770	2002-2014
5	Gojeb	7.42	36.38	1250	2002-2014
6	Delbi	7.4	36.87	2100	2002-2014
7	Shebe	7.52	36.52	1635	2002-2014
8	Shedatura	7.27	36.38	1800	2002-2014
9	Wush Wush	7.2	36.133	1620	2002-2014

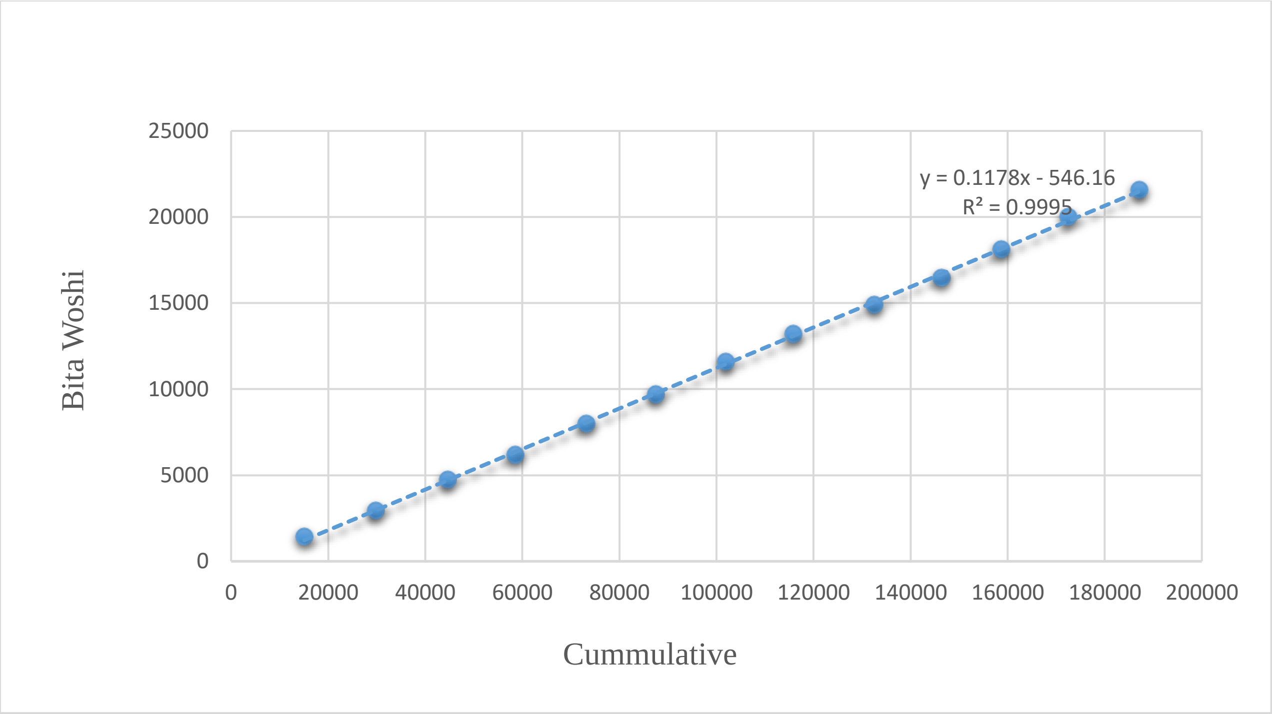
Appendix B: Mean monthly Rainfall for each station and their Double mass curve

Month	Boto	Babu	Delbi	Shebe	Gojeb	Bita woshi	Chekorsa	Wush-Wush	Shedatura
Jan	1.001	0.990	2.3048	1.2280	1.0618	1.7024	1.0333	2.0657	2.0606
Feb	1.186	1.152	1.3769	0.9902	1.5649	1.3283	1.3962	1.8223	1.9205
Mar	2.8403	2.9816	3.6754	2.7586	3.3093	3.8553	3.2651	4.1722	4.4280
April	4.1523	3.5151	5.6074	3.8541	4.0676	6.1385	4.1774	5.9879	7.1197
May	5.9692	7.0462	5.7837	5.7303	5.2154	7.1756	6.0812	6.6333	8.6638
Jun	8.5315	8.5069	7.2046	6.7767	6.8928	6.3333	7.6956	6.6609	8.4901
Jul	10.424	8.7540	8.6923	5.9606	7.1694	5.8801	7.6102	6.0426	8.8988
Aug	15.623	9.8618	9.7229	7.2104	5.9084	5.8263	6.8184	6.7730	9.4065
Sept	14.413	9.9733	7.4483	6.8557	5.1792	7.3074	6.9985	6.9345	10.1723
Oct	4.4227	4.1325	4.2604	3.9019	3.0381	4.4156	2.9985	4.6957	6.7035
Nov	1.6040	2.2333	3.0339	3.4017	2.5194	2.8661	1.7685	4.0119	2.1738
Dec	0.8561	1.0119	3.4675	1.6159	1.1473	1.5499	1.0978	2.5591	1.0914



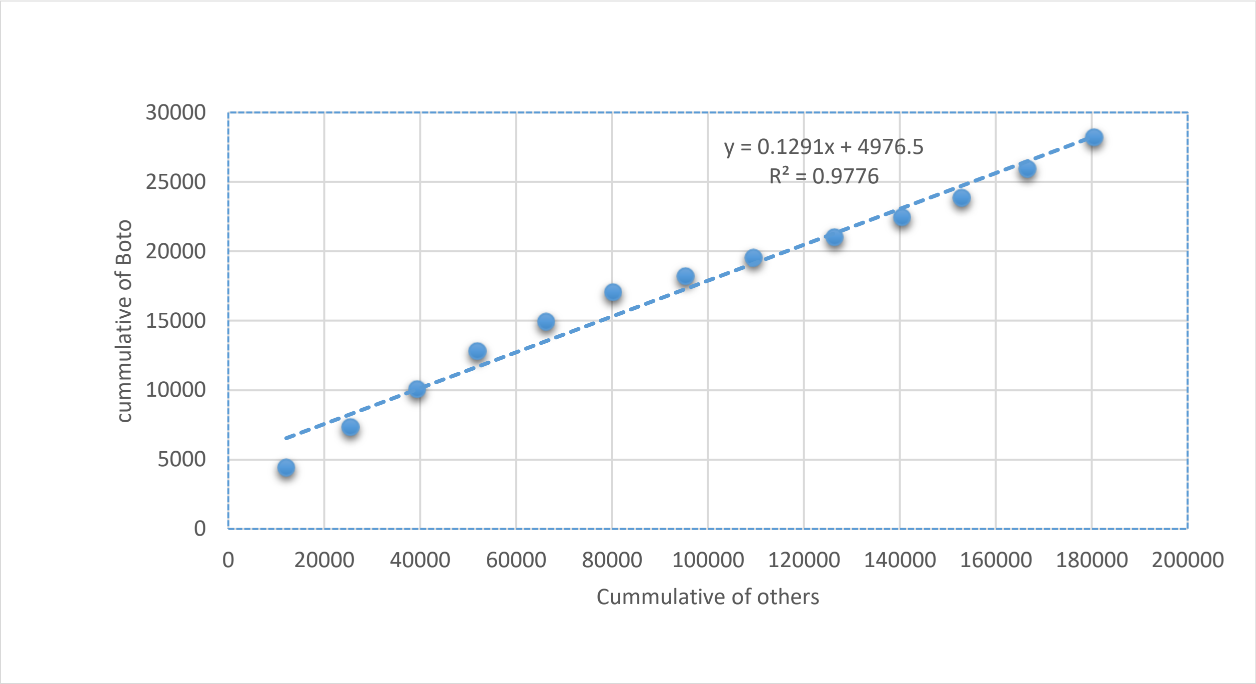
Appendix C: Double mass curve for Bita Woshi station.

