EVALUATING THE PERFORMANCE OF HEC-HMS AND SWAT HYDROLOGICAL MODELS IN SIMULATING THE RAINFALL-RUNOFF PROCESS FOR DATA SCARCE REGION OF ETHIOPIAN RIFT VALLEY LAKE BASIN

M.Sc. THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

OCTOBER, 2020

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BY

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MASTER'S THESIS SUBMITTED TO

FACULTY OF BIO-SYSTEMS AND WATER RESOURCES ENGINEERING

DEPARTMENT OF WATER RESOURCE AND IRRIGATION ENGINEERING

HAWASSA UNIVERSITY INSTITUTE OF TECHNOLOGY

HAWASSA UNIVERSITY

HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN WATER RESOURCE AND IRRIGATION ENGINEERING

(SPECIALIZATION: WATER RESOURCE ENGINEERING AND MANAGEMENT)

OCTOBER, 2020

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

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This is to certify that the thesis entitled "Evaluating the Performance of HEC_HMS and SWAT Hydrological Models in Simulating the Rainfall-Runoff Process for Data Scarce Region of Ethiopian Rift Valley Lake Basin'' submitted in partial fulfillment of the requirements for the degree of Master's Science with specialization in Water Resource Engineering and Management, the Graduate Program of the Faculty of Bio-systems and Water Resource Engineering, Department of Water Resource and Irrigation Engineering, and has been carried out by Mohammedreshid Abdala Id.No.WREMR/011/11. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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I, hereby declare that the thesis: ‘‘Evaluating the Performance of HEC_HMS and SWAT Hydrological Models in Simulating the Rainfall-Runoff Process for Data Scarce Region of Ethiopian Rift Valley Lake Basin ’’ is my original work and has not been presented for a degree in any other university and that all sources of material used for this thesis have been dully acknowledged.

Name: Mohammedreshid Abdala

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Date:________Oct 15, 2020________

Acknowledgment

I am so grateful to almighty Allah for His priceless help and protection during the whole activity of my work. It is also important and right to acknowledge the support and help of various people who had contributed to the successful completion of this study. First and foremost, I would like to express my genuine gratitude and appreciation to my Advisors, Dr. Alemu O. and my Co-Advisors Mr.Teshale T. Their encouragement, guidance and support from the start to the end enabled me to develop an understanding of the subject matter very well. I would also like to thank Bule Hora University for sponsoring my Master's study at Hawassa University. I sincerely thank my parents, family and friends who lend a hand, directly or indirectly, for the completeness of my thesis work.

Mohammedreshid Abdala.

Hawassa, Ethiopia

October 2020

ABSTRACT

Several physically-based and distributed watershed models have been developed to model the hydrology of the watershed. For a specific watershed, selecting the most suitable hydrological model is necessary to obtain good simulated results. In this study, two hydrologic models, Soil and Water Assessment Tool (SWAT) and Hydrological Engineering Centre–Hydrologic Modeling System (HEC-HMS), were applied to simulate streamflow in the Katar river basin, Ethiopia. The performances of these two models were compared to select the right model for the study basin. Both models were calibrated and validated with streamflow data of 11 years (1990-2000) and 7years (2001-2007) respectively. Nash-Sutcliffe Error (NSE) and Coefficient of Determination (R^2) were used to evaluate the efficiency of the models. The results of calibration and validation indicated that, for river basin Katar, both models could simulate fairly well the streamflow. SWAT gave the model performance with the $R^2 > 0.78$ and NSE > 0.67; and the HEC-HMS model provided the model performance with the $R^2 > 0.87$ and NSE > 0.73. Hence, the simulated streamflow given by the HEC-HMS model is more satisfactory than that provided by the SWAT model.

Key Words: *HEC-HMS, SWAT, Katar river basin, Peak Flow, Rainfall-Runoff Simulation*

Article:

Aliye M. A., Aga A. O., Tadesse T., and Yohannes P. (2020). Evaluating the Performance of HEC-HMS and SWAT Hydrological Models in Simulating the Rainfall-Runoff Process for Data Scarce Region of Ethiopian Rift Valley Lake Basin. OJMH, 10,4.

PUBLICATION

The thesis, entitled "Evaluating the Performance of HEC_HMS and SWAT Hydrological Models in Simulating the Rainfall-Runoff Process for Data Scarce Region of Ethiopian Rift Valley Lake Basin" has been published on one of the international reputable journal (Open Journal of Modern Hydrology).

Aliye M. A., Aga A. O., Tadesse T., and Yohannes P. (2020). Evaluating the Performance of HEC-HMS and SWAT Hydrological Models in Simulating the Rainfall-Runoff Process for Data Scarce Region of Ethiopian Rift Valley Lake Basin. OJMH, 10,4.

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List of Abbreviations and Acronyms

AGNPS	Agricultural Non-Point Source
AnnAGNPS	Annualized Agricultural Non-Point Source
APEX	Agricultural Policy/Environmental eXtender
CN:	Curve number
CRV	Central Rift valley
DEM:	Digital Elevation Model
FAO	Food and agricultural organization
DWSM	Dynamic Watershed Simulation Model
HSPF	Hydrological Simulation Program-Fortran
ESRI	Environmental System Research Institute
GCS :	Geographic Coordinate System
GIS	Geographical Information System
GLF	Global Land forecast
HEC-GeoHMS:	Hydrologic Engineering Centre-Geospatial Hydrologic Modeling System
GSSHA	Gridded Surface Subsurface Hydrologic Analysis
HEC-HMS:	Hydrologic Engineering Centre-Hydrologic Modeling System
HSG:	Hydrologic Soil Group
LU/LC	Landuse/Land Cover
MIKE-SHE	System Hydrologique European
MoWR:	Ministry of Water Resource
MoWRIE	Ministry of Water Resource, Irrigation, and Electricity
NRCS :	Natural Resources Conservation Service
SCS :	Soil Conservation Service
SRTM:	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool
USGS:	United States Geological Survey
UTM:	Universal Transverse Mercator
WGS:	World Geodetic System
WGEN	Weather Generator

1. INTRODUCTION

1.1 Background of Study

Modeling of hydrological processes, like rainfall-runoff, infiltration, evapotranspiration and groundwater discharge are the most essential tasks to manage the water resources of the basin (Golmohammadi et al., 2014; Khoi, 2016; Bredesen and Brown, 2019). To do so, many computer-based models have been developed to simulate the hydrologic processes and the hydrologic effects of different watershed management issues (Sith and Nadaoka, 2017; Aga et al., 2020). Today, the watershed models are using to implement an alternative management strategy in the areas of water resource allocation, reservoir siltation, flood control, land use land cover changes and climate change impact assessments (Aga et al., 2018).

Several physically-based and distributed watershed models have been developed to model the hydrology of the entire watershed (Bobba et al., 2000). For a specific watershed, selecting the most suitable hydrological model is necessary to obtain good simulated results and the success of hydrologic prediction lies in the proper selection of model input parameters (Bredesen and Brown, 2019). Such selection is highly challenging for developing countries due to a shortage of studies that tested the applicability of the models. Recently, the most commonly used hydrological models are Hydrological Engineering Centre–Hydrologic Modeling System (HEC-HMS), Hydrological Simulation Program-Fortran (HSPF), Agricultural Non-Point Source (AGNPS), Soil and Water Assessment Tool (SWAT) and MIKE SHE (Khoi, 2016; Sith and Nadaoka, 2017). These models are developed for a specific area with the help of statistical observations based on parameters detected in the field (Hajigholizadeh et al., 2018). Hence it may give fairly accurate results if they applied to conditions similar to those from where they were derived. But, As reported by Steenhuis et al. (2009), models are applied in different regions where they were developed. For example, SWAT is applied by Chu et al. (2004) in the Warner Creek watershed, Muleta and Nicklow (2005) in the Big Creek watershed, Jha et al. (2007) in the Raccoon River watershed and Aga et al. (2018); Demlie and Melesse (2018); Dessu et al. (2014); Dessu and Melesse (2013, 2012); Setegn et al. (2011) and Yesuf et al. (2015) in different basins of Ethiopia. Such a direct application of models in different regions where they were developed may be requires good dataset for calibration and validation.

In the Wabash River watershed, USA, Borah et al. (2007) were evaluated and compared SWAT and DWSM models. These results showed SWAT's weakness in predicting monthly peak flows (underestimating). Similarly, about eleven watershed-scale hydrological models were reviewed by Borah and Bera (2003) and concluded that only HSPF, AnnAGNPS, MIKE-SHE, AGNPS, DWSM, SWAT and HEC-HMS were able to simulate all major watershed hydrological components. The result of these studies indicated that further investigation was needed to reach a solid conclusion about the superiority of one model over the others.

In China, Xixian River Basin, SWAT and Xinanjiang (XAJ) models were evaluated and compared by Shi et al. (2011). Their result indicated that both models have been performed well in the Xixian River Basin. For calibration and validation periods, both models have a PBIAS < 15%, NSE > 0.69 and $r^2 > 0.72$. In Japan Ishigaki Island watershed, SWAT and GSSHA models were evaluated by Sith and Nadaoka (2017) for high time resolution prediction of streamflow and sediment concentration. As the result, they have reported that, for long-term simulations, both models yielded comparable results. Similarly, the applicability of MIKE SHE, APEX, SWAT models were tested by Golmohammadi et al. (2014) in Canagagigue Watershed, Canada. And, as the result, they reported as the mean daily/monthly flow at the outlet of the Canagagigue Watershed simulated by MIKE SHE was more accurate than that simulated by SWAT and APEX model, for both calibration and validation periods. In Virginia, Polecat Creek watershed, SWAT and HSPF were evaluated and reported as both models can simulate effectively the streamflow (Im et al., 2003).

From these studies, we can conclude that the models' performances are very site-specific and no one model is superior under all hydrologic conditions. Therefore, a complete understanding of comparative model performance requires applications under different hydrologic conditions and watershed scales. As reported by Aga et al. (2018), SWAT has been successfully applied to simulate streamflow in different basins of the country Ethiopia and HEC-HEM has been also successfully applied for hydrological studies in different Ethiopian basins (Demlie and Melesse, 2018). Therefore, this study aims to compare and assess the suitability of those two widely-used watershed simulation models, namely HEC-HMS and SWAT, for simulating the hydrology of a Katar River Basin, the Central Rift Valley (CRV) Lake Basin of Ethiopia.

1.2 Statement of the Problem

Runoff is one of the most important hydrological variables used in many water resources applications. Reliable prediction of the amount of runoff flowing upland to rivers is difficult and time-consuming (Kumar et al., 2010). Hence, rainfall-runoff models are often used as a tool for a wide range of tasks, such as for modeling of flood events, monitoring of water levels and prediction of floods (Jia, 2009). Today, several rainfall-runoff models have been developed to model the hydrology of the entire watersheds. For a specific watershed, selecting the most suitable model is necessary to obtain good simulated results (Bredesen and Brown, 2019).

In developed countries, researchers are attempting to determine which model is the most suitable for specific regions or conditions. For example, Borah et al. (2007), were evaluated and compared SWAT and DWSM models in the Wabash River basin (USA), In China, Xixian River Basin, Shi et al. (2011) were evaluated and compared SWAT and Xinanjiang (XAJ) models, in Canagagigue Watershed, Canada, Golmohammadi et al. (2014) were tested MIKE SHE, APEX, SWAT models and In Virginia, Polecat Creek watershed, SWAT and HSPF were evaluated by Im et al., (2003). However, in developing countries, the level of such investigation remains a big challenge due to a shortage of studies that tested the applicability of the models. For example, in the current study area (Sub Basin of Lake Ziway), the SWAT model was used to model the effect of LULC change on hydrology (Tolera, 2018; Molla,2014; Damtew et al., 2015) and the effect of sedimentation on the lake (Aga et al., 2018). In practical SWAT is not the only model that can be used to study the hydrology of the entire watershed. Hence, before directly applying the model, it is good to select the best fit model. Moreover, in this study area, researchers were not tested one of the widely used models HEC HMS. As reported by Demlie and Melesse (2018), the HEC-HMS model has been tested and calibrated at different parts of the world and has been also applied for hydrological studies in different sub-basins of upper Blue Nile, Ethiopian. Since the performances of the models are highly site-specific, evaluating, and selecting the best fit model is a vital issue. As an input, the result of this study will help scholars/ researchers/ who are going to study the hydrological related projects in the Katar river basin since they can easily use the best fit model identified for the basin.

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of the study is to compare and assess the suitability of the two widely-used watershed simulation models, namely HEC-HMS and SWAT, for simulating the hydrology of a Katar river basin, the Central Rift Valley (CRV) Lake Basin of Ethiopia.

1.3.2 Specific Objective

The specific objective of this research includes:

1. To generate the land use land cover map of the study area for the year 1990 and 2001
2. To model rainfall _runoff relationship of the basin by using HEC_HMS and SWAT models.
3. To assess the performance of models in runoff prediction and identify the best fit model for the study area.

1.4 Significance of the Study

This study has been applied to evaluate the performance of HEC_HMS and SWAT Hydrological models for the Katar river basin to estimate the amount of streamflow that plays a vital role. The benefit that draws from this study may contribute to current efforts by governments and other concerning bodies to solve the problem flood control and management schemes that contribute to the better service coverage. Select which models as interlink in the design of irrigation and drainage works, hydraulic structures and hydro-power generation. Furthermore, it can help researchers as a baseline for developing flood mapping and risk assessments of the study area.

2. LITERATURE REVIEW

2.1 Hydrologic Modeling

Hydrological models are mathematical descriptions of components of the hydrologic cycle. They have been developed for many different reasons and therefore have many different forms. However, hydrological models are in general designed to get a better understanding of the hydrologic processes in a watershed and of how changes in the watershed may these phenomena and for hydrologic prediction (Romali et al., 2018). Hydrological models are simplified, conceptual representations of a part of the hydrologic cycle. They are primarily used for hydrological prediction and for understanding hydrological processes. Whenever data is not available, hydrological models are important to establish baseline characteristics and determine long term impacts that are difficult to calculate (Lenhart et al., 2002). A modeler should understand the hydrological process and then simulate this process at a desired spatial and temporal resolution (Devos et al., 2006). The unit hydrograph techniques and watershed models can be used to estimate the design flood hydrograph in addition to the magnitude of the design flood peak (Kalita, 2011).

2.1.1 Classification of Hydrological Model

There are many classifications of hydrologic models, deterministic versus stochastic, lumped versus distributed, etc**.** Based on the process description, the hydrological models can be classified into three main categories such as lumped, semi-distributed and distributed model (Cunderlik and Simonovic, 2004).

Lumped models: Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. The parameters often do not represent the physical features of hydrologic processes and usually involve a certain degree of empiricism. These models are not usually applicable to event scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically-based models (Geographica and Comenianae, 2010).

Semi-distributed Models: Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into several smaller sub-basins. The main types of semi-distributed models: 1) kinematic wave theory models such as HEC-HMS and 2) probability distributed models such as SWAT. The kinematic wave models are simplified versions of the surface and/or subsurface flow equations of physically-based hydrologic models (Campling, 2002).

Distributed models: Parameters of distributed models are fully allowed to vary in space at resolution chosen by the user. The distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameters together with computational algorithms to evaluate the influence of this distribution on simulated precipitation runoff behavior (Campling, 2002). Distributed models generally require a large amount of data.

2.1.2 Hydrological Model Selection

Many criteria can be used for choosing the right hydrologic model. These criteria always project dependent, since every project has its specific requirements and needs. Further, some criteria are user-dependents, such as the personal preference for the graphical user interface (GUI), computer operating system, input and out management system and structure. There is a range of possible model structures within each class of models. Hence, choosing a particular model structure for a particular application is one of the challenges of the model user community (Sok and Oeurng, 2016) stated that selecting the best and appropriate model is an essential part of any research work and it depends on the basin and the objective of the hydrological prediction in the basin.

Different hydrological models simulate the flow of the stream. Hydrological models have been used for flow forecasting to support reservoir operation, for flood protection, in spillway design studies, and for several practical purposes (Ramesh, 2017). Some of the hydrological models that are used for hydrological and hydraulic analysis are HBV (Hydrologiska ByrånsVattenbalansav dealing), SWAT, HEC HMS (Hydrologic Engineering Center's Hydrologic Modeling System), HSPF (Hydrologic Simulation Program Fortran), MIKE SHE (System Hydrologique European) and others. Moreover, with the development of Geographic Information Systems (GIS) and remote sensing techniques, the hydrological models have been more physically based and distributed to enumerate various interactive hydrological processes considering spatial heterogeneity. According to (Cunderlik and Simonovic, 2004) the criterion for the choice of the most suitable model depends mainly on the requirement and needs of the research or project under interest such as output needed, Availability of input data, Prices, and availability of the model and model structure. Based on the above selection criteria SWAT and HEC_HMS model was selected for detailed analysis and investigation of rainfall-runoff simulation on streamflow of the Katar river basin.

Table 2.1: Description of selected semi-distributed hydrological models (Source: Cunderlik and Simonovic, 2004).

Description	SWAT	HEC-HMS
Model type	Semi-distributed Physically-based Long-term	Semi-distributed Physically-based
Model objective	Predict the impact of land management practices on water and sediment	Simulate the rainfall runoff process of watershed
Spatial scale	Medium +	Flexible
Process modeled	Continuous	Continuous & event
Cost	Public domain	Public domain

2.1.3 Rainfall-Runoff Modeling

Runoff modeling is the process of transformation of rainfall into a flood hydrograph and to the translation of that hydrograph throughout a watershed or any other hydrologic system. In this manner, the flooding processes, which consist of upstream watershed hydrological processes, approximated either physically or mathematically (through the use of mathematical equations) where the relationships between system states, input, and output are represented (Rathod et al., 2015).

Runoff modeling is one of the means to understand the behavior of flood in a particular area. Accurate representation of the actual processes is of paramount significance in predicting flood extent and depth, especially explaining the transient characteristics of river water flow in the model domain. Determining the variation of flow characteristics in the spatial and temporal resolution enables to design of a flood evacuation plan quite efficiently (Ramesh, 2017).