Babu	Shebe	Boto	Gojeb	Delbi	Chekorsa	Shedatura	wush wush	Sum	Cumm	Bita Woshi
1695.1	1124.0	4411.1	1740.7	1772.4	1393.4	1467.7	1459.0	15063.4	15063.4	1429.5
1768.4	1186.1	2901.4	1475.9	2184.2	1435.7	2193.9	1650.6	14796.2	29859.6	2950.3
1789.4	1336.6	2757.8	1607.7	2714.1	1185.6	1538.3	1861.6	14791.2	44650.8	4750.7
1533.3	1539.3	2722.3	1353.8	1820.9	1141.5	2056.8	1769.3	13937.1	58587.9	6174.4
1853.4	1743.9	2140.0	1499.9	1943.0	1493.0	1987.6	1956.9	14617.7	73205.6	7989.7
1612.6	1568.9	2107.1	1347.8	1585.5	1350.9	3003.8	1757.5	14334.1	87539.7	9698.1
1954.6	1339.5	1148.6	1520.4	1463.1	1536.1	3686.0	1786.8	14435.1	101974.9	11590.3
1539.0	2185.2	1328.2	1493.5	1701.6	1677.5	1950.2	1996.7	13872.0	115846.8	13205.4
2284.0	1923.2	1498.6	1567.6	1840.3	2104.1	3681.5	1810.8	16710.1	132556.9	14892.7
1867.7	1762.5	1447.5	1339.6	1971.3	1777.8	2001.0	1693.6	13861.0	146417.9	16467.6
2121.4	1308.9	1395.0	1218.7	1777.0	1268.3	1325.3	1828.6	12243.1	158661.0	18122.0
2345.8	1553.8	2083.5	1283.3	2112.2	1476.7	1329.7	1675.5	13860.5	172521.5	19996.0
1522.8	1385.4	2266.5	1222.8	1980.9	2369.9	2010.6	1899.5	14658.3	187179.8	21572.5



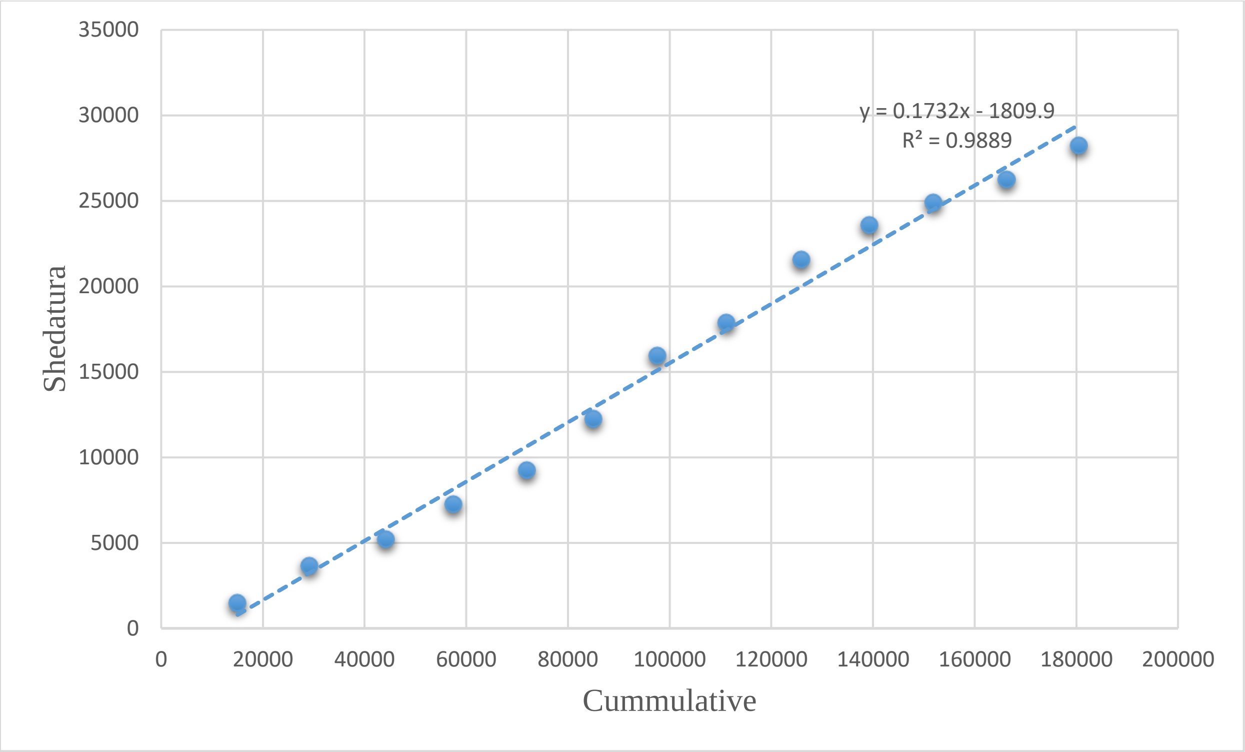
Appendix D: Double mass curve for Boto station.

Babu	Delbi	Shebe	Gojeb	Bita woshi	Chekorsa	Shedatura	wush wush	sum	Cum.	Boto cum.
1695.1	1772.4	1124.0	1740.7	1429.5	1393.4	1467.7	1459.0	12081.8	12081.8	4411.1
1768.4	2184.2	1186.1	1475.9	1520.8	1435.7	2193.9	1650.6	13415.6	25497.4	7312.5
1789.4	2714.1	1336.6	1607.7	1800.4	1185.6	1538.3	1861.6	13833.8	39331.2	10070.3
1533.3	1820.9	1539.3	1353.8	1423.7	1141.5	2056.8	1769.3	12638.6	51969.7	12792.6
1853.4	1943.0	1743.9	1499.9	1815.3	1493.0	1987.6	1956.9	14293.0	66262.7	14932.6
1612.6	1585.5	1568.9	1347.8	1708.4	1350.9	3003.8	1757.5	13935.4	80198.2	17039.7
1954.6	1463.1	1339.5	1520.4	1892.2	1536.1	3686.0	1786.8	15178.7	95376.9	18188.3
1539.0	1701.6	2185.2	1493.5	1615.1	1677.5	1950.2	1996.7	14158.9	109535.8	19516.5
2284.0	1840.3	1923.2	1567.6	1687.3	2104.1	3681.5	1810.8	16898.8	126434.6	21015.1
1867.7	1971.3	1762.5	1339.6	1574.9	1777.8	2001.0	1693.6	13988.4	140422.9	22462.5
2121.4	1777.0	1308.9	1218.7	1654.4	1268.3	1325.3	1828.6	12502.5	152925.4	23857.6
2345.8	2112.2	1553.8	1283.3	1874.0	1476.7	1329.7	1675.5	13651.0	166576.4	25941.1
1522.8	1980.9	1385.4	1222.8	1576.5	2369.9	2010.6	1899.5	13968.3	180544.7	28207.6