2.2 Model Description

2.2.1 HEC-GeoHMS Model

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 (USACE, 2010). It is a hydrology toolkit for engineers and hydrologists. The user can visualize information, document watershed characteristics, perform spatial analysis, and delineate sub-watersheds and streams, construct inputs hydrologic models, and assist with report preparation. It is used for preparing inputs parameter for HEC-HMS hydrological model (Fleming and Doan, 2013). HEC-GeoHMS provides the connection for translating GIS spatial information into hydrologic models (USACE, 2010). The result of the GIS processing is a spatial hydrology database that consists of the digital elevation model (DEM), soil types, land use information, rainfall, etc. HEC-GeoHMS derives parameters like Curve Number, Basin Lag, and Time of concentration and Los (USACE, 2010). The relation between GIS, HEC-GeoHMS, and HEC-HMS is shown below (Figure 2.1).

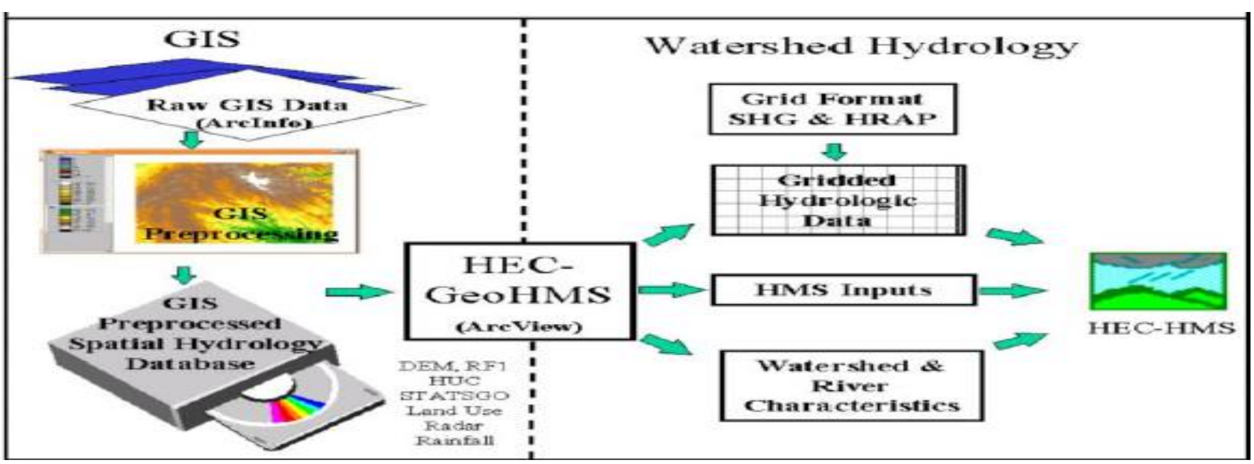


Figure 2.1: Overview of GIS, HEC-GeoHMS, and HEC-HMS (Fleming and Doan, 2013).

2.2.2 HEC-HMS model

Hydrologic Modeling System (HEC-HMS) is open-source computer software developed by the U.S. Army Corps of Engineering´s Hydrologic Engineering Center that helps in stimulating the hydrologic cycle (precipitation, evapotranspiration, infiltration, surface runoff, and base-flow) of a catchment by describing its physical and meteorological properties (USACE, 2010). Wide options of mathematical models for all the hydrological components that conceptually represent watershed behavior are incorporated in this program. The program uses a separate model to represent each component of the runoff process like a model to compute runoff volume, a model of direct runoff/base flow/ channel flow as well as alternative models to account for the cumulative losses (Feldman, 2005).

2.2.2.1 Rainfall Loss Modeling

HEC-HMS computes runoff volume by computing the volume of water that is intercepted infiltrated, stored, evaporated, or transpired and subtracting it from the precipitation. Interception, infiltration, storage, evaporation, and transpiration collectively are referred to in the HEC-HMS program and documentation as losses (USACE, 2010). HEC-HMS considers that all land and water in a watershed can be categorized as either directly-connected impervious surface or previous surface. Directly connected impervious surface in a watershed is that portion of the watershed for which all contributing precipitation runs off, with no infiltration, evaporation, or other volume losses (Lastoria, 2008). Precipitation on the pervious surfaces is subject to losses. Different alternative models are included to account for the cumulative Losses. However, a few of them are described below. A total of nine different loss methods are provided in HEC-HMS and some of these methods are designed primarily for simulating events, while others are intended for continuous simulation (Feldman, 2005). Gridded Loss Methods and Soil Moisture Accounting Loss Methods are not preferred for the simulation studies because they require a high number of parameters. Among the remaining loss methods, the SCS Loss method is selected for the event-based simulation studies (Feldman, 2005). The method is simple and practical because it requires only two input parameters such as CN number and impervious area (10 %). A curve number (CN), an index developed by the Soil Conservation Service (SCS) now called the Natural Resource Conservation Service (NRCS), is used to estimate the amount of rainfall that infiltrates into the soil and the amount of surface runoff (Feldman, 2005). It has several advantages over other methods in that: It is a simple conceptual method for the estimation of the direct runoff amount from a storm rainfall event and is well supported by empirical data (Feldman, 2005). One of the empirical methods that are widely and globally used by hydrologists, water project planners, and water engineering, is the curve numbers method that has been suggested and supported by the department of agriculture natural resources conservation service of the USA. Some applications of GIS are mapping curve number (CN) of the catchment by using the digital data analysis, vegetation cover, land use, and hydrologic soil groups. This method is a versatile and widely used approach for quick runoff estimation and also relatively easy to use with minimum data and gives adequate results (Nasiri and Alipur, 2014).The SCS Runoff Curve Number (CN) method developed by Natural Resources Conservation Service (NRCS) used for estimating direct runoff from storm rainfall described on the following Equation:

$$\mathrm{Q} = \frac{(P - I_a)^2}{(P - I_a) + S} \text{-------------------------------} 2.1$$

Through studies of many small agricultural watersheds, Ia was found to be approximated by the following empirical equation.

$$I_a = 0.2S \text{----------------------------------} 2.2$$

And thus the equation became:

$$\mathrm{Q} = \frac{(P-0.2S)^2}{(P+0.8S)} \text{ For } P > 0.2S\text{; otherwise, } \mathrm{Q} = 0 \text{--------------------} 2.3$$

$$\mathrm{S} = \frac{25400}{CN} - 254 \text{-------------------------------} 2.4$$

Where: Q: is the surface runoff (mm), P: is the precipitation; S potential maximum retention (mm), Ia: is the initial loss (mm), and, CN: is the curve number. Initial abstraction (Ia) is all losses before runoff begins.

2.2.2.2 Excess Rainfall Modeling

Modeling direct runoff is the transformation of the excess precipitation into point runoff at a given point outlet. HEC-HMS includes two options, systems type and conceptual type of transformation (Mokhtari et al., 2016). The systems type transformation included in HMS consists of Snyder's unit hydrographs model, SCS UH model, Clark's model, Modified Clark's model. The conceptual model includes only a kinematics wave model of overland flow (Mokhtari et al., 2016). Unit hydrograph can be defined as the runoff hydrograph produced from excess rainfall of unit depth occurring over the watershed (Subramanya, 2008). The transformation method used for this study was SCS Unit Hydrograph. The resulting runoff hydrograph from this model is described by properties of unit hydrograph using one or more equations of the parameters involved. The peak of the unit hydrograph and its time of the peak is given by the following equations.

$$\mathrm{Up} = 208 * \mathrm{A} * \mathrm{Tp} ---------------------------- 2.5$$

$$\mathrm{Tp} = \Delta \mathrm{t}/2 + \mathrm{tlag} ---------------------------- 2.6$$

Where, Up = Peak of unit hydrograph, A = Area of the watershed, Tp = Time of a peak, Δt = Excess precipitation duration, and tlag = Basin lag (Feldman, 2005).

The lag time (Tlag) is the only input for this method. It is the time from the center of mass of excess rainfall to the hydrograph peak and is calculated for each watershed based on the time of concentration. To determine how runoff is distributed over time we must introduce a time-dependent factor called Time of concentration. The Time of concentration (Tc) is defined as the time required for a particle of water to travel from the most hydrological remote point in the basin to the outlet. The time of concentration (Tc) can be determined by equation 2.7.

$$\mathrm{T_C} = 1.67\mathrm{T_L} ---------------------------- 2.7$$

$$\mathrm{T_L} = \frac{\mathrm{L}^{0.8}[(1000/\mathrm{CN})-9]^{0.7}}{1900\mathrm{S}^{0.5}} ---------------------------- 2.8$$

Where Tc is the time of concentration (hours), L is the length of the longest stream (meters)

S is the slope of the longest hydraulic length (m/m).

2.2.2.3 Routing Model

As the flood runoff travels through the channel reach, it becomes attenuated due to channel storage effects. The routing models available in HEC-HMS account for this attenuation. Muskingum method was developed by McCarthy (1938) is a popular lumped flow routing technique that was selected for this study. The Muskingum routing method is a simple approximate method to calculate the outflow hydrograph at the downstream end of the channel reach from the inflow hydrograph at the upstream end. Among many models used for flood routing in rivers, it is a straightforward hydrological flood routing technique used in natural channels (Shaw, 1994), and it has been extensively applied in river engineering practice since its introduction in the 1930s (Tewolde, 2006). In this model calibration, two parameters are needed; travel time (K) of the flood wave through routing reach; and dimensionless weight (X) which corresponds to the attenuation of the flood wave as it moves through the reach. The routing parameters in the models are usually derived through calibration using measured discharge hydrographs (Birkhead and James, 2002).

2.2.3 Soil and Water Assessment Tool (SWAT)

SWAT is a relatively recent model used to assess watershed hydrology (Jha et al., 2007). According to Jha et al. (2007), it is the best among the different hydrological models due to its capability for an application to large-scale watersheds (> 100 km^2), interface with a Geographic Information System (GIS), continuous-time simulations performance, and generation of the maximum number of sub-basins and ability to characterize the watershed in enough spatial detail.

The SWAT model is a semi-distributed physically-based simulation model and can predict the impacts of land-use change and management practices on hydrological regimes in watersheds with varying soils, land use, and management conditions over long periods and primarily as a strategic planning tool (Neitsch et al., 2005). The interface of the SWAT model is compatible with ArcGIS that can integrate numerous available geospatial data to accurately represent the characteristics of the watershed. In the SWAT model, the impacts of spatial heterogeneity in topography, land use, soil, and other watershed characteristics on hydrology are described in subdivisions (Neitsch et al., 2005). The hydrologic cycle as simulated by SWAT is based on the water balance equation. Here the runoff volume is estimated by using the Soil Conservation Service (SCS) curve number technique (USDA, 1972). For simulation, a basin is divided into several watersheds. The use of watersheds in a simulation is particularly beneficial when different areas of the watershed are dominated by land uses or soils dissimilar enough in properties to impact hydrology (Jha et al., 2007). The total runoff mainly depends on the actual hydrologic condition of each LULC, soil type, and slope present in the basin (Jha et al., 2007).

Therefore, the impact of each type of land use is considered in this modeling to calculate the runoff of the basin. After the overlay of the LULC, soil maps, and slope, the distributions of the Hydrological Response Units (HRUs) were determined. HRUs divide the watershed into the area of similar land use, soil type, and slope. Runoff is predicted separately for each HRU and routed to obtain the total runoff of the basin. The SWAT model simulates eight major components: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Neitsch et al, 2005). Major hydrologic processes that can be simulated by this model include evapotranspiration, surface runoff, infiltration, percolation, shallow aquifer, and deep aquifer flow, and channel routing (Neitsch et al, 2005). Streamflow is determined by its component's surface runoff and the groundwater flow from the shallow aquifer.

2.2.3.1 SWAT Calibration and Uncertainty Procedures (SWAT-CUP)

Distributed hydrological models are increasingly being used to support decision making in LULC change that affects rainfall-runoff (Neitsch et al, 2005). These models should pass through careful calibration and uncertainty analysis. Large-scale distributed models are difficult to calibrate and to interpreter the calibration because of large model uncertainty, input uncertainty, and parameter nonuniqueness. To perform parameter calibration and uncertainty analysis different programs are introduced (Abbaspour, 2014). SWAT-CUP is one of the programs which are currently used by different researchers. SWAT-CUP is a public domain and any calibration, uncertainty, or sensitivity can be linked to SWAT. The program links Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (ParaSol), Sequential Uncertainty Fitting (SUFI2), and Markov Chain Monte Carlo (MCMC) procedures to SWAT (Abbaspour, 2014). It enables sensitivity analysis, calibration, validation, and uncertainty analysis of SWAT models. SUFI method determines uncertainty through the sequential and fitting process in which iteration and unknown parameter estimates are achieved before the final estimates (Abbaspour, 2014).

2.3 Previous Study by HEC-HMS

Previous studies on HEC-HMS proved its ability to simulate and forecast streamflow based on different datasets and catchment types. Chu and Steinman (2009); Zelelew and Melesse (2018) stated that the results of the model simulation were location-specific, in that different combinations of a model set containing the loss methods, runoff transform methods, and baseflow separation techniques were found to respond variably.

Currently, many researchers have applied HEC-HMS for rainfall-runoff modeling all over the world and have obtained satisfactory results. Abdessamed *et al*. (2018) developed a rainfall-runoff model in a semi-arid region of Ain Sefra watershed in Algeria through employing an HEC-HMS model. They used frequency storm, Soil Conservation Service Curve Number (SCS-CN), and Soil Conservation Service-Unit Hydrograph (SCS-UH) methods for meteorological modeling, excess precipitation modeling, and excess precipitation transformation to direct runoff and obtained nearly the same computed and observed flow. Mokhtari *et al*. (2016) performed hydrologic modeling of rainfall-runoff using the HEC-HMS model on a watershed of the wadi CheliffGhrib in Algeria, and based on their results, they suggested that HEC-HMS is applicable and the result was accepted for that particular area. Majidi and Shahedi (2012) utilized the HEC-HMS hydrological model to simulate rainfall-runoff in the watershed of Abnama situated in south Iran. They used Green-Ampt, SCS unit hydrograph, and Muskingum routing techniques to calculate infiltration loss, rainfall surplus conversion to runoff, and flow routing, and lastly found that the model had a decent correlation with the observed flow and was acceptable. Bitew *et al*. (2019) have applied HEC-HMS for streamflow simulation in Lake Tana Basin Upper Blue Nile Ethiopia. They used SCS-CN, SCS-UH, and Muskingum method for precipitation loss, direct runoff, and flood routing respectively.

Moreover, in a study conducted by (Sardoii et al., 2012) on Amirkabir Dam Watershed, Iran the Calibration of loss estimation methods for simulation of surface runoff showed that the HEC-HMS model can give more acceptable results than other models. Radmanesh et al (2006) calibrated and validated the HEC-HMS model in the Yellow River watershed in southwestern Iran. Rostami et al (2012) used the HEC-HMS and GIS to simulate the rainfall-runoff process in the Amirkabir watershed. Sabzevari et al (2009) estimated the flood hydrograph in no statistical watersheds using the HEC-HMS model and GIS in the Kasi-lian watershed. Shaghaeghi (2001) applied the HEC-HMS model to simulate river flow in the Mohammadabad watershed (located in the north of Iran).

2.4 Previous Study by SWAT Model

Ndomba (2002) was applied the SWAT model in the modeling of the Pangani River (Tanzania) to evaluate the applicability of the model is complex and data-poor watersheds. The result of SWAT is good to evaluate for Pangani River. Tripathi et al., (2003) applied the SWAT model for the Nagwan watershed in India to identify and prioritize critical sub-watersheds to develop an effective management plan and the model was verified for both surface runoff and sediment yield. Accordingly, the study concluded that the SWAT model can be used in ungauged watersheds to simulate the hydrological and sediment processes. SWAT has gained international acceptance as a robust interdisciplinary watershed modeling tool as evidenced by international SWAT conferences, hundreds of SWAT-related papers presented at numerous other scientific meetings, and a large number of articles published in peer-reviewed journals (Gassman et al, 2007). However, Cibin et al. (2010) indicated that SWAT model parameters show varying sensitivity in different years of simulation suggesting the requirement for dynamic updating of parameters during the simulation.

Through modeling of the Gumara watershed (in Lake Tana basin), Awulachew et al. (2008) indicated that streamflow and sediment yield simulated with SWAT were reasonably accurate. A study conducted on the modeling of the Lake Tana basin with the SWAT model also showed that the SWAT model was successfully calibrated and validated (Setegn et al., 2008). Modeled by Pilate watershed by Tekle (2010) also indicated that the SWAT model can simulate streamflow at a reasonable accuracy.

3. MATERIAL AND METHODS

3.1 Description of Study Area

3.1.1 Location

The study area, the Katar river basin is a sub-catchment of the Ethiopian CRV Basin. It is located in the Oromia Regional State of Ethiopia and the Northern part of CRV catchment in the part of the Ziway Langano basin. In terms of the geographic coordinate system, the basin lies between 7^{0}21’34’’ to 8^{0}9’55’’ North latitudes and 38^{0}53’57’’ to 39^{0}24’46’’ East longitudes. The Katar river and its tributaries start from the eastern parts of mountains Chilalo, Galema, and Kakka of Arsi Zone and drain to Lake Ziway. Topographically, the Katar river basin shows the variation with altitude ranging from around 1617m near Abura (at gauging station) to about 4211m above mean sea level on the high volcanic ridges along the eastern basin. The total area of the basin, upstream of the gauging station is estimated to be 3354 Km^{2}.