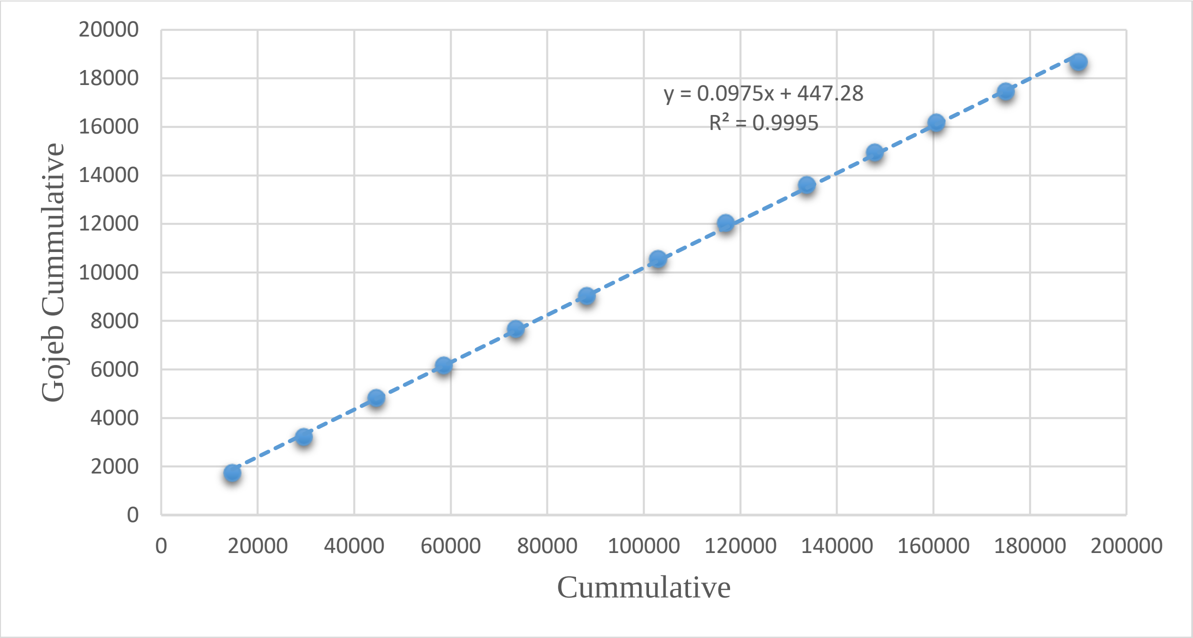
Appendix E: Double mass curve for Shedatura station.

Babu	Shebe	Boto	Gojeb	Delbi	Chekorsa	wush wush	Bita woshi	Sum	Cum.	Shedatura
1695.1	1124.0	4411.1	1740.7	1772.4	1393.4	1459.0	1429.5	15025.2	15025.2	1467.7
1768.4	1186.1	2901.4	1475.9	2184.2	1435.7	1650.6	1520.8	14123.1	29148.3	3661.6
1789.4	1336.6	2757.8	1607.7	2714.1	1185.6	1861.6	1800.4	15053.3	44201.5	5199.9
1533.3	1539.3	2722.3	1353.8	1820.9	1141.5	1769.3	1423.7	13304.0	57505.6	7256.7
1853.4	1743.9	2140.0	1499.9	1943.0	1493.0	1956.9	1815.3	14445.4	71951.0	9244.3
1612.6	1568.9	2107.1	1347.8	1585.5	1350.9	1757.5	1708.4	13038.7	84989.7	12248.1
1954.6	1339.5	1148.6	1520.4	1463.1	1536.1	1786.8	1892.2	12641.3	97631.0	15934.1
1539.0	2185.2	1328.2	1493.5	1701.6	1677.5	1996.7	1615.1	13536.9	111167.9	17884.3
2284.0	1923.2	1498.6	1567.6	1840.3	2104.1	1810.8	1687.3	14715.9	125883.8	21565.8
1867.7	1762.5	1447.5	1339.6	1971.3	1777.8	1693.6	1574.9	13434.9	139318.7	23566.8
2121.4	1308.9	1395.0	1218.7	1777.0	1268.3	1828.6	1654.4	12572.2	151890.9	24892.1
2345.8	1553.8	2083.5	1283.3	2112.2	1476.7	1675.5	1874.0	14404.8	166295.7	26221.8
1522.8	1385.4	2266.5	1222.8	1980.9	2369.9	1899.5	1576.5	14224.2	180519.9	28232.4



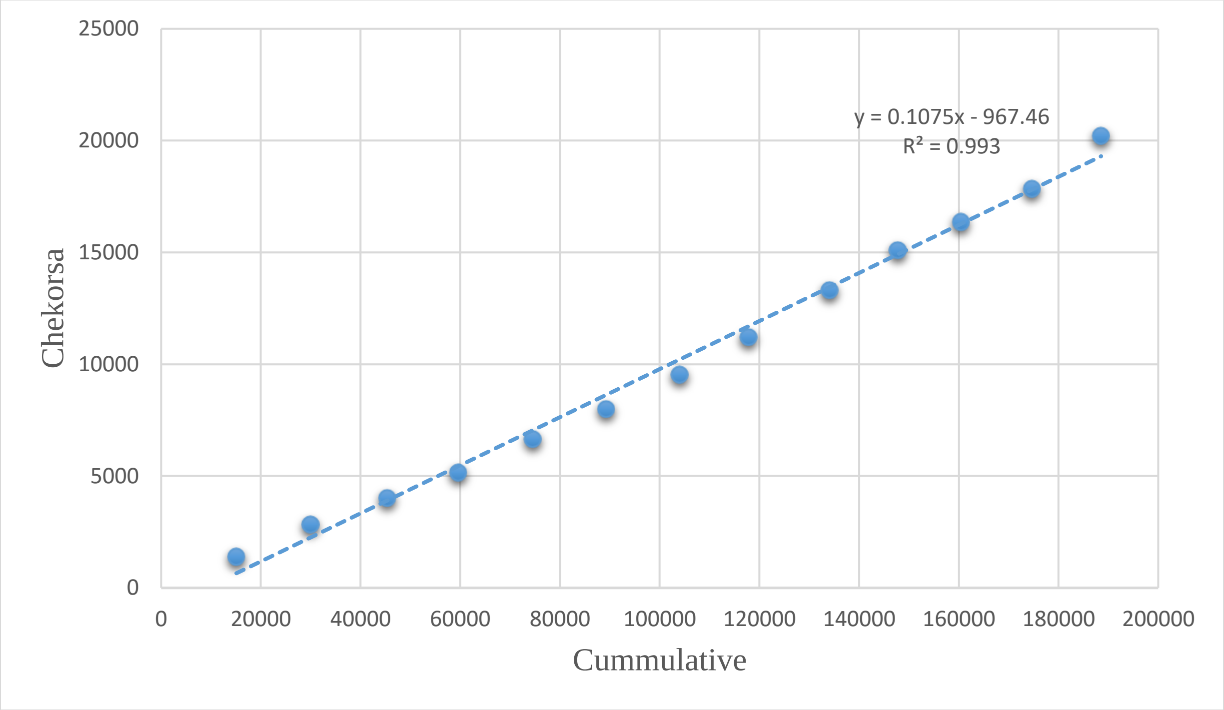
Appendix F: Double mass curve for Gojeb station.

Babu	Shebe	Boto	Delbi	Chekorsa	wush wush	Bita woshi	Shedatura	Sum	Cum.	Gojeb Cumm
1695.1	1124.0	4411.1	1772.4	1393.4	1459.0	1429.5	1467.7	14752.2	14752.2	1740.7
1768.4	1186.1	2901.4	2184.2	1435.7	1650.6	1520.8	2193.9	14841.1	29593.3	3216.6
1789.4	1336.6	2757.8	2714.1	1185.6	1861.6	1800.4	1538.3	14983.8	44577.1	4824.3
1533.3	1539.3	2722.3	1820.9	1141.5	1769.3	1423.7	2056.8	14007.0	58584.2	6178.1
1853.4	1743.9	2140.0	1943.0	1493.0	1956.9	1815.3	1987.6	14933.1	73517.3	7678.0
1612.6	1568.9	2107.1	1585.5	1350.9	1757.5	1708.4	3003.8	14694.7	88212.0	9025.8
1954.6	1339.5	1148.6	1463.1	1536.1	1786.8	1892.2	3686.0	14806.9	103018.9	10546.2
1539.0	2185.2	1328.2	1701.6	1677.5	1996.7	1615.1	1950.2	13993.6	117012.5	12039.7
2284.0	1923.2	1498.6	1840.3	2104.1	1810.8	1687.3	3681.5	16829.8	133842.3	13607.3
1867.7	1762.5	1447.5	1971.3	1777.8	1693.6	1574.9	2001.0	14096.2	147938.5	14946.9
2121.4	1308.9	1395.0	1777.0	1268.3	1828.6	1654.4	1325.3	12678.8	160617.3	16165.6
2345.8	1553.8	2083.5	2112.2	1476.7	1675.5	1874.0	1329.7	14451.2	175068.6	17448.9
1522.8	1385.4	2266.5	1980.9	2369.9	1899.5	1576.5	2010.6	15012.1	190080.6	18671.7



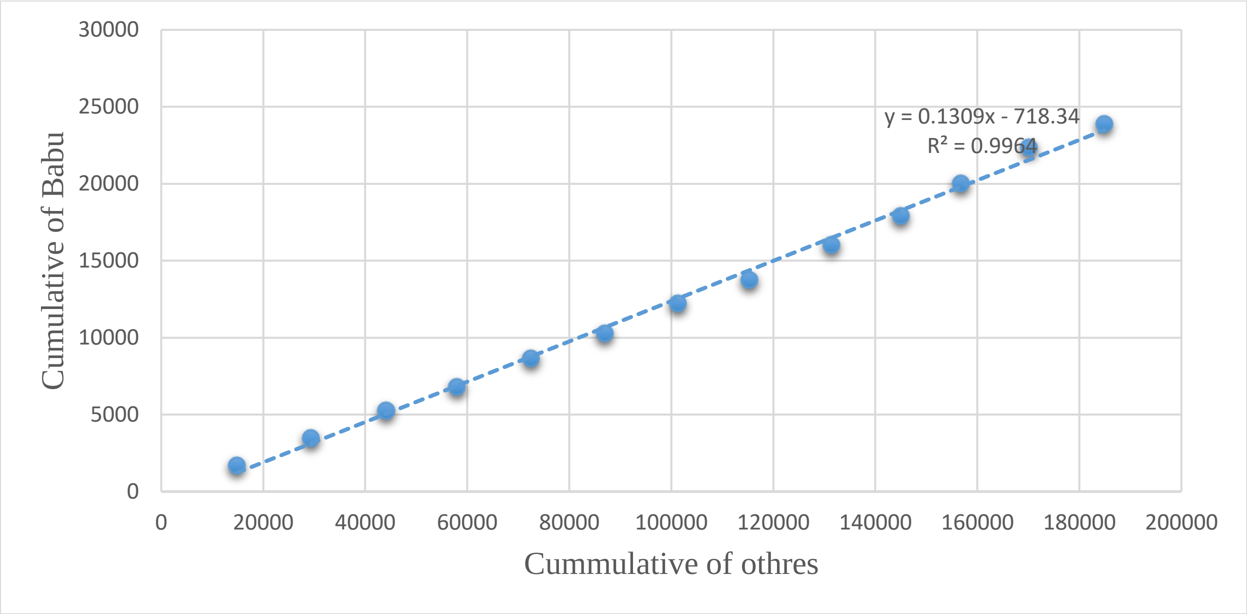
Appendix G: Double mass curve for Chekorsa station.

Shebe	Boto	Babu	Delbi	Gojeb	wush wush	Bita woshi	Shedatura	Sum	Cum.	Chekorsa
1124.0	4411.1	1695.1	1772.4	1740.7	1459.0	1429.5	1467.7	15099.5	15099.5	1393.4
1186.1	2901.4	1768.4	2184.2	1475.9	1650.6	1520.8	2193.9	14881.3	29980.8	2829.1
1336.6	2757.8	1789.4	2714.1	1607.7	1861.6	1800.4	1538.3	15406.0	45386.8	4014.7
1539.3	2722.3	1533.3	1820.9	1353.8	1769.3	1423.7	2056.8	14219.3	59606.1	5156.2
1743.9	2140.0	1853.4	1943.0	1499.9	1956.9	1815.3	1987.6	14940.0	74546.1	6649.2
1568.9	2107.1	1612.6	1585.5	1347.8	1757.5	1708.4	3003.8	14691.6	89237.7	8000.1
1339.5	1148.6	1954.6	1463.1	1520.4	1786.8	1892.2	3686.0	14791.2	104028.9	9536.2
2185.2	1328.2	1539.0	1701.6	1493.5	1996.7	1615.1	1950.2	13809.6	117838.5	11213.7
1923.2	1498.6	2284.0	1840.3	1567.6	1810.8	1687.3	3681.5	16293.3	134131.8	13317.8
1762.5	1447.5	1867.7	1971.3	1339.6	1693.6	1574.9	2001.0	13658.0	147789.9	15095.6
1308.9	1395.0	2121.4	1777.0	1218.7	1828.6	1654.4	1325.3	12629.2	160419.1	16363.9
1553.8	2083.5	2345.8	2112.2	1283.3	1675.5	1874.0	1329.7	14257.8	174676.9	17840.6
1385.4	2266.5	1522.8	1980.9	1222.8	1899.5	1576.5	2010.6	13864.9	188541.8	20210.5