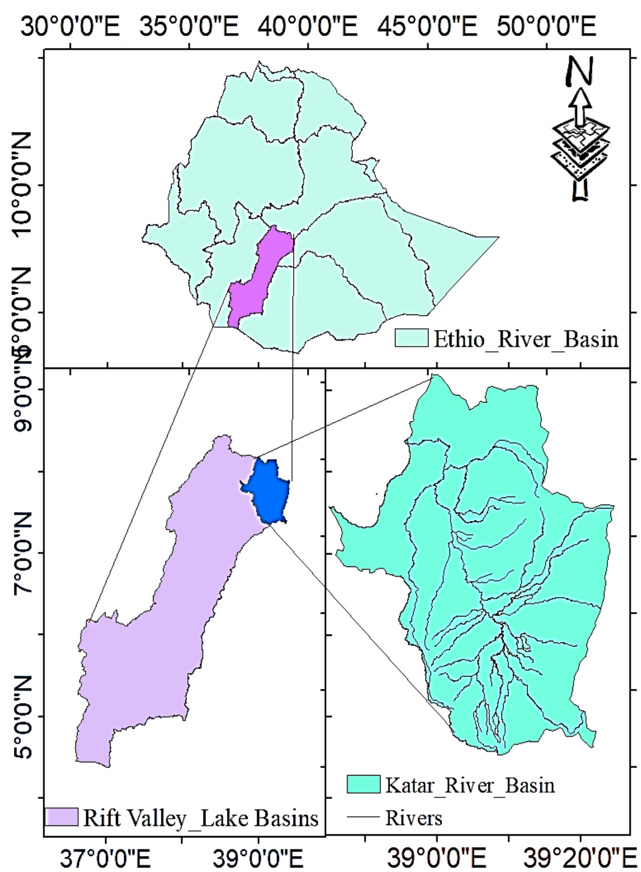


Figure 3.1: Location of Katar river basin

3.1.2 Climate

Regards to climate, the River basin is characterized by a dry to sub-humid climate with mean annual precipitation of 650 to 1200 mm and the temperature of the basin varies between 15 and 25°C (Aga, 2019). The rainfall pattern of the basin is largely influenced by the annual oscillation of the inter-tropical convergence zone. As a result, Legesse (2002) has classified the basin into three main seasons namely the warm period (small rainy season) which extends from March to May, wet summers or longest rain season (Jun to September), and dry period (October–February).

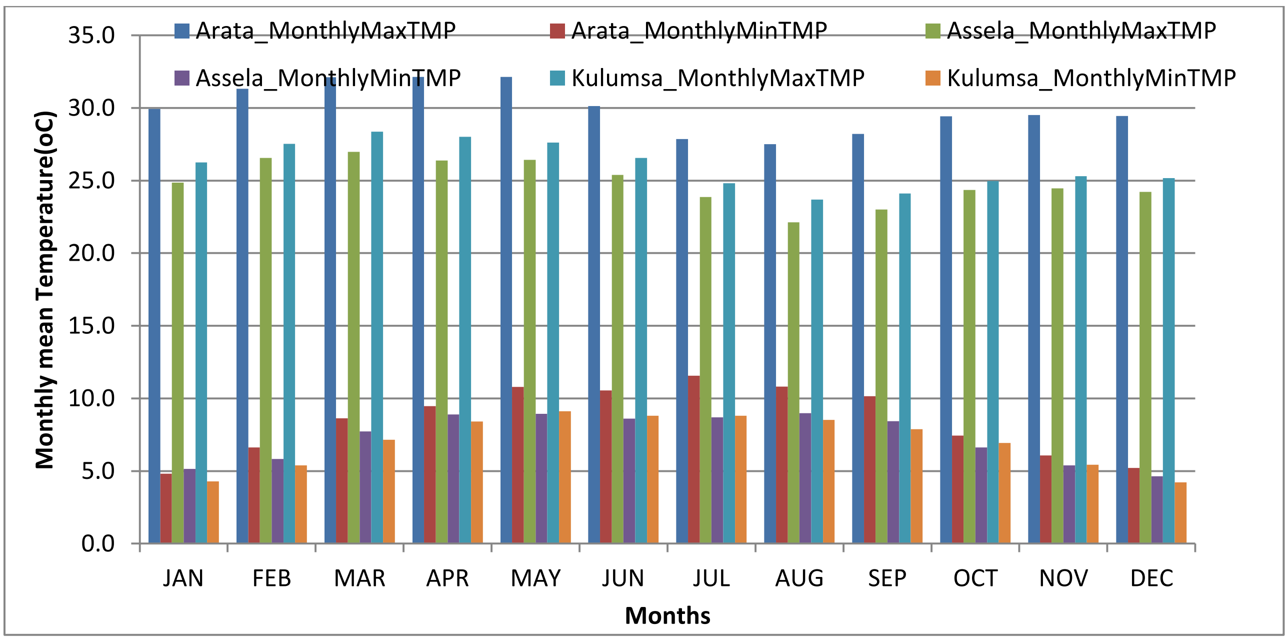


Figure 3.2: Monthly mean temperature (1987_2018)

Figure 3.2 indicated that the mean monthly maximum temperature of the Katar river basin was 32.1^{o}C in May and the mean monthly minimum temperature 4.2^{o}C in December from data was collected MoWRE.

3.1.3 Landuse and Land Cover

In the basin, there is dynamic land-use change (Barth, 2012; MOWR, 2010 and Zeray et al., 2006) and this has extended to cultivate the marginal lands and for poor land management practices (MOWR, 2010). Inside the basin, land degradation, soil erosion and declining soil fertility are seen due to the cultivation of more marginal lands and improper land management systems (Aga et al., 2020 and MOWR, 2010). Around the lakes, the dominant species are Acacia tortilis (Tolera, 2018). The basin is as a whole intensively cultivated and different crops are grown in the basin using both rain and irrigation (Tolera, 2018).

3.1.4 Soil

In the year 2010, the Ethiopian Rift Valley Lake Basin Master Plan study was conducted and, in this study, the soil samples were collected from all soil units of the basin. In the Ethiopia Water Works Design and Supervision Enterprise soil analyses laboratory, all physical and chemical parameters of those soils were tested. Accordingly, six soil types were identified by MOWR (2010) and are shown in Table 3.1 and its spatial distribution is shown in Figure 3.3.

Table 3.1: Major soil classification of the study area (source: MOWR, 2010)

Major Soil Groupings	Identified Soil Units	Code	Area(km^2)	% coverage's
Andosols (AN)	Vitric Andosols	ANz	212.06	6.32
Cambisols (CM)	Eutric Cambisols	CMe	0.17	0.01
Fluvisols (FL)	Calcaric Fluvisols	FLc	1.56	0.05
Luvisols (LV)	Haplic Luvisols	LVh	1884.80	56.19
Nitisols (NT)	Rhodic Nitisols	NTr	1054.99	31.45
Vertisols (VR)	Eutric Vertisols	VRe	198.97	5.93
Water			1.52	0.05
			3354.08	100

The spatial distribution of dominant soil type of the study area is shown in (figure 3.3) indicated dominant soils were founded in Katar river basins are Luvisols and Nitisols which cover 56.19% and 31.45% of the total area respectively.

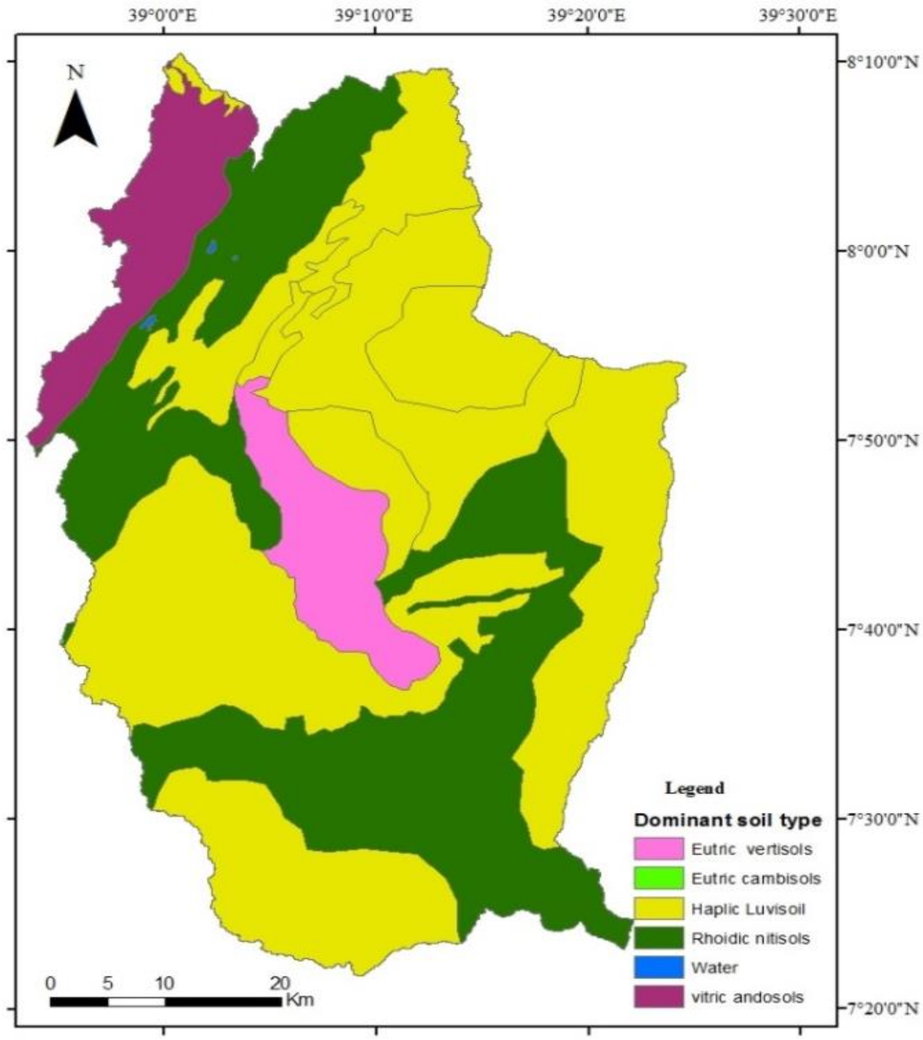


Figure 3.3: The spatial distribution of major soil type of the study area (source: MOWR, 2010).

3.2 Data Collection

3.2.1 Digital elevation model

The digital elevation model is the basic input data for any hydrological modeling study, including SWAT and HEC-HMS. A30 m × 30 m DEM were obtained from the shuttle radar topography mission (SRTM) of https://earthexplorer.usgs.gov/. From the collected DEM (Figure 3.4) the relevant basic information of the basin-like physiographic characteristics of the catchment, including slope and elevation were extracting in the ArcGIS program.

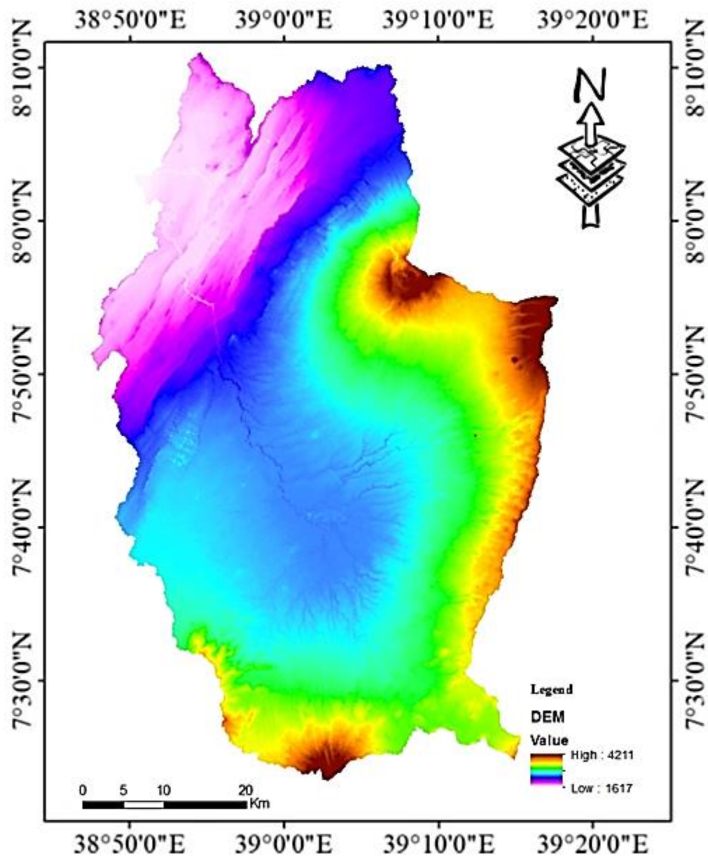


Figure 3.4: Topographic map of the study area (Digital Elevation Model)

3.2.2 Hydro_ Meteorological Data Analysis

The rainfall data for the Katar river basin were collected from the National Meteorological Agency (NMA), Ethiopia (Table 3.2). The collected data were appropriately adjusted for inconsistency, corrected for errors, extended for insufficient and filled for missing.

Table 3.2: Meteorological station name, year of data recorded and data existing

Station name	year of recorded	latitude	longitude	elevation	type of data
Arata	1987-2019	7.982778	39.059444	1777	PCP and TMP
Assela	1987-2019	7.9557	39.1383	2413	PCP and TMP
Kulumsa	1987-2019	8.0097	39.1553	2211	all
Sagure	1987-1999	7.46	39.09	2480	PCP and TMP
Ketera Genet	1987-2018	7.8333	39.1	2400	PCP
Ogolcho	1987-2018	8.0398	39.0182	1682	PCP and TMP

Meraro	2006-2018	7.45	39.366667	2940	all
Bokoji	1987-2018	7.5333	39.25	2388	PCP,TMP and HMD

From the above table, PCP indicated (Precipitation), TMP (Temperature), HMD (Relative humidity), and all represent including solar radiation and Wind speed.

The precipitation data was checked by spatial and temporal consistency checks to ensure the quality of the data for further investigation, as advised by Vedula and Mujumdar (2016).

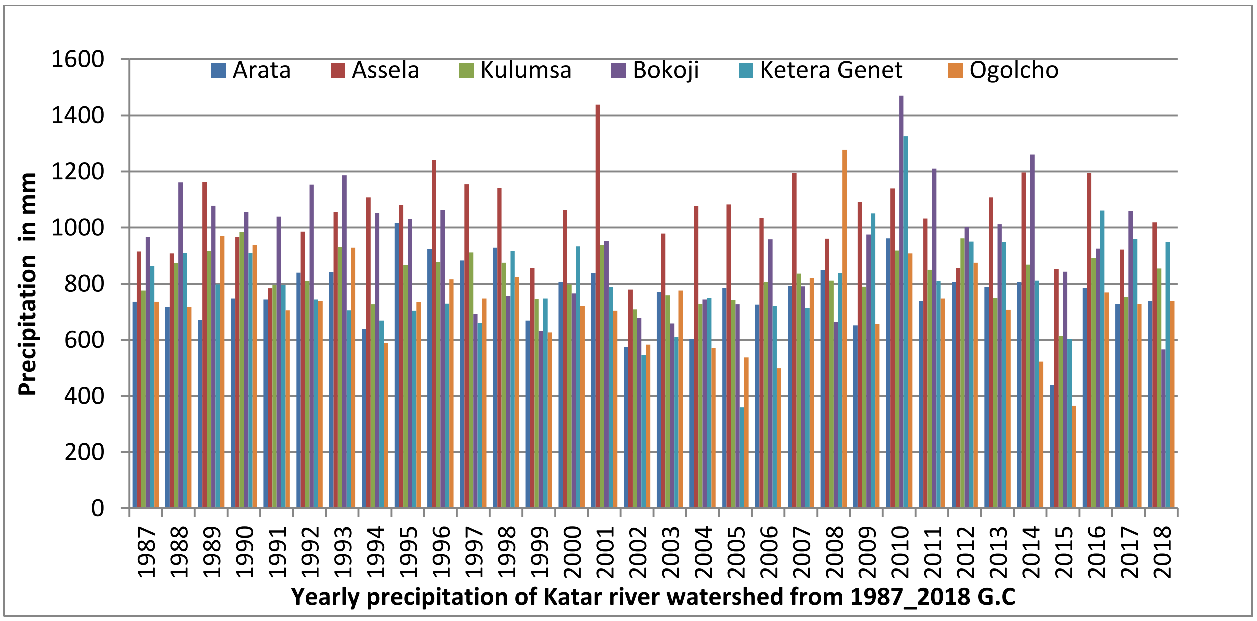


Figure 3.5: Yearly precipitation of Katar river basin from 1987-2018G.C

The above figure indicates that Katar river basin precipitation varies from 359.2 mm in Ketera Genet station during 2005 and 1469.8mm in Bokoji station during 2010.

3.2.1.1 Filling Missed Data for Rainfall

Several methods have been proposed for estimating missing rainfall data. They are station-average, normal-ratio, inverse distance, and regression methods. The station-average method is the simplest. The normal-ratio and inverse distance methods provide a weighted mean, with the former basing the weights on the mean annual rainfall at each gage and the latter having weights that depend on the distance between the gages where recorded data are available and the point where a value is required. For this study, the station average and normal ratio methods were used. Because, station average method is simple and used for flat area and the normal-ratio method is conceptually simple, but it differs from the station-average method in that the average annual catchment is used to derive weights for the rainfall depths at the individual stations. The missed data was estimated by using the data of the neighboring stations as advised by Subramanya (2008).

Considering the normal precipitations vary considerably, the missed precipitation P_X is estimated by weighing the precipitations at various stations by the ratio of normal precipitation. The normal ratio method is a given equation.

$$P\text{x} = \frac{Nx}{M!}\left(\frac{P1}{N1} + \frac{P2}{N2} + \cdots + \frac{Pn}{Nn}\right) - 3.1$$

Where, N1, N2, Nn =Normal annual rainfall, P1, P2, Pn =Precipitations at particular years, M=Number of neighboring stations. The second method is the station average method for estimating missing data uses n gages from a region to estimate the missing point rainfall, P, at another gauge.