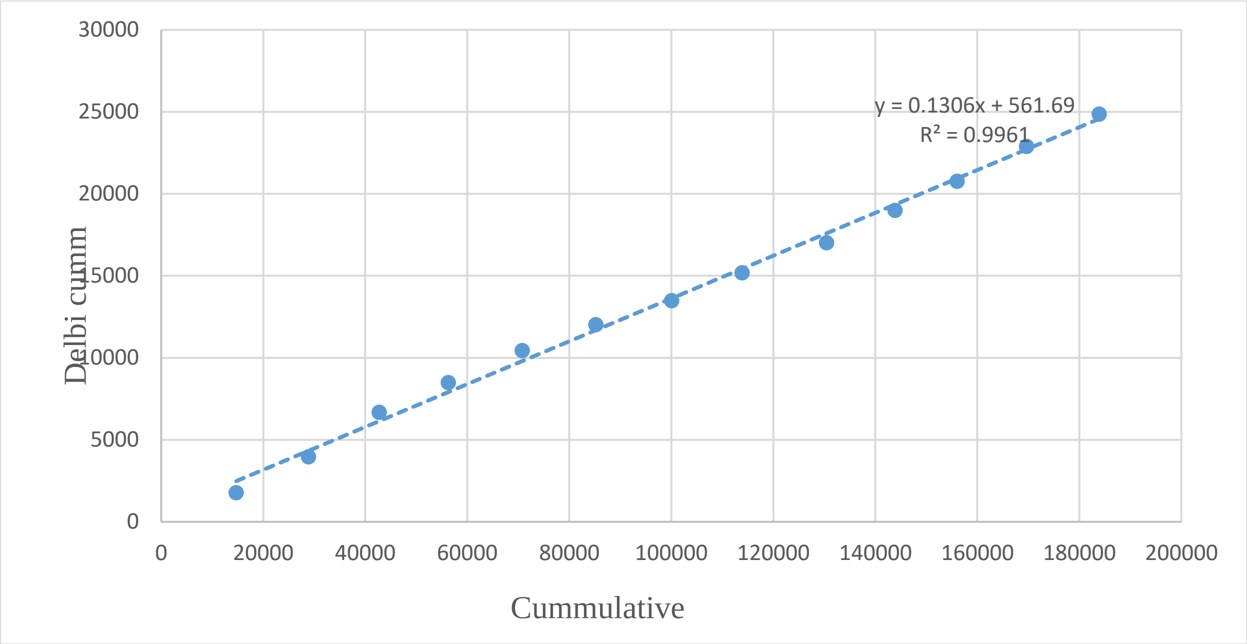
Appendix H: Double mass curve for Babu station.

Delbi	Shebe	Gojeb	Bita woshi	Chekorsa	Shedatura	wush wush	Boto	Sum	Cum.	Cum.of Babu
1772.4	1124.0	1740.7	1429.5	1393.4	1467.7	1459.0	4411.1	14797.8	14797.8	1695.1
2184.2	1186.1	1475.9	1520.8	1435.7	2193.9	1650.6	2901.4	14548.6	29346.4	3463.5
2714.1	1336.6	1607.7	1800.4	1185.6	1538.3	1861.6	2757.8	14802.2	44148.6	5252.9
1820.9	1539.3	1353.8	1423.7	1141.5	2056.8	1769.3	2722.3	13827.5	57976.1	6786.2
1943.0	1743.9	1499.9	1815.3	1493.0	1987.6	1956.9	2140.0	14579.6	72555.6	8639.6
1585.5	1568.9	1347.8	1708.4	1350.9	3003.8	1757.5	2107.1	14429.9	86985.6	10252.2
1463.1	1339.5	1520.4	1892.2	1536.1	3686.0	1786.8	1148.6	14372.7	101358.3	12206.8
1701.6	2185.2	1493.5	1615.1	1677.5	1950.2	1996.7	1328.2	13948.1	115306.4	13745.9
1840.3	1923.2	1567.6	1687.3	2104.1	3681.5	1810.8	1498.6	16113.4	131419.8	16029.9
1971.3	1762.5	1339.6	1574.9	1777.8	2001.0	1693.6	1447.5	13568.1	144987.9	17897.6
1777.0	1308.9	1218.7	1654.4	1268.3	1325.3	1828.6	1395.0	11776.2	156764.1	20018.9
2112.2	1553.8	1283.3	1874.0	1476.7	1329.7	1675.5	2083.5	13388.7	170152.7	22364.7
1980.9	1385.4	1222.8	1576.5	2369.9	2010.6	1899.5	2266.5	14712.0	184864.8	23887.5



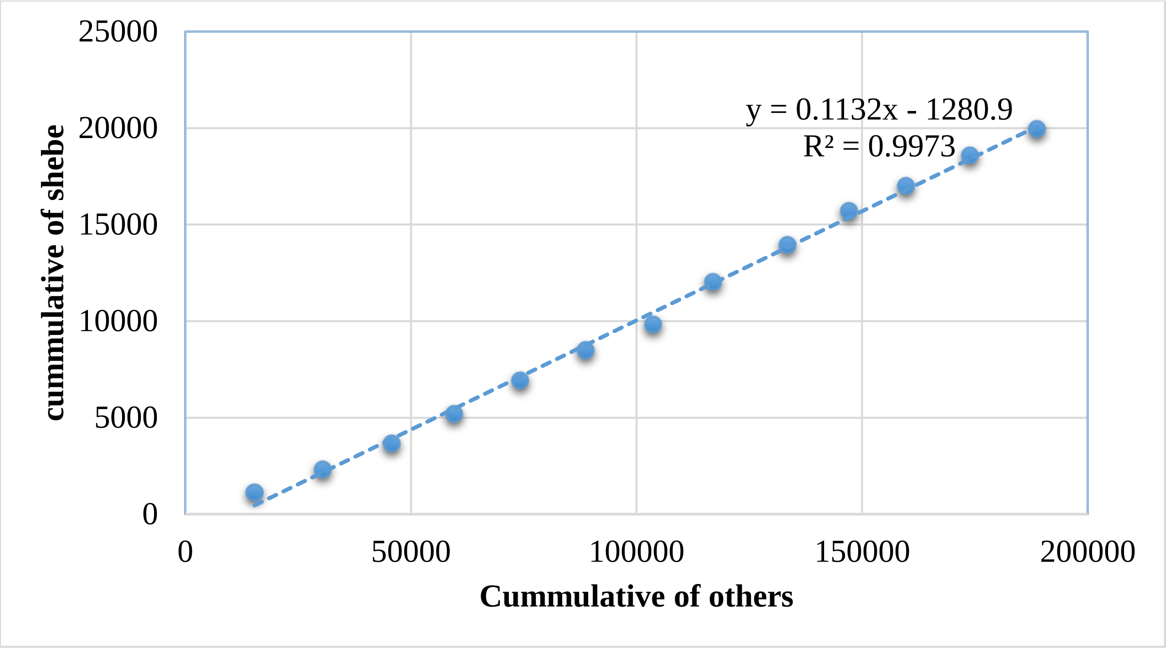
Appendix I: Double mass curve for Delbi station.

Babu	Boto	Gojeb	Shebe	Bita woshi	Chekorsa	Shedatura	wush wush	Sum	Cum.	Delbi Cum.
1695.1	4411.1	1740.7	1124.0	1429.5	1393.4	1467.7	1459.0	14720.5	14720.5	1772.4
1768.4	2901.4	1475.9	1186.1	1520.8	1435.7	2193.9	1650.6	14132.8	28853.3	3956.6
1789.4	2757.8	1607.7	1336.6	1800.4	1185.6	1538.3	1861.6	13877.5	42730.8	6670.7
1533.3	2722.3	1353.8	1539.3	1423.7	1141.5	2056.8	1769.3	13539.9	56270.7	8491.6
1853.4	2140.0	1499.9	1743.9	1815.3	1493.0	1987.6	1956.9	14490.0	70760.7	10434.6
1612.6	2107.1	1347.8	1568.9	1708.4	1350.9	3003.8	1757.5	14457.0	85217.7	12020.1
1954.6	1148.6	1520.4	1339.5	1892.2	1536.1	3686.0	1786.8	14864.2	100081.9	13483.2
1539.0	1328.2	1493.5	2185.2	1615.1	1677.5	1950.2	1996.7	13785.5	113867.4	15184.8
2284.0	1498.6	1567.6	1923.2	1687.3	2104.1	3681.5	1810.8	16557.1	130424.5	17025.1
1867.7	1447.5	1339.6	1762.5	1574.9	1777.8	2001.0	1693.6	13464.5	143889.0	18996.5
2121.4	1395.0	1218.7	1308.9	1654.4	1268.3	1325.3	1828.6	12120.5	156009.5	20773.4
2345.8	2083.5	1283.3	1553.8	1874.0	1476.7	1329.7	1675.5	13622.3	169631.8	22885.6
1522.8	2266.5	1222.8	1385.4	1576.5	2369.9	2010.6	1899.5	14254.0	183885.8	24866.5



Appendix J: Double mass curve for Shebe station.

Babu	Boto	Delbi	Gojeb	Bita woshi	Chekorsa	Shedatura	wush wush	Sum	Cum.	Cum. of Shebe
1695.1	4411.1	1772.4	1740.7	1429.5	1393.4	1467.7	1459.0	15368.9	15368.9	1124.0
1768.4	2901.4	2184.2	1475.9	1520.8	1435.7	2193.9	1650.6	15130.9	30499.8	2310.1
1789.4	2757.8	2714.1	1607.7	1800.4	1185.6	1538.3	1861.6	15254.9	45754.7	3646.7
1533.3	2722.3	1820.9	1353.8	1423.7	1141.5	2056.8	1769.3	13821.6	59576.3	5186.0
1853.4	2140.0	1943.0	1499.9	1815.3	1493.0	1987.6	1956.9	14689.1	74265.4	6929.9
1612.6	2107.1	1585.5	1347.8	1708.4	1350.9	3003.8	1757.5	14473.6	88739.0	8498.8
1954.6	1148.6	1463.1	1520.4	1892.2	1536.1	3686.0	1786.8	14987.8	103726.8	9838.3
1539.0	1328.2	1701.6	1493.5	1615.1	1677.5	1950.2	1996.7	13301.9	117028.7	12023.5
2284.0	1498.6	1840.3	1567.6	1687.3	2104.1	3681.5	1810.8	16474.2	133502.9	13946.7
1867.7	1447.5	1971.3	1339.6	1574.9	1777.8	2001.0	1693.6	13673.3	147176.3	15709.2
2121.4	1395.0	1777.0	1218.7	1654.4	1268.3	1325.3	1828.6	12588.6	159764.9	17018.1
2345.8	2083.5	2112.2	1283.3	1874.0	1476.7	1329.7	1675.5	14180.6	173945.5	18571.9
1522.8	2266.5	1980.9	1222.8	1576.5	2369.9	2010.6	1899.5	14849.4	188795.0	19957.3



Appendix K: Sensitivity analysis for each sub basin and for reach

Sub-basin	parameter	Initial Value	Optimized Value	Sensitivity	Sub-basin	parameter	Initial value	Optimized value	sensitivity
W1070	CN	80.467	81.917	-0.03	W750	CN	79.906	81.473	-0.01
	Ia	12.33	11.605	0.00		Ia	12.775	12.024	0.00
	Tlag(min)	510.9	510.9	0.00		Tlag	280.19	280.19	0.00
W1140	CN	82.759	84.379	-0.01	W840	CN	81.562	83.079	-0.01
	Ia	10.583	9.96	0.00		Ia	11.484	10.809	0.00
	Tlag	243.54	243.5	0.00		Tlag	370.89	370.89	0.00
W1300	CN	82.864	84.283	-0.01	W860	CN	81.648	83.134	-0.02
	Ia	10.505	9.887	0.00		Ia	11.418	10.747	0.00
	Tlag	275.79	275.79	0.00		Tlag	496.98	496.98	0.00
W1350	CN	82.230	83.459	0.00	W940	CN	80.987	82.537	-0.01
	Ia	10.978	11.143	0.00		Ia	11.926	11.225	0.00
	Tlag	269.5	269.5	0.00		Tlag	417.04	417.04	0.00
W1400	CN	81.44	82.904	-0.01	W950	CN	82.037	83.646	-0.01
	Ia	11.574	10.893	0.00		Ia	11.123	10.469	0.00
	Tlag	327059	327.59	0.00		Tlag	301.69	301.69	0.00
W1410	CN	84.335	85.919	-0.01	W970	CN	79.171	80.692	-0.02
	Ia	9.435	8.88	0.00		Ia	13.365	12.579	0.00
	Tlag	243.7	243.7	0.00		Tlag	436.40	436.40	0.00
W1420	CN	83.235	84.772	-0.01	W740	CN	79.06	80.35	-0.01

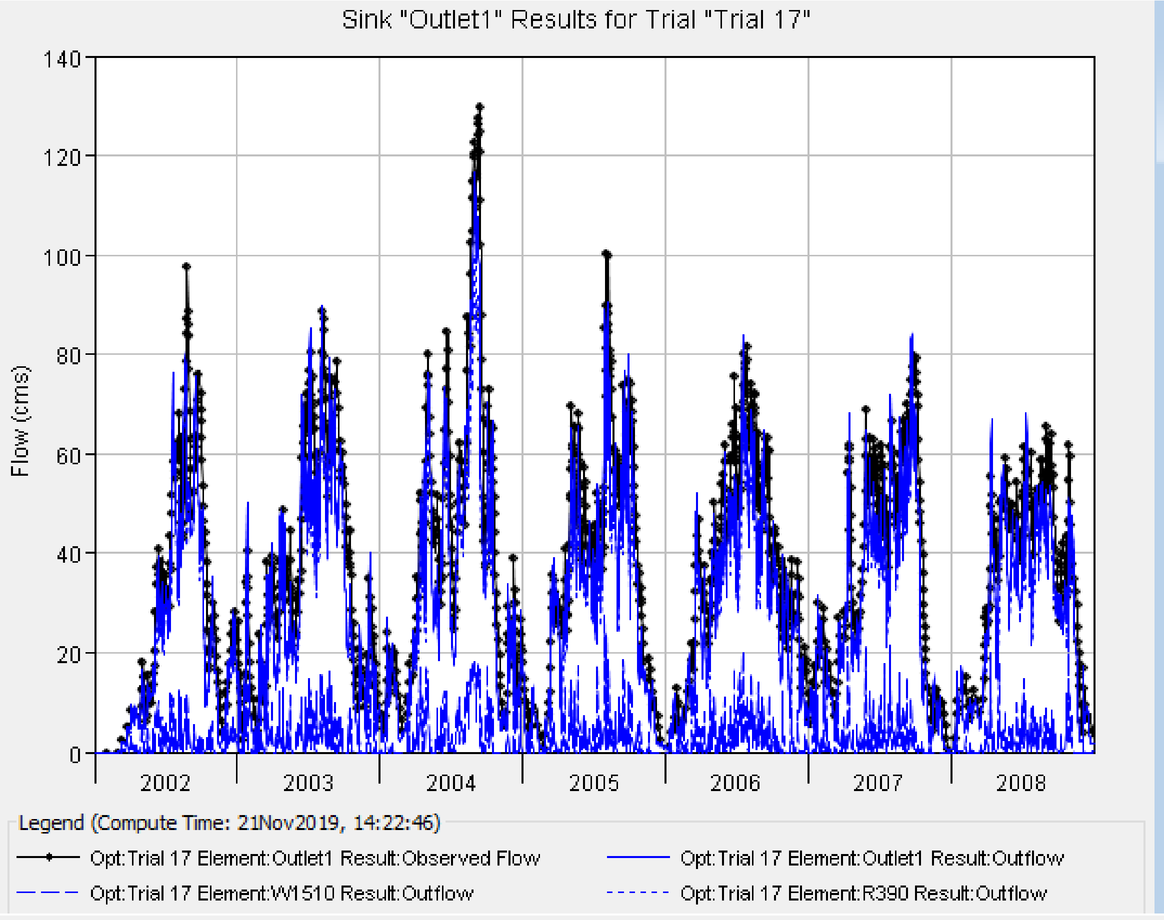
	Ia	10.232	9.63	0.00
	Tlag	329.84	329.84	0.00
W1510	CN	83.59	99	-0.30
	Ia	9.97	9.386	0.01
	Tlag	287.31	287.31	0.00