Where $P=\frac{1}{n}\sum_{i=1}^{n} pi$ - - - - - -- -- --- --------------- ---------------- --- ---- ---- ---- --- --3.2

Where p is mean precipitation of missed and Pi is catch at gage i

Table 3.3: Estimation of missing data by normal ratio and station average method

Gage	Annual precipitation (mm)	Monthly precipitation(mm)
Arata	638	9.3
Assela	1074.3	X
Kulumsa	727	32.9
Bokoji	701.6	11.3
Katara Genet	668.8	11.2
Ogolcho	589.2	6.7

First of all to check 10% of annual precipitation of Assela gage which gives ±107.43 so its range 966.87-1181.73.fromn these annual precipitations of the nearest gauging station was out of range .for this reason normal ratio method was applied.

$$Px=\frac{1074.3}{5}\left(\frac{9.3}{638}+\frac{32.9}{727}+\frac{11.3}{701.6}+\frac{11.2}{668.8}+\frac{6.7}{589.2}\right)=22.4mm$$

3.2.1.2 Filling Missed Data for Stream Flow

The missed streamflow data of the study area was filled using the linear regression method by XLSTAT that correlates long term flow rate records with other hydrological stations. For this study, the correlation of Katar streamflow data at Abura with Katar streamflow data at Fete and Timela streamflow data at Sagure were tested using linear regression and found that Fete streamflow data have shown high correlation with Katar at Abura streamflow data as shown in Table 3.4. Hence, the missed Katar at Abura streamflow data was filled using a linear equation of Y=1.80X+1.27.

Table 3.4: Correlation of two streamflow gauging stations with Katar river**.**

Stream gauging station	Coefficient of correlation(R^2)	Linear equation
Katar river at Abura versus Katar river at Fete	0.701	Y=1.80X+1.27
Katar river versus Timela river at sagure	0.443	Y=3.80X-1.89
Where: Y= Missed discharge at Katar river and X = discharge at Fete gauging station		

3.2.1.3 Consistency Test of Rainfall Data

The trend of the rainfall records at a station may change through time due to a change in the physical environment which affects the catchment of the gauge due to change in the wind pattern or exposure. Adjustment of the measured data is necessary to provide a consistent record. Adjusting for gauge consistency involves the estimation of an effect rather than a missing value. The consistency of records at the station is tested by a double mass curve. The double mass curve is plotting the cumulative annual (or seasonal) rainfall at the station against the concurrent cumulative values of mean annual (or seasonal) rainfall for a group of surrounding stations of several years of record. From the plot, if any change occurs, is indicated by the change in the slope of the straight-line plot, the rainfall records of the station are adjusted by multiplying the recorded values of rainfall by the ratio of slopes of the straight lines before and after a change in environment. In the watershed, each rainfall station's annual records are tested against surrounding stations and are consistent temporally. Consistency tests for all stations in the watershed have been undertaken after missed data were filled.

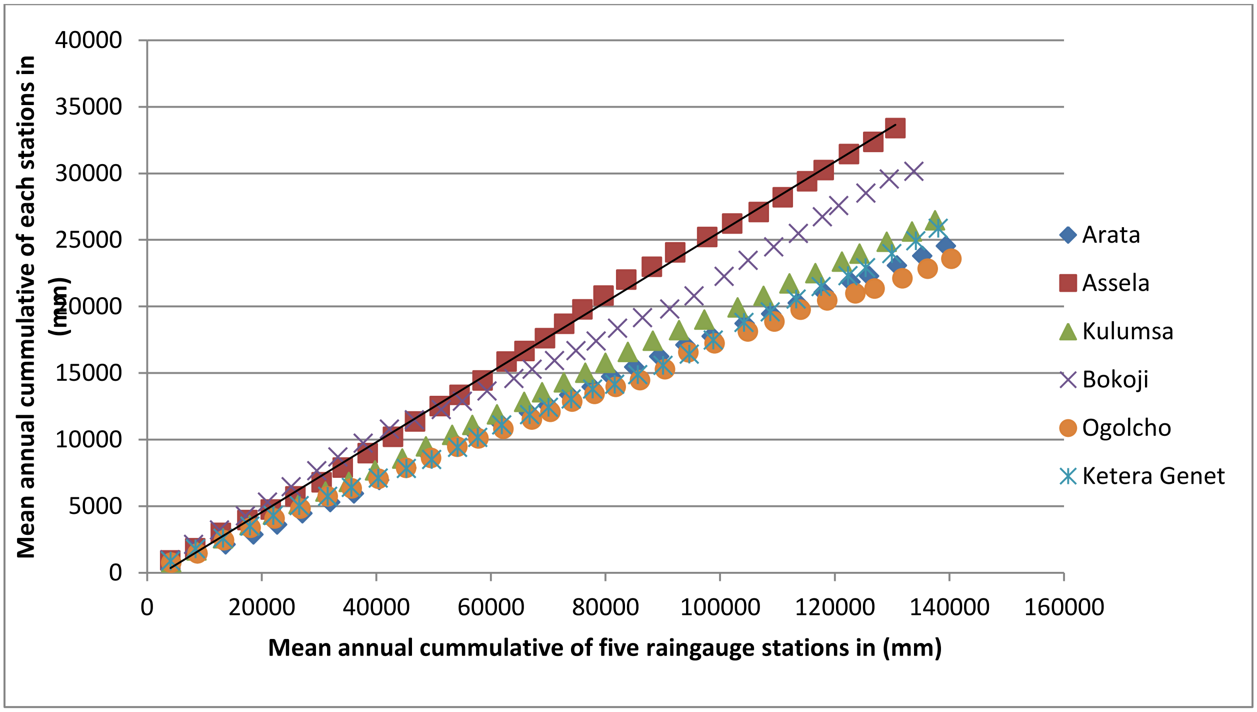


Figure 3.6: Double mass curve analysis of rainfall data for the study area

$$Y2 = \frac{S2}{S1} * Y1 \text{ --------------------------------------- } 3.3$$

Where: Y2= corrected precipitation at station x, Y1=original recorded precipitation at station x,

S2=slope of the double mass curve to be corrected and S1= original slope of the double mass curve is used.

3.2.1.4 Homogeneity Test for Precipitation

Homogeneity analysis was used to separate a change in the statistical properties of the time-series data. The causes can be either natural or man-made. These include alterations to land use and relocation of the observation gauging station. Therefore to select the representative meteorological station for the analysis of areal rainfall estimation, checking the homogeneity of group stations is essential, the homogeneity of the selected gauging stations daily rainfall records was carried out by non-dimensional equation (Tadesse, 2016).

$$Pi=\frac{Pi}{P} \quad \text{---} 3.4$$

Where Pi=non dimensional value of precipitation for the month i

Pi=over years averaged monthly precipitation for station i

P=over year's average yearly precipitation of the station

According to homogeneity test analysis, the selected stations were plotted for comparison with each other; for illustration figure 3.7 shows the result of the homogeneity analysis results. The Same model and pattern of the stations are observed. From the figure below it indicated that all station was the same patterns, which mean homogenous.

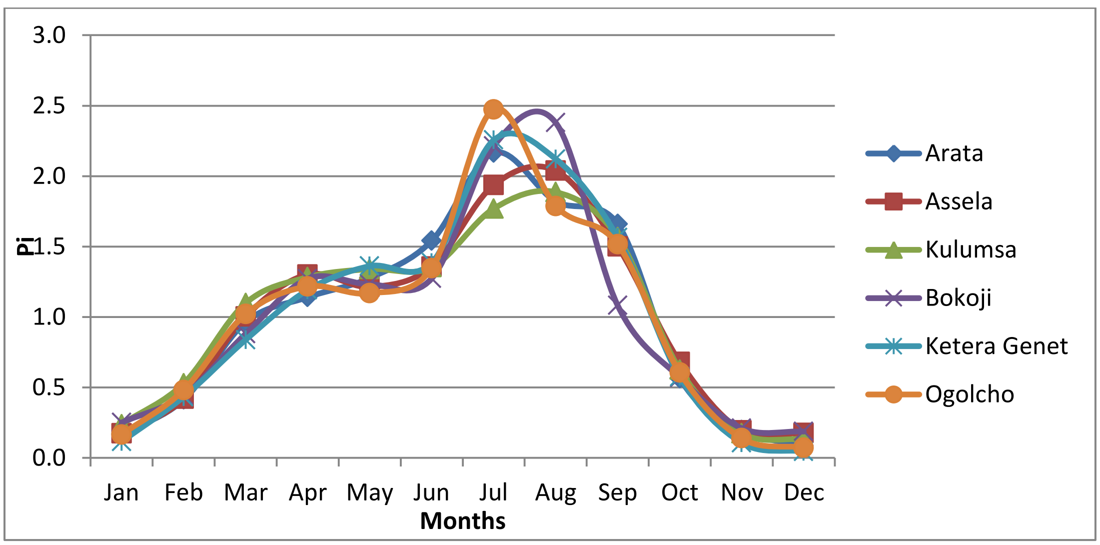


Figure 3.7: Homogeneity test analysis for Katar river basin of selected precipitation stations

3.2.1.5 Determination of Areal Rainfall

Areal Rainfall is the average rainfall over an area, and is referred to as the areal rainfall distribution and is restricted to long-term average values. It is expressed as a mean depth (mm) over the catchment area (Subramanya, 2008). There are three methods of determining the average depth of rainfall over the area. These methods are the Arithmetic mean, Thiessen polygon, and Isohyetal method. Thiessen polygon method is used to estimate weighted precipitations both observed and future scenario datasets of the sub-basin (Subramanya, 2008).

Katar river basin topography is flat and hilly so, the Thiessen polygon method applicable both in a flat and hilly area. Moreover, the Thiessen polygon method is best due to its sound theoretical basis and availability of computational tools. To determine the mean areal rainfall, the rainfall amount of each station is multiplied by the area of its polygon and the sum of these products is divided by the total area of the catchment. Mathematically it is given as follows.

$$Pave = \frac{P1*A1+P2*A2+P3*A3\cdots Pn*An}{A1+A2+A3+\cdots An} \qquad 3.5$$

Where: P1, P2….Pn = Are the rainfall magnitudes recorded,

1, 2….n = the stations and $A1, A2, A3 \ldots \ldots .. An = \text{area of sub} - \text{catchments}$

$Pave =$ The average rainfall over the catchment

Table 3.5: Percent of the areal annual depth of precipitation computed by Thiessen polygon method

Subbasin	Meteorological station name					
	Assela	Arata	Ketera genet	Kulumsa	Ogolcho	Bokoji
	From (%)					
W450(sub1)		10	10		80	
W460(sub2)	15	15		70		
W490(sub3)	60	15	25			
W470(sub4)		25	60	5	10	
W600(sub5)	5		75	5		15
W710(sub6)			10			90

The table above and the figure below indicate how to point rainfall distributes over areal rainfall. From the above table Sub-basin, 1(W450) received precipitation 10%,10%,80% from Assela, Arata and Ogolcho station respectively and the blow figure also described the above table.

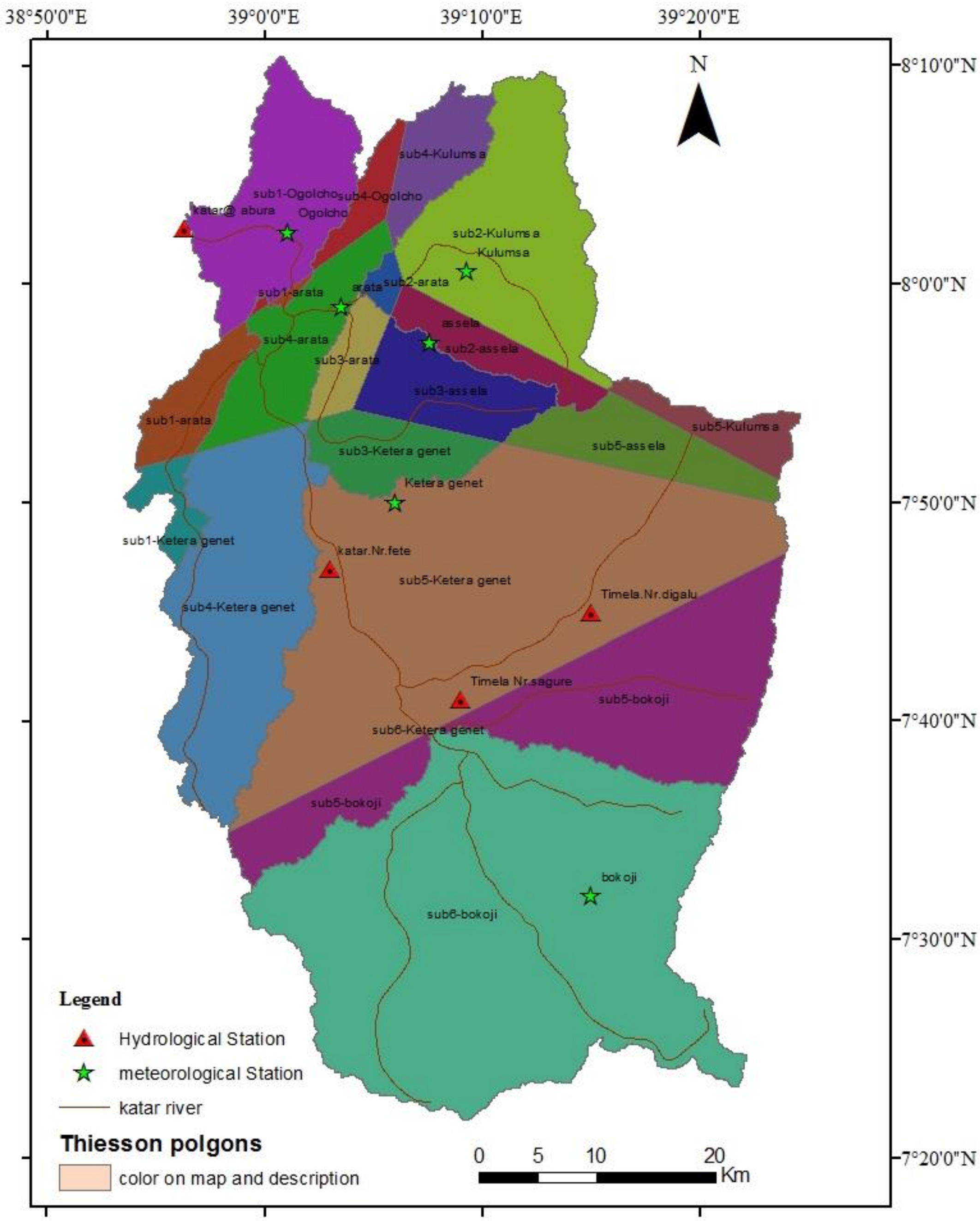


Figure 3.8: Thiessen polygon of the study area

Figure 3.8 more of used for HEC_HMS software converted point rainfall to areal rainfall during depth weights in percent received from one sub-basin from a different station. In the place of the Thiessen polygon on the SWAT model the weather generator model was generated by all stations.

3.3 Methods

The following framework illustrates the general workflow of the study

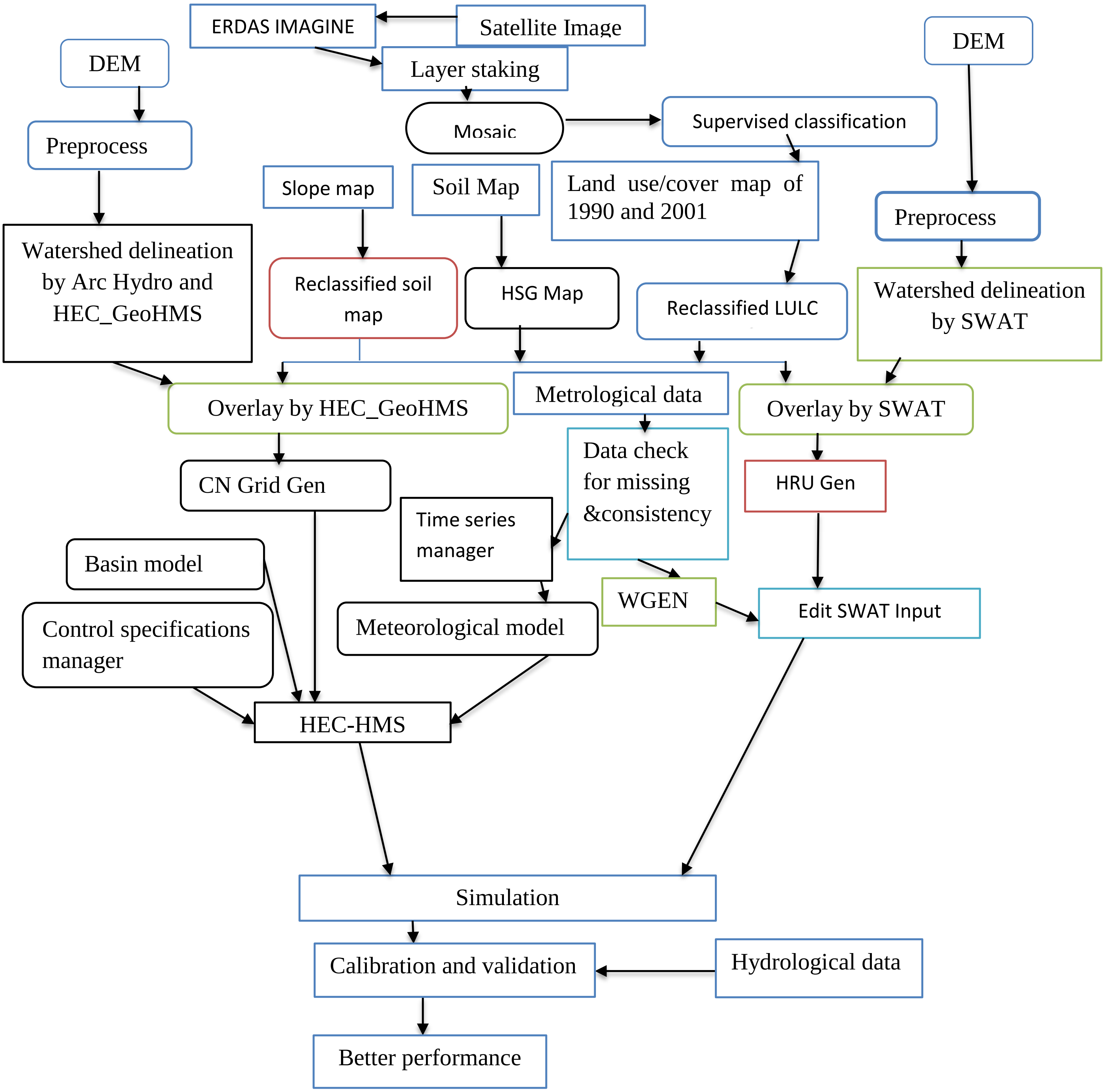


Figure 3.9: Schematic diagram of overall thesis methods

3.3.1 Generating the Different Years Land Use Land Cover Maps of the Study Area

3.3.1.1 Land Sat Images

To develop the SWAT and HEC-HMS model, one of the basic input data is the land use cover map of the study area. For model calibration and validation, researchers are using different years of metrological and streamflow data with a fixed land use land cover map. Practically, the land use land cover pattern of the study area also changed with the season. Unless we assume a constant land-use type inside the study area, using a single land use map for model calibration and validation may be erroneous. In this study, the models are going to be calibrated and validated for the years 1990 to 2000 and 2001 to 2007 respectively. Hence the streamflow, metrological and Land use land cover data should be prepared for each calibration and validation period. To do so, the land use land cover map of the study basin is prepared for the years 1990 and 2001 from Land sat images by downloading from the United States Geological Survey website (https:earthexplorer.usgs.gov).

Table 3.6: Characteristics of used satellite images

Spacecraft ID	Path/row	date	Pixel size	Band number	Sensor -ID
LANDSAT_5	168/54,55	18/12/1990	30*30	7	ETM^+
		16/12/2001			

The downloaded image has its acquisition dates, sensor, path row, resolution and the producers of satellite images based on the study area (Table 3.6). The selection of the Land sat satellite images date is influenced by the quality of the image especially for those with limited or low cloud cover and also to prevent seasonal variation of vegetation coverage. Therefore, the downloaded images are cloud-free which is in December and the same annual season.

3.3.1.2 Image Preprocessing

The image is available in the form of a GCS_WGS_1984 raster form with 30m*30m resolutions. Preprocessing such as layer stacking, mosaicking, and band color combination is carrying out to Ortho-rectify the images. The images are processed using ERDAS IMAGINE and GIS software. The development of land use and the land cover image was changed into Universal Transverse

Mercator (UTM) projection by considering the zone of the study area which is WGS-1984, UTM Zone 37N by using Arc GIS 10.2 software package. The exact study area's land use land cover was clipped from the projected land use map.

In a remote sense, there is various image classification such as supervised, unsupervised, and hybrid. For this study, the supervised classification type was applied. It is the most common type of classification technique in which all pixels with similar spectral values are automatically categorized into land cover classes or themes. A supervised classification that relies on prior knowledge of pattern recognition of the study area was used. It requires the manual identification of the point of interest areas as a reference or ground truth within the images, to determine the spectral signature of identified features. Depending on the above criteria the image was classified as water bodies, built-up area, forest, agricultural land, grassland, wetland, and afro_afline in the year (1990 and 2001).

Table 3.7: SWAT database and code of LULC for the study area

Land use/land Cover	Land Use According to SWAT DataBase	SWAT Code
Agriculture	Agricultural Land-Close-grown	AGRC
Afro-Alpine	Forest Evergreen	FRSE
Forest	Forest Mixed	FRST
Grassland	Pastureland	PAST
Wetlands	Wetlands Non-Forested	WETN
Build Up Area	Residential Medium Density	URMD
Water Body	Water	WATR

Finally, the LULC mapping output was subjected to an accuracy assessment.

3.3.1.3 Accuracy Assessment

Accuracy assessment is a necessary step to determine and quantify a LULC map. The accuracy assessment was done by comparing the classification product with the reference data, which accurately reflects the true land cover. The accuracy assessment reflects the difference between the classified data and the referenced data. The most common way to represent the classification accuracy of remotely sensed data is an error matrix (Congalton and Green, 1999). The user and producer accuracy are two widely used measures of accuracy assessment. The producer's accuracy is the percentage of pixels in the reference data for a certain class that is correctly identified by the classifier. The user's accuracy is the percentage of pixels classified as a certain class that agrees with the reference data. The Kappa coefficient (*K*) measures the relationship between beyond chance agreement and expected disagreement. The estimate of Kappa is the proportion of agreement after the chance agreement is removed from consideration. Kappa statistics/index was computed for a classified map to measure the accuracy of the results. The Kappa coefficient was calculated according to the formula given by (Congalton and Green, 1999).

$$K=\frac{N\sum_{i=1}^{r} xii-\sum_{i=1}^{r}(xi+.x+i)}{N^2-\sum_{i=1}^{r}(xi+.x+i)} \quad \text{---}3.6$$

Where '*r*' is the number of rows in the matrix, *xii* is the number of observations in row *i*, and column *i*, *xi*+, and *x*+*i* is the marginal totals of row *i* and column *i*, respectively, and *N* is the total number of observations.

3.3.2 Assessing the Runoff Potential and Developing Peak Runoff of the Basin

3.3.2.1 SWAT Model

The Soil and Water Assessment Tool (SWAT) is a physical-based model used to estimate the runoff, sediment, and chemical yields in gauged and un-gauged basins (Arnold and Fohrer 2005). The hydrologic cycle of a basin simulated by SWAT is based on the following water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \qquad (3.7)$$

Where: SWt is final soil water content (mm), SW0 is initial soil water content (mm),
t is time (days), Rday is amount of precipitation (mm),
Qsurf is amount of surface runoff (mm),
Ea is amount of evapotranspiration (mm),
Wseep is amount of water entering the vadose zone from the soil profile (mm) and
Qgw is amount of return flow (mm).

In SWAT, the surface runoff from daily rainfall is estimated using a modified SCS curve number method, which estimates the amount of runoff based on local land use, soil type, and antecedent moisture conditions (SCS, 1972). The surface runoff component of the water balance is determined from the SCS method as:

$$Q_{surf} = \frac{\left(R_{day} - I_a\right)^2}{R_{day} - Ia + S} \tag{3.8}$$

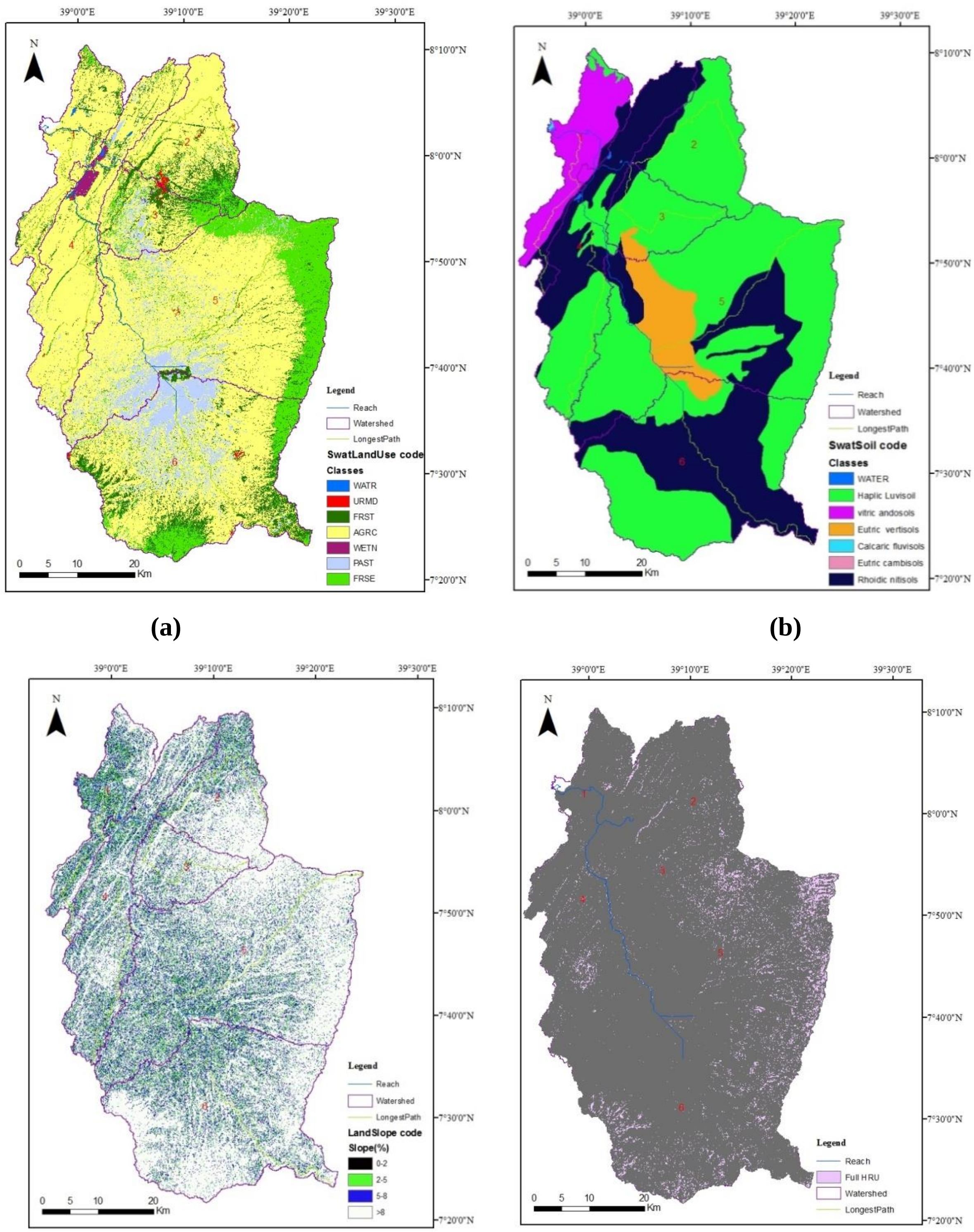
Where Ia =0.2S and S= 25.4 (1000/CN-10); hence the amount of surface runoff is equated as:

$$Q_{surf} = \frac{\left(R_{day} - 0.2S\right)^2}{R_{day} + 0.8S} \tag{3.9}$$

Where: I is an initial abstraction (mm), S is relation parameter (mm) and CN is curve number

3.3.2.1.1 Watershed delineation

The first step in generating the SWAT model is watershed delineation. Using the 30 * 30 m resolution DEM data, the upstream of the gauging station Abura was delineated using ArcGIS 10.2 (Esri, Redlands, CA, USA). Accordingly, the entire study area has been divided into six sub-watersheds. After watershed delineation, land use, soil and slope characterization for watershed was performed using commands from the HRU analysis menu on the Arc SWAT Toolbar. The watershed was divided into hydrologic response units (HRU) which have a unique soil and land use combination. Based on the model setup with land use, soil and slope, and minimum area threshold values set as 5%, 10%, and 10% respectively. 69 and 54 Hydrological Response Units (HRU) were identified, which are unique combinations of land use, soil type and slope (Figure 3.13, d). From this, for model validation, the figure below 2001 LULC code, soli code, slope code, and HRU respectively put as the example. For the year 1990 SWAT code was attached to the appendix.



(a) **(b)**

(c) **(d)**

Figure 3.10: (a) LULC swat code; (b) major soil ;(c) slope classification and d) full hydrologic response unit 2001 of the study area

3.3.2.2 Arc Hydro and HEC_GeoHMS models

Arc Hydro is a Geodatabase design and a set of accompanying tools geared for support of water resources applications in the GIS environment. The Arc Hydro tools had been developed by ESRI and can be used to process Digital Elevation Model data to delineate watershed and drainage network patterns. Terrain Pre-processing was the first step in doing any kind of hydrologic modeling like delineating streams and watersheds.

The results obtained from terrain pre-processing were used to create input files for HEC-GeoHMS. Once defined the project for HEC-GeoHMS, a new data frame was created and all the terrain preprocessing data were extracted and imported to a new project. After the new project has been created, the basin processing menu was used to revise or customize the sub-basin delineation, dividing sub-basins and merging streams. Accordingly, HEC-GeoHMS produced many sub-basins but to increase the performance of the model, the watershed was merged into six sub-basins with twelve reaches, twelve junctions.

HEC-GeoHMS consists of different menus that provide different functions. These are preprocessing, project setup, basin processing, basin characteristics, basin parameters, HMS, and utility Figure 3.11. For each of the stream segments and the related sub-basins, a series of physically-based characteristics were generated by HEC-GeoHMS tools. These characteristics include the area, length, and slope of each river segment as well as the average basin slope and the longest flow path of each sub-basin. The resulting data is automatically stored in the attribute table of the river and sub-basin layer.

After successful completion of the Arc Hydro and HEC-GeoHMS process shown in figure 3.11, a background shapefile and basin characteristics were exported to HEC-HMS for processing of further analysis.

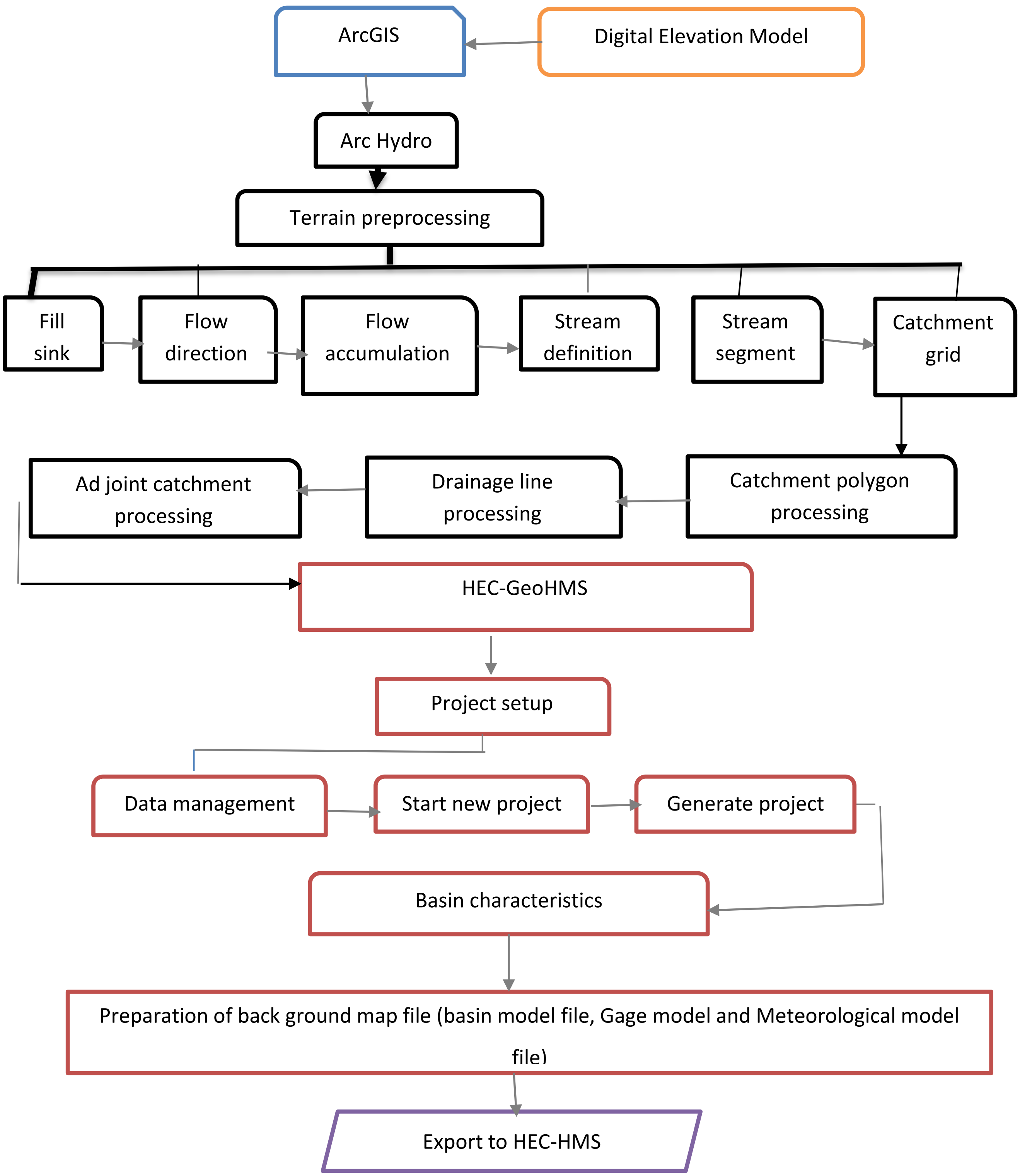


Figure 3.11: Arc Hydro and HEC-GeoHMS processing workflow diagram

3.3.2.3 HEC-HMS Model

HEC-HMS 4.3 is hydrologic modeling software developed by the US Army Corps of Engineers-Hydrologic Engineering Center (HEC) and is designed to simulate the rainfall-runoff processes in a wide range of geographic areas such as large river basin water supply and flood hydrology to small urban and natural watershed runoff (Demlie and Melesse, 2018). HEC-HMS model setup consists of a basin model, meteorological model, control specifications, and input data (time series data). Hence to prepare the input files for HEC-HMS, the DEM of the study area was processed using the geographic information system (GIS) interface of the HEC_GeoHMS model in an ArcGIS program. Terrain pre-processing and basin processing tools were used to generate basin characteristic parameters and input files for HEC-HMS including a stream network, sub-basin boundaries, and the connectivity of various hydrologic elements. The basin model and basin features derived from HEC-GeoHMS were taken as a background map file and imported to HEC-HMS (Figure 3.12). In the meteorological model, the Priestley-Taylor evapotranspiration method was used for hydrological simulation and the sub-basins areal precipitation was estimated by the Thiessen polygon method concerning the centroid point of each sub-basin.