	Ia	13.499	12.705	0.00
	Tlag	457.82	457.82	0.00

Element	Parameter	Initial value	Optimization value	sensitivity
R120	K	12	150	-0.07
	X	0.25	0.0043	0.00
R200	K	12	150	-0.08
	X	0.25	0.145	0.00
R210	K	12	150	-0.14
	X	0.25	0.145	0.00
R230	K	12	150	-0.08
	X	0.25	0.1448	0.00
R240	K	12	150	-0.16
	X	0.25	0.154	0.00
R280	K	12	96.719	-0.16
	X	0.25	0.196	0.02
R310	K	12	150	-0.28
	X	0.25	0.154	0.01
R330	K	12	150	-0.28
	X	0.25	0.154	0.01
R340	K	12	150	-0.29
	X	0.25	0.154	0.01
R350	K	12	150	-0.29
	X	0.25	0.153	0.01
R390	K	12	19.012	-0.08
	X	0.25	0.208	0.01
R420	K	12	150	-0.29
	X	0.25	0.154	0.01
R430	K	12	98.162	-0.21
	X	0.25	0.185	0.02
R460	K	12	19.012	-0.08
	X	0.25	0.208	0.01
R480	K	12	28.380	-0.08
	X	0.25	0.208	0.01
R490	K	12	28.350	-0.08
	X	0.25	0.208	0.01
R510	K	12	98.16	-0.21
	X	0.25	0.185	0.02

R520	K	14	33.110	-0.09
	X	0.25	0.208	0.01
R530	K	12	66	-0.01
	X	0.25	0.5	0.011
R80	K	12	150	-0.07
	X	0.25	0.0059	0.00

Appendix L: Calibration result of HEC- HMS for the study area



Summary Results for Sink "Outlet1"

Project: gojebproject   Optimization Trial: Trial 17

Sink: Outlet1

Start of Trial:	01Jan2002, 00:00	Basin Model:	gojebproject
End of Trial:	31Dec2008, 00:00	Meteorologic Model:	Gojebmet
Compute Time:	21Nov2019, 14:22:46		