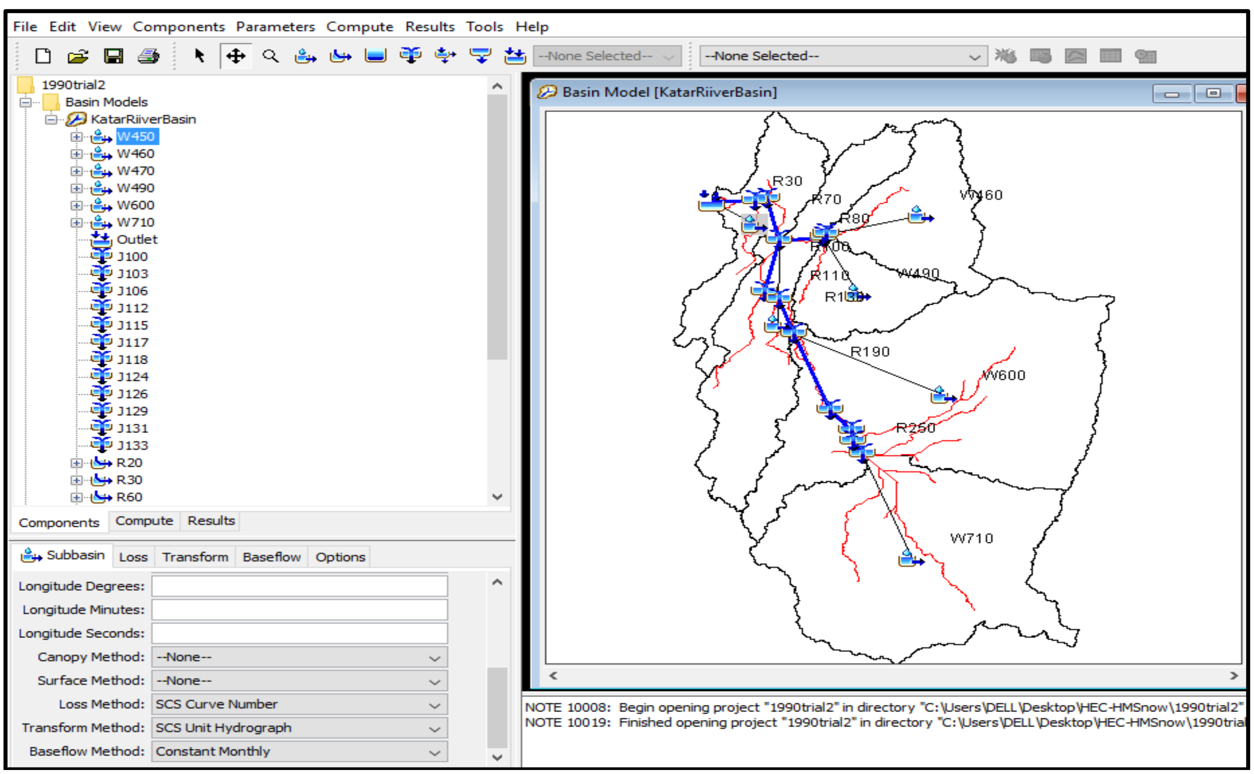


Figure 3.12: Background map file of Katar river basin

The system encompasses runoff volume by computing the volume of water that is intercepted, evaporated, infiltrated, stored, and subtracting it from the total precipitation. In the HEC-HMS model, around eleven kinds of loss estimation methods are embedded in the program and are described as follows.

3.3.2.3.1 Rainfall Loss Modeling

Rainfall may lose through interception by vegetation and building, evaporations, infiltration deep percolation, surface storage. So, to know the amount of excess rainfall from the watershed that joins the river channel proper modeling of these losses is vital. For rainfall lose modeling the HEC-HMS has options like deficit constant, initial and constant, Green-Ampt, Soil Conservation Service Curve Number, and Soil Moisture Accounting. In this study, Soil Conservation Service Curve Number was selected to model rainfall losses because it is a versatile and widely used approach for quick runoff estimation and also relatively easy to use with minimum data and give adequate results (Nasir and Alipur, 2014). Moreover, it is the most popular method for computing surface runoff (Nasir and Alipur, 2014).

To do so the soil map obtained from MoWRIE and land use cover map developed in this study were employed. For all soil class of the basin, both physical and chemical tests were done by MoWRIE and the lab results of the tests were obtained from MoWRIE. By using these characteristics, and mainly relying on soil texture and depth, the map of hydrological soil group of basins according to standard definitions of SCS (soil conservation services) was prepared. In the tables about the curve number for various land use and hydrological soil groups, the amount of CN (Curve Number) was determined and presented in (USDA 1972, 2004; Chow et al. 2002). Then from the map of land uses and hydrological soil groups of the basin, the (USDA, 2004) amount of CN for conditions of primary moisture average (mode II) was calculated. The basin's surface runoff was calculated as:

$$S = \left(\frac{24500}{CN}\right) - 254 \tag{3.10}$$

$$Q = (P - 0.2S)^2 / (P+0.8S) \tag{3.11}$$

$$CN = (S * (Ci * Ai))/A \quad (3.12)$$

Where CN is a weighted curve number, CNi is a curve number from 1 to any no. N, Ai is an area with curve number CNi and P is rainfall (mm)

The CN value of the study area has been determined as Figure 3.13. The minimum and maximum CN value of the study area was 30 for the area covered by forests and 100 for the area covered by the water body. However, in the rainfall-runoff simulation, each sub-basin requires a single value of CN. Hence, the weighted CN values were already extracted by HEC-GeoHMS for each sub-basin. The maximum curve number value was 82.66 whereas; the minimum CN value was 67.40. This minimum and maximum CN values were found in sub-basin W450 and W470 respectively.

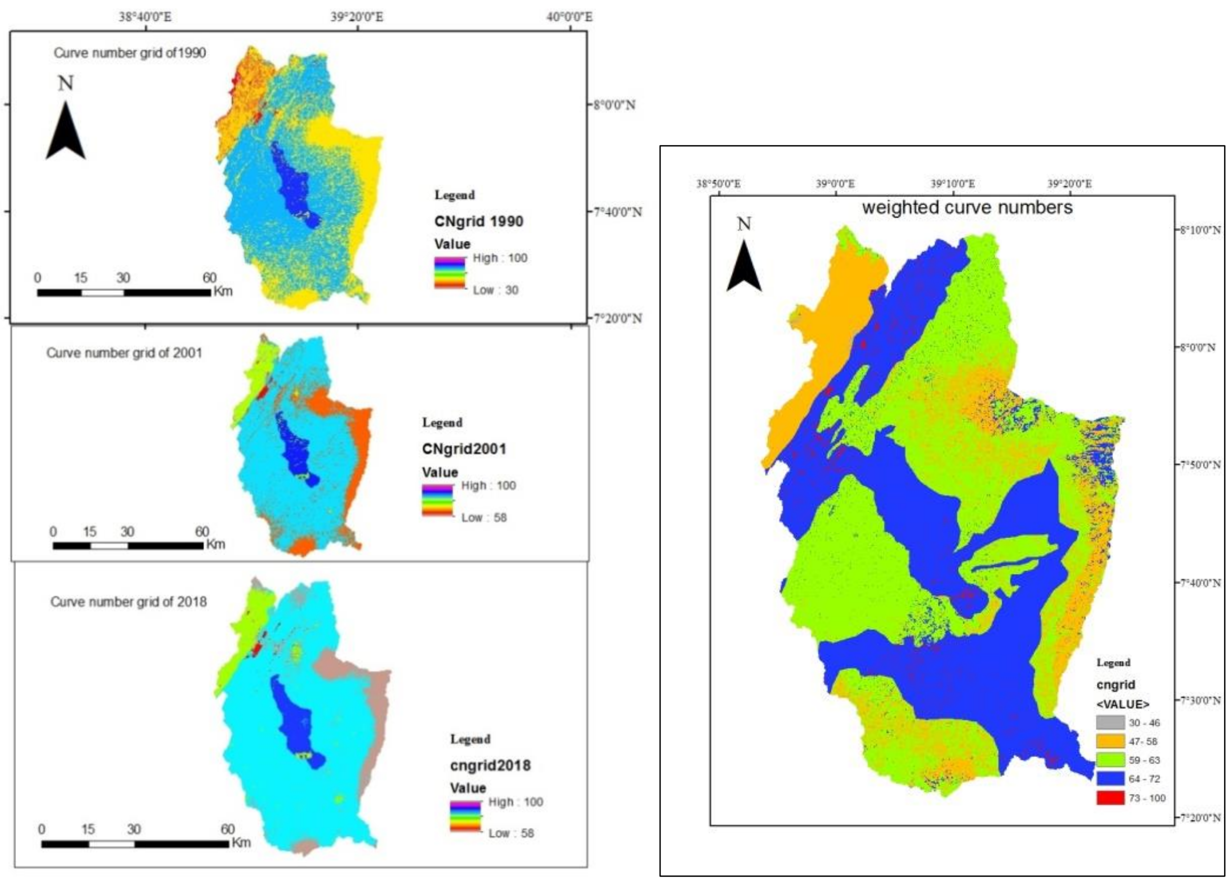


Figure 3.13: Weighted curve number map of the Katar river basin

Table 3.8: Estimation of runoff by SCS_CN method

year	subbasin	annual rainfall (mm)	Basin CN(AMC_II)	S(Max.p.retention(mm)	Ia=0.1 S(mm)	Runoff (mm)	Ia=0.2 S(mm)	Runoff (mm)	Ia=0.3 S(mm)	Runoff (mm)
1990	W450	939.4	67.40	122.88	12.29	818.61	24.58	797.05	36.86	775.79
	W460	984	77.33	74.48	7.45	907.35	14.90	893.56	22.34	879.88
	W470	747	80.82	60.27	6.03	685.24	12.05	674.13	18.08	663.12
	W490	967.7	77.24	74.84	7.48	890.79	14.97	876.96	22.45	863.24
	W600	910.1	77.86	72.22	7.22	836.01	14.44	822.69	21.67	809.48
	W710	812.6	76.91	76.25	7.62	735.32	15.25	721.46	22.87	707.73
2001	W450	703.7	76.33	78.780	7.88	625.05	15.76	610.98	23.63	597.07
	W460	938.9	79.92	63.830	6.38	872.78	12.77	860.87	19.15	849.04
	W470	837	82.66	53.266	5.33	781.61	10.65	771.63	15.98	761.72
	W490	1438.8	79.66	64.840	6.48	1370.28	12.97	1357.91	19.45	1345.58
	W600	788.4	80.84	60.192	6.02	726.49	12.04	715.35	18.06	704.30
	W710	953.1	80.31	62.268	6.23	888.45	12.45	876.80	18.68	865.23

Table 3.8 indicated that as the coefficient of initial abstraction (λ) is an increase in value shows a decrease in runoff based on the potential retention parameter (S). If the initial abstractions like interceptions of plant, surface storage, infiltration rate, and evaporation are high, runoff is possible only when rainfall is greater than 0.2S. Else, the resulting runoff is zero.

3.3.2.3.2 Excess Rainfall Modeling Method

For the computation of excess precipitation, there are seven different methods in the HEC-HMS program namely Clark Unit Hydrograph, Kinematic wave, Modified Clark, Soil Conservation Service Unit Hydrograph, Snyder Unit Hydrograph, and User Specified Unit Hydrograph. For this study, Soil Conservation Service Unit Hydrograph was selected to model excess precipitation. This method was preferred based upon input data needed and various researchers as discussed in the literature review recommend this method for modeling excess rainfall. It uses basin lag time which was already generated by HEC-GeoHMS as input.

3.3.2.3.3 Flood Routing Method

Different flood routing methods are available in the HEC-HMS model. These are Kinematic wave, Lag, Modified pulse, Muskingum, and Muskingum-Cunge method. Muskingum method was selected for this study. Muskingum method most popular and frequently used for flood routing in natural channels (Chang, 2009). This method requires Muskingum k (flood wave traveling time) and the weighting coefficient of discharge (x). Flood wave traveling time and Muskingum x range from 0.0016-150 and 0 to 0.5 respectively (Chang, 2009) .

According to Subramanya (2008) and (Feldman, 2005), the Muskingum flood routing method uses the following hydrologic flood routing equation.

$$\mathrm{I} - \mathrm{Q} = \frac{ds}{dt} \qquad 3.13$$

$$\mathrm{S} = \mathrm{k}[\mathrm{xI} + (1 - \mathrm{x})\mathrm{Q}] \qquad 3.14$$

Where I is inflow, Q is an outflow, ds is changed in storage, dt is changed in times, S is storage, K is flood wave traveling time, x is the weighting coefficient of discharge. K can be calculated as equation 3.15.

$$\mathrm{k} = \frac{v}{l} \qquad 3.15$$

Where v is allowable flow velocity, l is the length of the reaches

Allowable velocity is the velocity that causes neither erosion nor deposition of silt in the river channel (Subramanya, 2008). Permissible velocity ranges from 0.75 to 2.0 (ERA, 2013). Hence, the permissible velocity of 1.4 m/s was assumed to determine the initial value of flood traveling time (k).

3.3.2.3.4 Base Flow Modeling

The constant monthly base flow was considered for this study by assuming the minimum mean monthly of observed streamflow as base flow contribution.

3.3.3 Assessing the Ability of HEC_HMS and SWAT Models to simulate Stream Flow for the Study Area.

3.3.3.1 Model Calibration and Validation

The successful application of the hydrologic watershed model depends upon how well the model is calibrated which in turn depends on the technical capability of the hydrological model as well as the quality of the input data. The objective of the model calibration is to match the simulated runoff volumes, hydrographs, and timing of hydrographs with the observed ones. Sensitivity analysis is defined as the process of determining the significance of one or a combination of parameters concerning the objective function or model output (Arnold, 2012). Therefore, before the calibration and validation process, a sensitivity analysis was carried out to reduce the number of parameters that need optimization. In this research semi-automated Sequential Uncertainty Fitting (SUFI-2) was used to identify the sensitive parameters. This was done to select the most flow influencing parameters in the catchment and involves stochastic calibration, where the errors and uncertainties in the model are recognized and expressed as ranges accounting for all driving variables and a used a two-year warm-up has been used for the SWAT-CUP model. Therefore, calibration was done mainly considering the simulated outflow volume. After calibration, the models were validated using the same input parameters as determined by the calibration process but with different simulation time. Validation is the process by which a calibrated model is shown to be capable of reproducing a set of field observations or predicting future conditions without further adjustment to the calibrated parameters (Moriasi et al., 2013).

3.3.3.2 Model Performance Evaluation

To calibrate and validate the models and for comparison purposes, some quantitative information is required to measure model performance. In this study, the streamflow data measured at the outlet of the watershed was used to assess the model performance.

Several studies recommended four statistics coefficient to test the model performance; the Nash–Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance, coefficient of determination (R^2)

describes the degree of collinearity between simulated and measured data (Moriasi et al., 2013; (Pachepsky et al., 2016; Golmohammadi et al., 2014).

Table 3.9: Performance measurements for stream flow simulation (Moriasi et al., 2013)

Performance rating	NSE	R^2
Unsatisfactory	$NSE \leq 0.5$	$R^2 < 0.50$
Satisfactory	$0.5 < NSE \leq 0.65$	$0.50 < R^2 < 0.70$
Good	$0.65 < NSE \leq 0.75$	$0.70 < R^2 < 0.80$
Very good	$0.75 < NSE \leq 1$	>0.80

$$R^2 = \frac{\sum(Qm - Qmean)(Qs - Qmeans)}{\sum(Qm - Qmean)2 \sum(Qs - Qsmean)2} \quad \text{------------} 3.16$$

Where: R^2 is the coefficient of determination

Qm measured value, Qs are simulated values, m average measured values, s average simulated values.

$$NS = 1 - \left[\frac{\sum_i^n (Qm - Qs)2}{\sum_i^n (Qm - Qmean)2}\right] \quad \text{------------} 3.17$$

The value of the coefficients varies from minus infinity to one with the latter value indicating perfect agreement between the simulated and observed data. A smaller NS value indicates a poorer fit between the simulated and observed data (Moriasi et al., 2013)

3.3.3.3 Model comparison methods

The two rainfall–runoff models were compared based on their performances in the time domain and in the quantile domain. The time-domain comparison technique is used to investigate the robustness of hydrological models for real-time operation and to manage water resources. A robust hydrological model for climate change impact assessment and planning of water resources management should reproduce the observed discharges in the quantile domain associated with the low and high flows for climate change impact studies. Hydrological low-flow periods and droughts affect the water supply for drinking, irrigation, industrial needs, hydropower production, and ecosystems; therefore, in the study basin, peak flow analysis is useful mainly for flood protection and water resources planning. Quantile curve analysis is used to identify intervals, which can be used as general indicators of hydrologic conditions. Quantile curve intervals can be grouped into several categories. A standard approach is to divide the quantile curve it into five zones: high flows (0–10%), moist flows (10–40%), mid-range flows (40–60%), dry conditions (60–90%), and low flows (90–100%) (Kannan and Jeong, 2011).Correspondingly, we have evaluated the performances of the two hydrological models for these five flow conditions (i.e. by dividing the flow duration curve into five zones).

4. RESULTS AND DISCUSSIONS

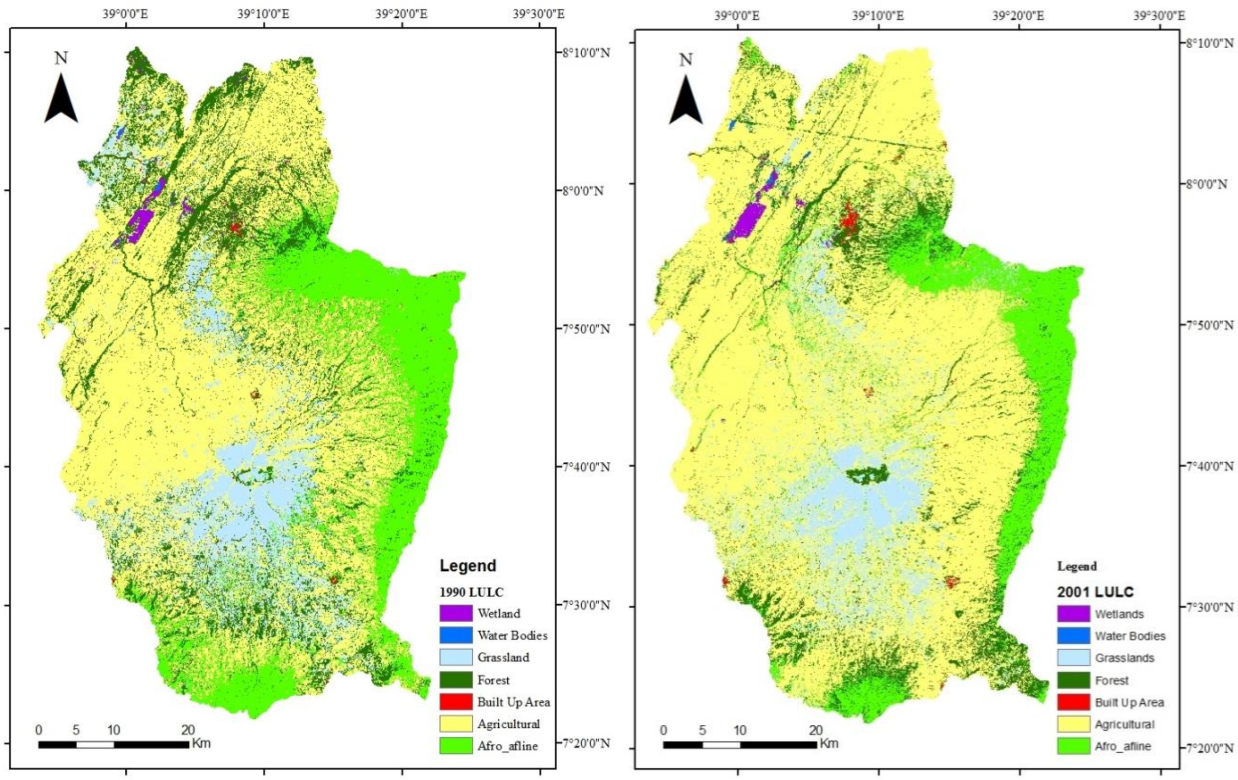
4.1. Landuse and Land Cover Map of Katar River Basin

A total of 7 classes were mapped in 1990 and 2001 for the basin: Wetland, water bodies, grassland, forest, built-up area, agricultural land, and afro_afline (Figure 4.1) and the area statistics are presented in Table 4.1.

Table 4.1: Table showing various land use land cover categories of the Katar river basin

LULC type	`1990		2001		1990 to2001
	Area(Km^2)	Area (%)	Area(Km^2)	Area (%)	Change (%)
Water bodies	1.3	0.04	2.322	0.07	+0.03
Built up area	14.8	0.44	18.09	0.54	+0.1
Forest land	523.9	15.62	314.5	9.38	-6.24
Agricultural land	1707.5	50.91	2208	65.84	+14.93
Wetland	20.1	0.60	21.5	0.64	0.04
Grassland	404.6	12.06	357.7	10.66	-1.4
Afro_afline	681.7	20.33	431.8	12.87	-7.46
	3354	100.00	3354	100	

As shown in the above table the land use/land cover maps analyzed from 1990 to 2001 show that the agricultural land occupies the maximum area of about 50.9% - 65.84%. The next predominant class found was afro_afline decreases 20.33%_12.87 % from 1990 to 2001 years. During 1990–2001 (Figure 4.1a–c, Table 4.1), it has been inferred that there was an increase in agricultural (from 50.9% in 1990 to 65.84% in 2001), followed by a decrease in forest cover (15.62–9.38%), a decrease in afro_afline (20.33–12.87%), a decrease grassland (12.06-10.66%), an increase in the wetland (0.6-0.64%), an increase in water bodies (0.04–0.07%) and an increase in a built-up area (0.44–0.54%).



(a) (b)

Figure 4.1: Landuse/land cover (LULC) cover map of the Katar river basin of the years (a) 1990 and (b) 2001

The results indicate that the increase of built-up land and agricultural from 1990 to 2001 showed the urbanization and agricultural activities of the people living in this area. The decrease of forest, afro_afline, and grassland was also observed, which might be utilized for agricultural activities. The results revealed that the overall LULC in the basin showed a reverse trend for the forest cover and cropland classes, i.e., decreasing forests and increasing agricultural land. The expansion of the built-up, agricultural, and water bodies may be due to the deforestation. I have evaluated the accuracy of the LULC 1990 and 2001 map using 149(102 from actual ground and 47 from google map) random points from the total study area used the confusion error matrix, which was created with the mapped and ground reference points, to determine the user's accuracy and Cohen's kappa accuracy (Table 4.2-4.3) showing overall classification accuracy of 88.6 and 89.93% and kappa coefficient 0.86 and 0.88 respectively. As reported by Anderson (1976) the minimum accuracy value for reliable land cover classification is 85%.

Table 4.2: Confusion Matrix for the accuracy assessment of the LULC Classification of 1990

	WB	BUA	FST	AGL	WL	GRL	AA	Ground truth	Users Accuracy
WB	11	0	0	0	0	0	0	11	100.0
BUA	0	12	0	0	0	0	2	14	85.7
FRS	0	0	25	0	0	3	0	28	89.3
AGL	1	1	4	36	1	0	0	43	83.7
WL	1	0	0	0	8	0	0	9	88.9
GRL	0	1	1	1	0	21	0	24	87.5
AA	0	0	0	1	0	0	19	20	95.0
Total	13	14	30	38	9	24	21	149	
Producers accuracy	84.6	85.7	83.3	94.7	88.9	87.5	90.5		

Over all classification accuracy= (11+12+25+36+8+21+19)/149*100=88.6 %

Where: WB=Water body, GRL=grassland, BUA=Built up area, FST=forest, WL=Wetlands, AA=afro_afline, AGL=agricultural land.

Table 4.2 indicates overall accuracy is 88.6 % and the kappa coefficient is 0.86 and the users' accuracy and producers' accuracy were 83.7_100 and 84.6_94.7 respectively.

Table 4.3: Confusion Matrix for the accuracy assessment of the LULC Classification of 2001

	WB	BUA	FST	AGL	WL	GRL	AA	Total	Users Accuracy
WB	10	0	0	0	1	0	0	11	90.91
BUA	0	12	1	1	0	0	0	14	85.71
FRS	0	0	22	1	1	0	2	26	84.62
AGL	0	1	1	43	0	1	0	46	93.48
WL	1	0	0	1	14	0	0	16	87.50
GRL	0	0	1	1	0	13	0	15	86.67
AA	0	0	0	0	0	1	20	21	95.24
Total	11	13	25	47	16	15	22	149	
Producers accuracy	90.91	92.31	88.00	91.49	87.50	86.67	90.91		

Table 4.3 indicates overall accuracy is 89.93 % and the kappa coefficient is 0.88 and the users' accuracy and producers' accuracy were 84.62_95.24 and 86.67_92.31 respectively.

In addition to the above, the results from the figure (4.1a-c) and table 4.1 when compared to past researches such as (Tolera, 2018; Damtew et al., 2015 and MoWR, 2010) study approximately indicated that the same trend (increase or decrease) except Tolera (2018) for classification of forest and built-up area results regarding land use and land cover changes. As classified Damtaw (2015) in the year 1986 agricultural land, forest, grassland, afro_afline, the built-up area was 46.09,12.9,19.72,18.75 and 0.77 % respectively and also Tolera (2018) classified in the year 1995 was got 43.45, 0.57, 23.73, 31.42 and 0.12% respectively .in addition to Halcrow limited company classified LULC of Rift Valley the same pattern except for the value of classification. But, as Tolera (2015) the percent of built-up increased from 0.12 to 8.65% and forest land also increased from 0.57 to 0.67 from (1995-2015) differ from another paper.

For this study, the land use land cover map generated above (Figure 4.1) is used for both models (SWAT and HEC-HMS).

4.2 Performance Assessment HEC_HMS and SWAT Models

4.2.1 Sensitivity Analysis of Stream Flow Parameters for Both Models

Out of the 16 parameters, only a few parameters that are most sensitive for flows were determined. Based on p-test and t-stat; A t-stat determines the relative significance of each parameter and ranks the parameter based on the absolute values (i.e. larger the absolute values, more sensitive the parameter) whereas a p-test determines the sensitivity of the parameter (i.e. value closes to zero has more significance) (Aga et al., 2018). To obtain optimal fitting with the measured data, calibration was conducted manually and automatically by the SUFI-2 program and HEC_HMS its own optimization algorithm menu tools. The sensitive parameters identified during calibration are SCS runoff curve number (CN2.mgt), effective hydraulic conductivity in the main channel (mm/hr) (CH_K2.rte), Saturated hydraulic conductivity (mm/hr) (SOL_K.sol), Groundwater "revap" coefficient (GW_REVAP.gw), an available water capacity of the soil layer (mm H2O/mm soil) (SOL_AWC.sol), surface runoff lag time (SURLAG.bsn), the slope of the watershed (HRU_SLP.hru), base flow alpha-factor (days) (ALPHA_BF.gw) and groundwater delay (days) (GW_DELAY.gw) for SWAT model and HEC_HMS models sensitive parameter was SCS unit hydrograph, lag time, SCS curve number, initial abstraction, Muskingum (k and x) and sub reaches (Table 4.4). The sensitivity result shows the SCS runoff curve number (CN2.mgt) as a major critical parameter for the SWAT model and surface runoff lag time is the most sensitive for the HEC_HMS model. Curve number and surface runoff lag time are directly related to land use/cover and soil characteristics of the basin. The rest flow parameters tested for their sensitivity values for monthly and daily time steps are attached (Appendix C).

Table 4.4: Parameters sensitivity rank based on P-value, t-stat, and objective function

Parameter name	description	Min _value	Max_ value	Fitted value	Rank For monthly
SWAT model					
CN2.mgt	Initial SCS CN II value	35	98	58.9	1
GW_DELAY.gw	Groundwater delay (days)	0	500	401	2
SOL_K.sol	Saturated hydraulic conductivity	0	2000	33.3	3
GW_REVAP.gw	Groundwater "revap" coefficient	0	0.2	0.19	4
SURLAG.bsn	Surface runoff lag time (hr.)	0	3.56	1.89	5
CH_K2.rte	Channel hydraulic conductivity	0.01	500	286.	6
SOL_AWC.sol	Available water capacity	0	1	0.61	7
HRU_SLP.hru	Average slope steepness (%)	0	1	0.58	8
ALPHA_BF.gw	Base flow alpha factor (days)	0	1	0.15	9
HEC_HMS model					
SCS.Lag(MI)	SCS unit hydrograph_ lag time	0.1	30000	*	1
Curve number (AMC_II)	SCS curve number	35	99	*	2
Initial abstraction(MI)	SCS Curve number _initial abstraction	0.001	500	*	3
Muskingum_k(hr)	Flood wave traveling time	0.001	150	*	4
Muskingum_x	Weighted coefficient of discharge	0.001	0.5	*	5
Muskingum reaches	Muskingum sub reaches	1	100	*	6

*Indicate depends on the sub-basin

4.2.2 Model Calibration and validation by HEC_HMS

HEC-HMS model calibration was done by adjusting model parameters to match the simulated with observed flow data as much as possible with an accepted range of deviation and the calibration result for gauging station Abura is determined as follows.

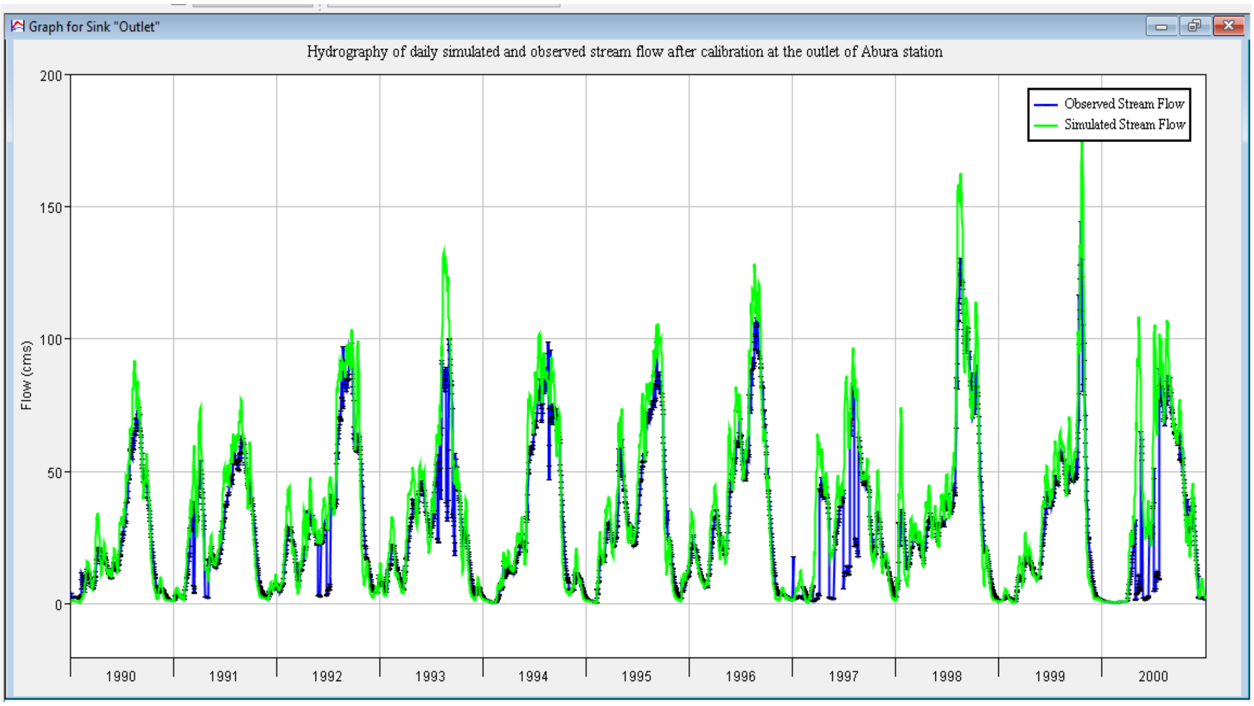


Figure 4.2: Daily Simulated and observed flow hydrographs after calibration

Figure 4.2, indicates the simulated and observed flow hydrographs of the Katar river basin at outlet after the calibration period. The goodness-of-fit analysis of the calibration and validation stages is shown in the table below.

Table 4.5: Daily streamflow calibration model performance statistics.

Performance rating	Model	Calibration (1990_2000)
R^2	HEC-HMS	0.88
NSE	HEC-HMS	0.75

As shown in figure 4.2 the low flows and peak flow of simulated and observed hydrographs were well matched and followed the same pattern during the calibration period. In the same manner, the goodness-of-fit test statistics for calibration sown in Table 4.5 is in an acceptable range.

In the same manner, the model is validated for streamflow at gauging station Abura. The purpose of model validation is to check whether the model can predict streamflow for another range of periods than those the model was calibrated. Model validation involves rerunning the model using input data independent of data used in calibration by the differing period of simulation with keeping the calibrated parameters unchanged. To validate the model performance, some period of data is needed. In this case, the selected validation period was after the respective calibration period. Hence, daily streamflow data from the year 2001 to 2007 and the developed land use land cover map of the year 2001 were used for validation, and the result is shown in Figure 4.3 below.

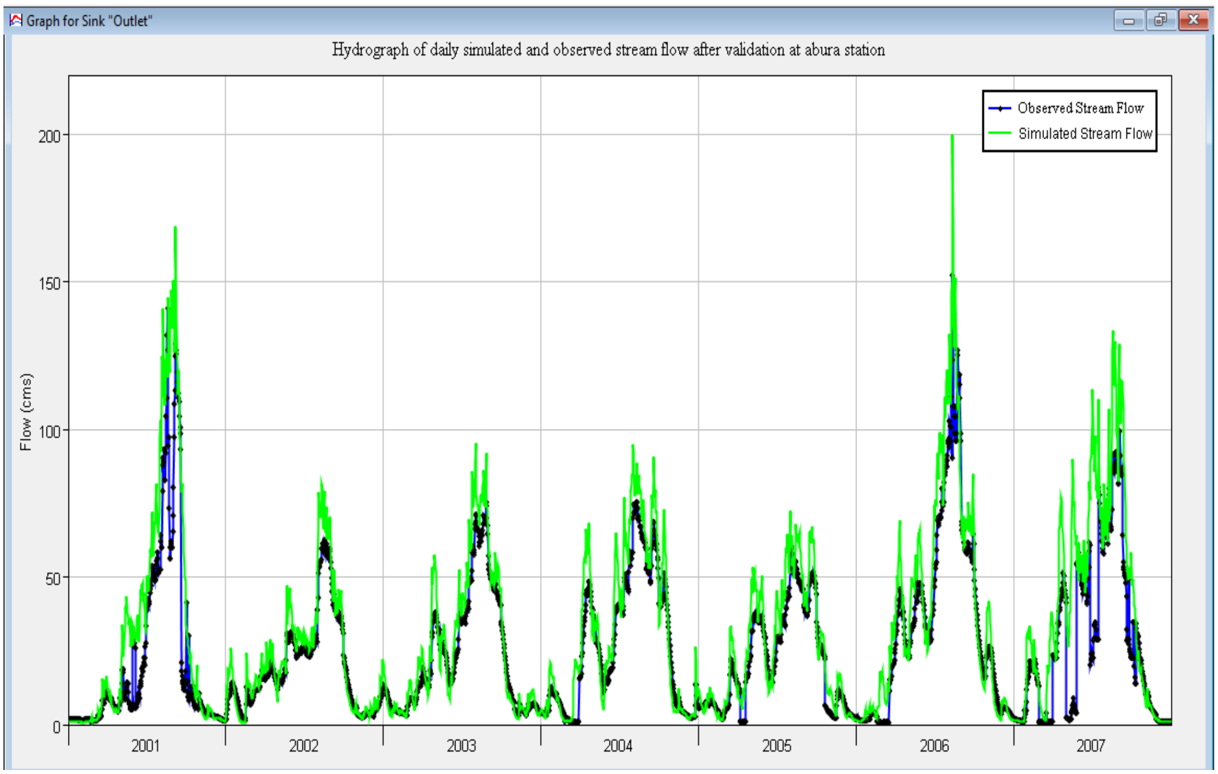


Figure 4.3: Daily simulated and observed streamflow hydrographs after validation

The graphical representation of measured and simulated flows matched well during validation periods (Figure 4.3). This shows that the model produced a similar trend between observed and simulated streamflow during the validation periods. However, total runoff volume and peak flow were slightly overestimated (Table 4.6). This difference might be due to the routing coefficients or simulating at an hourly time step.