Volume Units: ● MM ○ 1000 M3

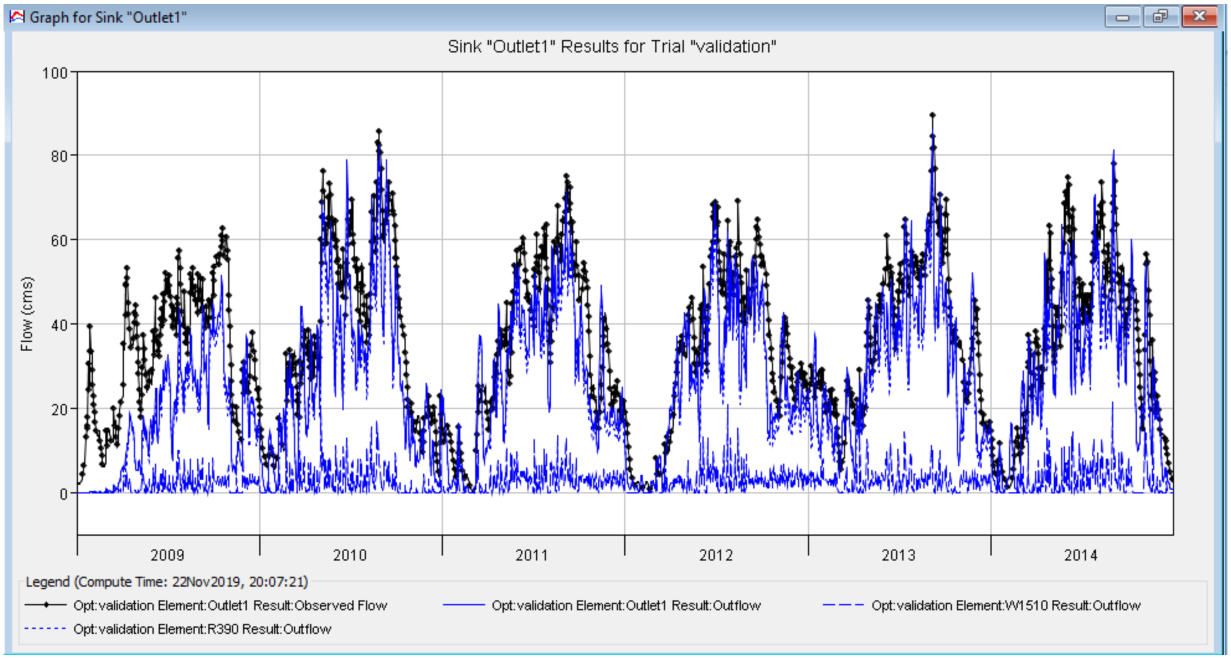
Computed Results

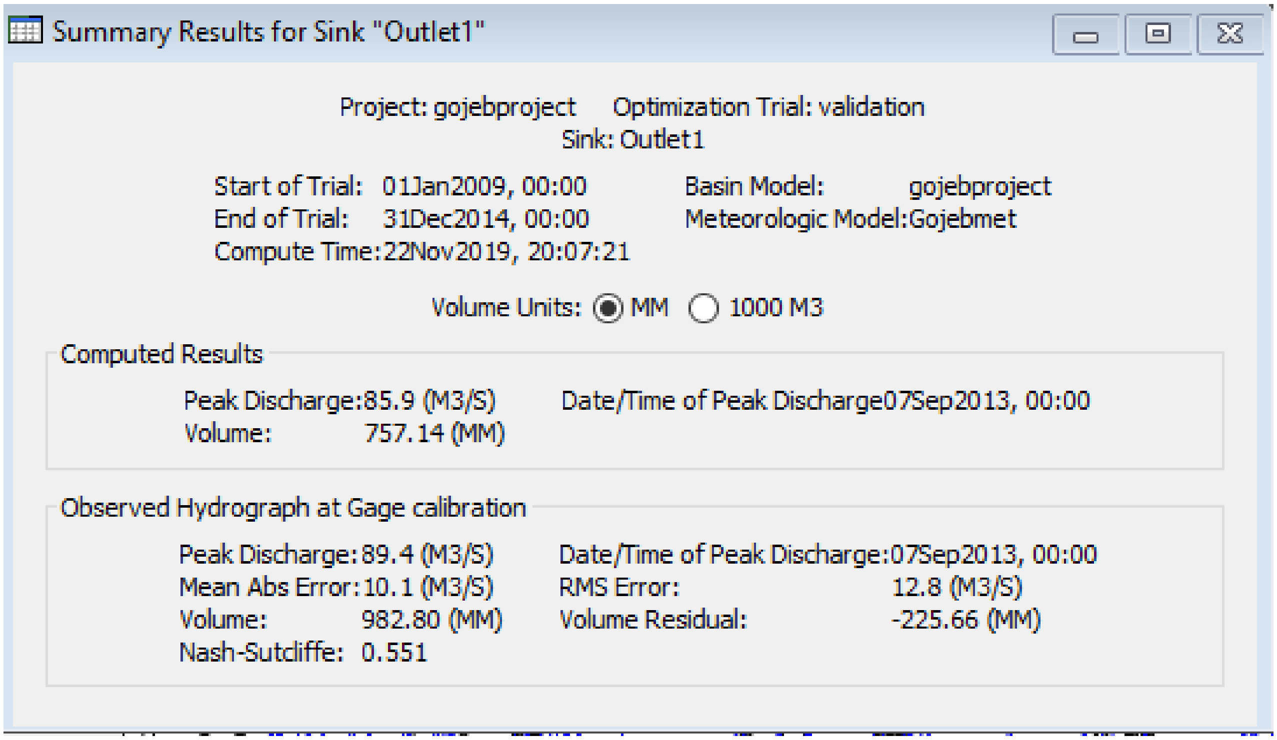
Peak Discharge:	116.5 (M3/S)	Date/Time of Peak Discharge	30Aug2004, 00:00
Volume:	943.68 (MM)		

Observed Hydrograph at Gage calibration

Peak Discharge:	129.9 (M3/S)	Date/Time of Peak Discharge:	11Sep2004, 00:00
Mean Abs Error:	7.6 (M3/S)	RMS Error:	10.4 (M3/S)
Volume:	1129.35 (MM)	Volume Residual:	-185.67 (MM)
Nash-Sutcliffe:	0.810		

Appendix M: Validation result of HEC- HMS for the study area





Summary Results for Sink "Outlet1"

Project: gojebproject Optimization Trial: validation
Sink: Outlet1

Start of Trial: 01Jan2009, 00:00 Basin Model: gojebproject
End of Trial: 31Dec2014, 00:00 Meteorologic Model:Gojebmet
Compute Time:22Nov2019, 20:07:21

Volume Units: ● MM ○ 1000 M3

Computed Results

Peak Discharge:85.9 (M3/S) Date/Time of Peak Discharge07Sep2013, 00:00
Volume: 757.14 (MM)

Observed Hydrograph at Gage calibration

Peak Discharge:89.4 (M3/S) Date/Time of Peak Discharge:07Sep2013, 00:00
Mean Abs Error:10.1 (M3/S) RMS Error: 12.8 (M3/S)
Volume: 982.80 (MM) Volume Residual: -225.66 (MM)
Nash-Sutcliffe: 0.551

Appendix N: Distribution of run off volume and peak discharge for each sub basin .

Sub Basin	Run Off Volume
W740	1185.3
W750	389.03
W840	642.43
W860	1203.09
W940	639.95
W950	374.17
W970	622.59
W1070	1621.21
W1140	259.6
W1300	1085.47
W1350	1050.6
W1400	854.7
W1410	426
W1420	701.29
W1510	1015.95

Appendix O: Distribution of peak discharge for each sub basin.

Sub Basin	Peak Discharge
W740	35.5
W750	4.1
W840	8.2
W860	36
W940	10.5
W950	6.7
W970	10.7
W1070	36.8
W1140	3.5
W1300	31.4
W1350	33
W1400	18.4
W1410	5.4
W1420	11.7
W1510	27.5

Appendix P: sample of weighted precipitation data for each sub basin.

Year	1/1/2002	1/2/2002	1/3/2002	1/4/2002	1/5/2002	1/6/2002	1/7/2002	1/8/2002	1/9/2002	1/10/200
W740	0.00	0.05	0.00	0.57	0.02	0.11	0.65	0.60	1.46	0.53
W750	0.00	0.06	0.10	0.19	0.25	0.27	0.05	0.16	0.13	0.00
W860	0.00	0.01	0.53	0.10	1.20	0.68	0.15	0.04	0.65	0.00
W940	0.00	0.14	0.00	0.39	0.06	0.33	0.05	0.34	0.44	0.00
W970	0.00	0.01	0.19	0.01	0.11	0.08	0.21	0.02	0.66	0.04
W1140	0.00	0.03	0.03	0.05	0.52	0.15	0.02	0.25	0.08	0.02
W1300	0.00	0.00	0.00	0.00	0.27	0.22	0.29	0.23	0.00	1.12
W1070	0.01	0.06	0.12	0.09	1.62	0.93	0.82	0.69	0.55	0.37
W1400	0.00	0.01	0.01	0.02	0.39	0.21	0.21	0.26	0.03	0.79
W1410	0.00	0.00	0.00	0.00	0.11	0.09	0.12	0.10	0.00	0.47
W1420	0.00	0.01	0.02	0.02	0.41	0.19	0.16	0.25	0.04	0.59
W1510	0.00	0.00	0.00	0.00	0.25	0.21	0.27	0.21	0.00	1.05
W840	0.00	0.00	0.06	0.15	0.03	0.02	0.28	0.17	0.96	0.19
W950	0.00	0.00	0.22	0.00	0.11	0.07	0.22	0.00	0.16	0.00
W1350	0.00	0.00	0.00	0.56	0.00	0.00	0.80	0.62	1.29	0.67

1/20/200	1/19/2002	1/18/2002	1/17/2002	1/16/2002	1/15/2002	1/14/2002	1/13/2002	1/12/2002	1/11/2002
0.00	0.00	0.34	0.00	0.71	0.06	0.02	0.28	0.03	0.00
0.00	0.00	0.00	0.02	0.00	0.27	0.20	0.32	0.03	0.00
0.00	0.00	0.00	0.12	0.00	1.34	0.89	1.68	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.28	0.08	0.00
0.00	0.00	0.00	0.13	0.06	0.12	0.37	0.45	0.02	0.19
0.00	0.00	0.00	0.09	0.00	0.52	0.06	0.10	0.01	0.00
0.00	0.00	0.00	0.00	0.00	0.77	1.39	0.77	0.63	0.00
0.00	0.24	0.21	0.34	0.02	1.29	0.81	0.78	0.20	0.05
0.00	0.00	0.00	0.04	0.00	0.74	0.99	0.58	0.44	0.00
0.00	0.00	0.00	0.00	0.00	0.32	0.58	0.32	0.26	0.00
0.00	0.00	0.00	0.05	0.00	0.67	0.75	0.45	0.33	0.00
0.00	0.00	0.00	0.00	0.00	0.72	1.30	0.72	0.59	0.00
0.00	0.00	0.12	0.04	0.27	0.05	0.11	0.38	0.00	0.06
0.00	0.00	0.00	0.15	0.07	0.11	0.36	0.10	0.00	0.22
0.00	0.00	0.43	0.00	0.90	0.06	0.00	0.00	0.00	0.00