Table 4.6: Global summary of objective function result during validation

Compute Time:02Jun2020, 07:31:02

Objective Function at Basin Element "Outlet"

Start of Function:01Jan2001, 03:00 Type: RMS Error
End of Function: 31Dec2007, 03:00 Value:14.32

Volume Units: (•) MM ( ) 1000 M3

Measure	Simulated	Observed	Difference	Percent Difference
Volume (MM)	2098.61	1645.37	453.24	27.55
Peak Flow (M3/S)	199.7	152.0	47.7	31.3
Time of Peak	12Aug2006, 03:00	12Aug2006, 03:00		
Time of Center of Mass	21Oct2004, 04:13	19Oct2004, 09:30		

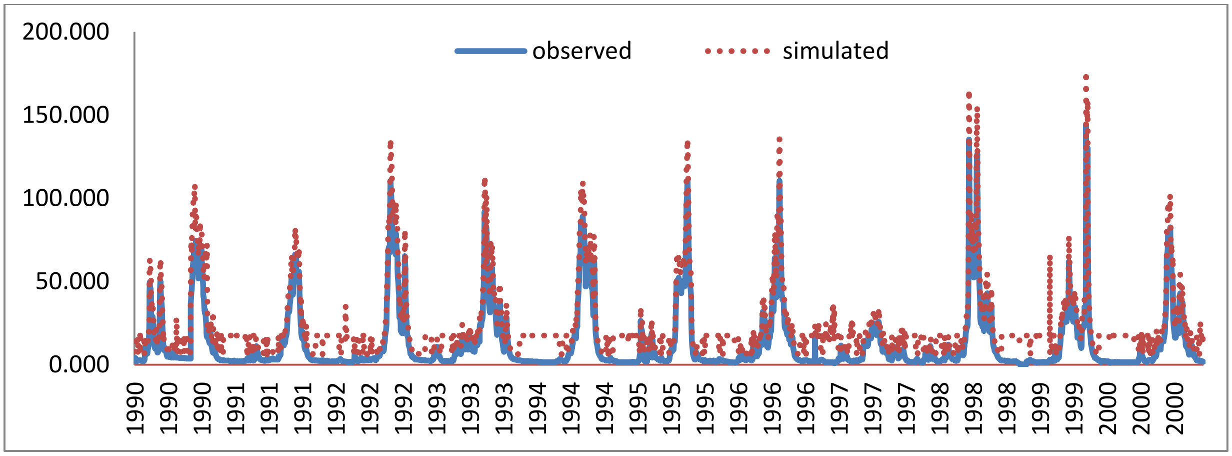
In Table 4.7 the statistical error tests were determined and based on the recommendation given by Moriasi et al. (2007), like to that of the calibration period, it is within an acceptable range. Thus a result verifies that the rainfall-runoff process of the Katar river basin can be modeled efficiently by HEC-HMS hydrological model.

Table 4.7: Daily streamflow validation model performance statistics.

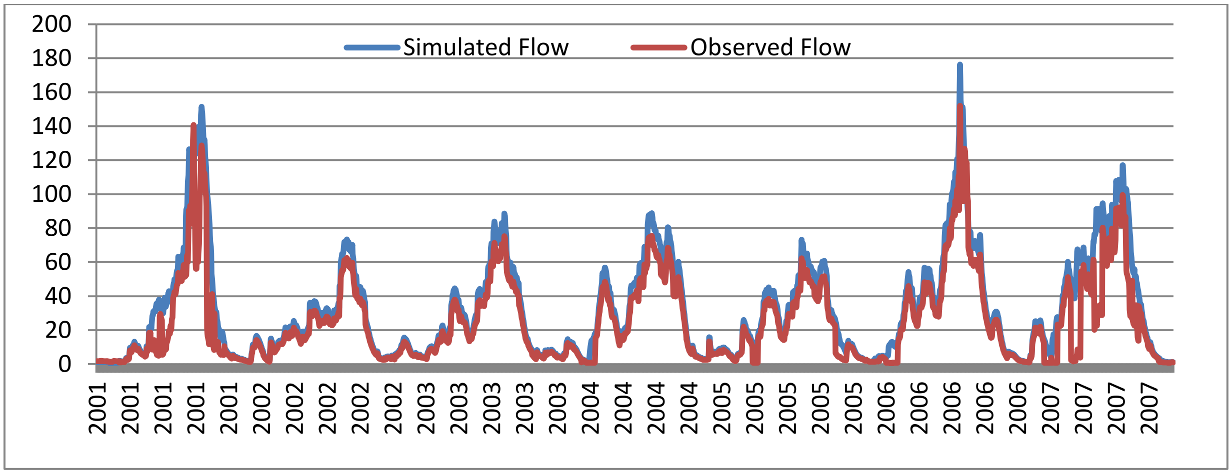
Performance rating	Model	Validation (2001_2007)
R^2	HEC-HMS	0.87
NSE	HEC-HMS	0.73

4.2.3. Calibration and validation by SWAT model

After sensitivity analysis, the sensitive parameters were used for model calibration (1990-2000) to optimize the values of those sensitive parameters and validation is described as the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, also sufficiently accurate results can vary based on project goals (Arnold, 2012). It is used to test the calibrated parameters with an independent set of data without further changes to the parameters. In this study, the validation was performed to compare the model outputs with an independent data set without making a further change to parameters obtained during the calibration process. Based on the determined land use land cover change result of the area, the 1990 and 2001 LULC were selected respectively for model calibration and validation of the Katar river basin at Abura Gauging station (Figure 4.4).



(a)



(b)

Figure 4.4: Daily streamflow at Abura gauging station by SWAT models after (a) calibration (b) validation.

The goodness-of-fit analysis of the calibration and validation stages is shown in the table below.

Table 4.8: Daily streamflow calibration and validation model performance statistics.

Parameter	Katar river basin (at station Abura)	
	Calibration	Validation
NSE	0.69	0.67
R^2	0.80	0.78

As shown in Table 4.8, all the numerical model performance indicators designated for the model performance evaluation are concordant with NSE and R^2 values were put in the table above. Hence, all numerical model performance measures are in the acceptable range that the model accurately simulated the measured streamflow. Therefore, similar to that of the HEC-HMS model, a result verifies that the rainfall-runoff process of the Katar river basin can be modeled efficiently by SWAT hydrological model through their level of accuracy/statistical strength/ is different.

4.3. Assessing the Runoff Potential and Developing Peak Runoff of the Basin

4.3.1 HEC-HMS Model Simulation Result

The simulated daily peak discharge at the outlet of the study area is found to be 289.6m^3/s for each sub-basin and rivers, the daily simulated discharge is given in Table 4.9. Based on the result, the higher discharges are generated from W600 and W710 sub-basins, whereas, the minimum discharge is contributed by the W450 sub-basin. The water depth increases as the river reaches approaches to the outlet point.

Table 4.9: Simulated results at each sub-basin and river reach

Sub-basin	Daily peak discharge (m^3/s)	River channel	Routed flood (m^3/s)	River channel	Routed flood (m^3/s)
W450	27.1	R20	275.2	R190	88.5
W460	54.6	R30	275.2	R210	88.1
W470	60.4	R60	54.7	R230	89.5
W490	30.8	R70	275.2	R250	89.6
W600	102.3	R80	85.6		
W710	89.8	R100	151.5		
outlet	289.6	R130	151.4		

Also, an attempt was made to model the hydrology of the Katar river basin using the HEC-HMS and SWAT models. The rainfall over the years, LULC and soils in the Katar river basin had shown drastic changes in the water resources of the Katar river basin.

The common graph for both measured and simulated periods is shown in Figure 4.5 below. The graphical representation of measured and simulated flows matched somewhat well for a common outlet station Abura.

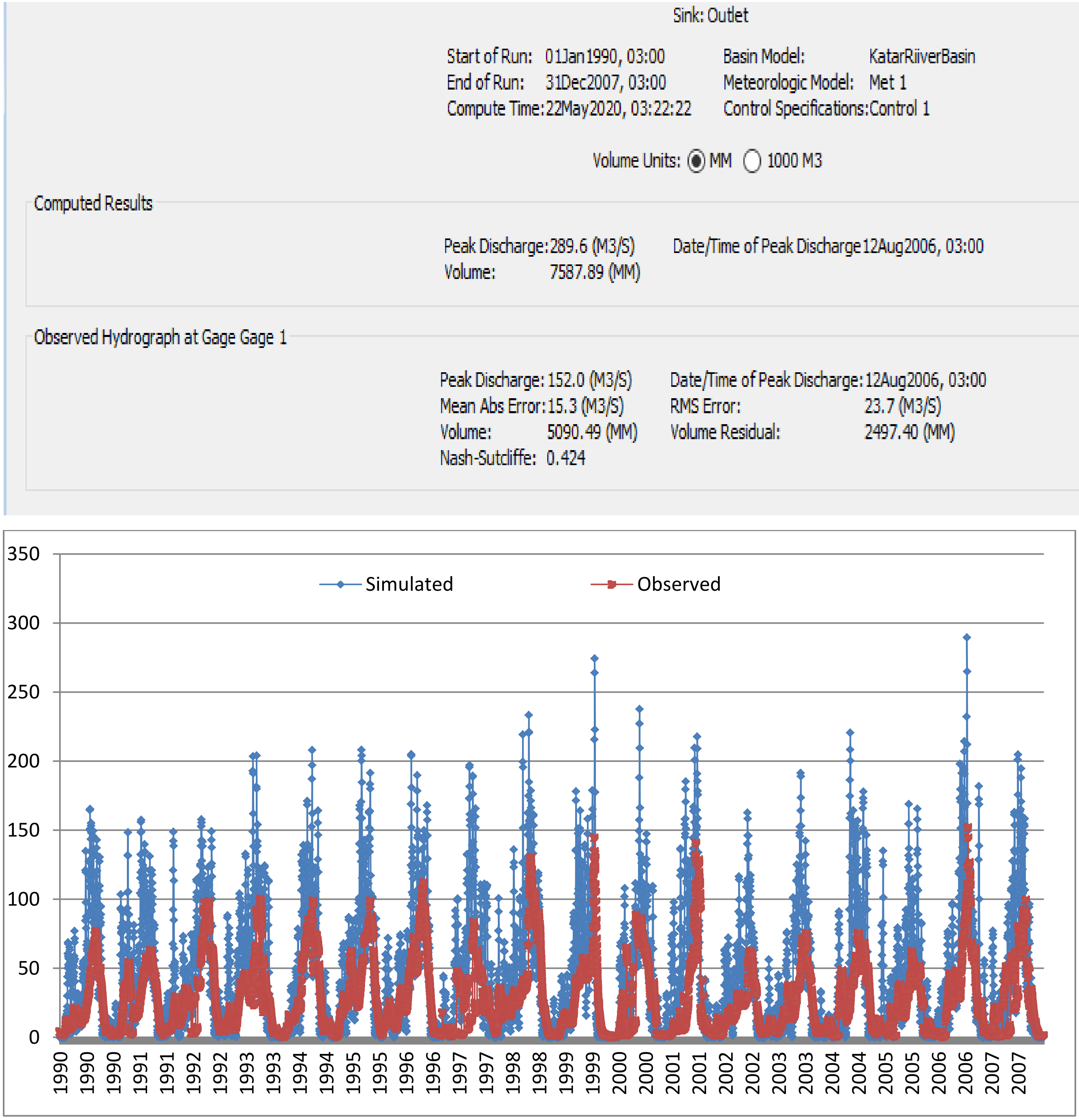


Figure 4.5: Simulated and observed streamflow before calibration and validation by the HEC-HMS model

Figure 4.5 shows that the simulated and observed discharges followed somewhat similar trends, with an NSE 0.42. The simulated and observed peak discharges were observed on the same date as 12/8/2006. Although the agreement between the observed and simulated discharges is over-estimation is inherent in the simulation. This is because the HEC-HMS model simulates the naturalized flows, and the derived discharge used for validation is based on human interventions. The model performance showed good agreement at the Abura outlet despite the presence of major natural and artificial reservoirs such as Arata hora, Genet, Cheleka Hora and Harata since the calibration was done at this outlet. The model had overestimates (S > O) because of the reservoir storage, due to which the observed flows were less than the simulated values. It may be concluded that the agreement between the observed and simulated values largely depends on the LULC conditions, soils, and hydrological components in the basin, as well as their assumptions. The error may be due to the flood plain inundation in the basin.

4.3.2 SWAT Model Simulation Result

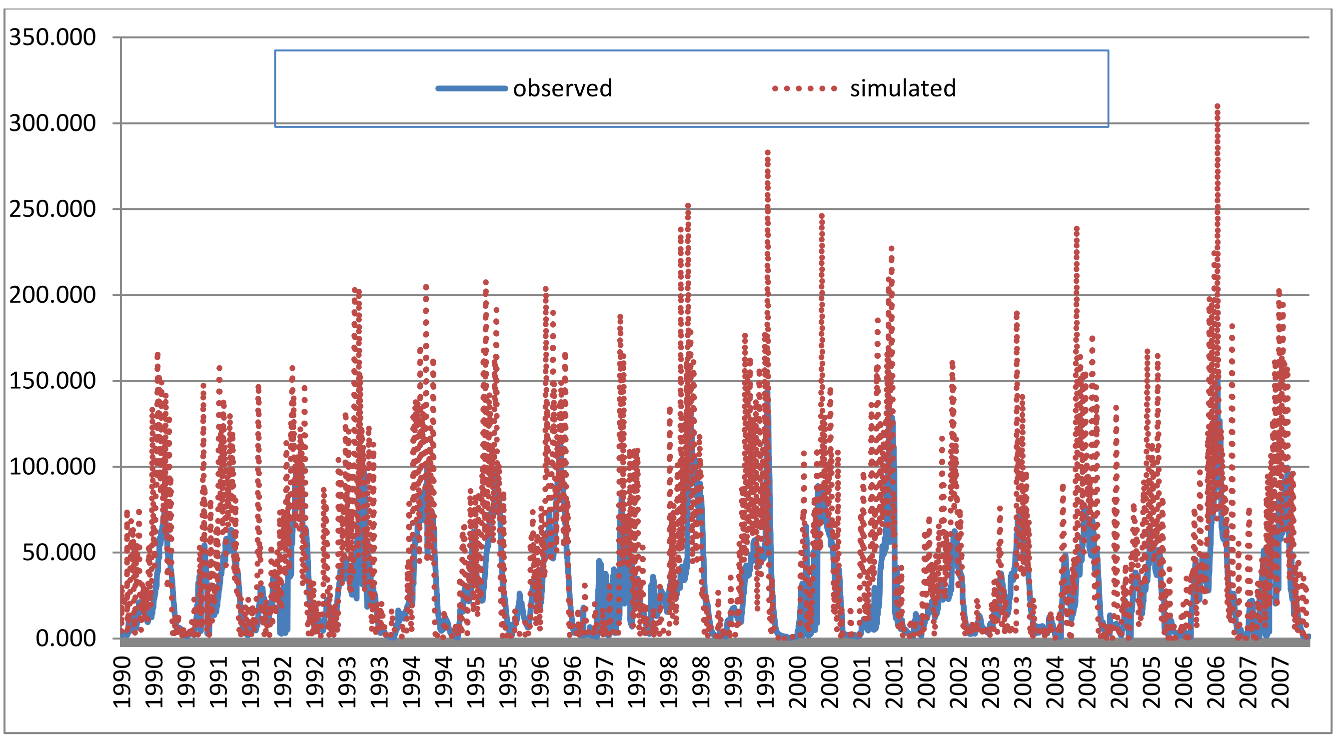


Figure 4.6: Simulated and observed streamflow before calibration and validation by the SWAT model

Figure 4.6 indicated that as discussed under 4.3.1 there is overestimation inherent also by the SWAT model. These may be due to data quality between derived data from MoWRIE and data from NMA of Ethiopia both have not self-recording data. That means the accuracy of error due to material and recording person.

4. 4 Comparison of SWAT and HEC-HMS models in simulating the rainfall-runoff process.

To compare the model performance in producing stream flow, experiments based on the well-calibrated HEC-HMS and SWAT models were conducted. These results are shown for the daily simulation period of the year 1990-2007 (Figure 4.2 to 4.4). Based on the performance evaluation of HEC_HMS and SWAT models, I arrived with the following conclusions.

One: Depending on observed and simulated discharge predicted by SWAT and HEC_HMS, the value of discharge by HEEC_HMS was more related to observed.

Second by statistical indices (NSE and R^2) performance evaluation criteria the results indicated that both models were generally able to simulate effectively the streamflow. However, HEC-HMS simulated hydrology of the basin more accurately than the SWAT model for both calibration and validation periods. As shown in Table 4.10, HEC-HMS has the best NSE (0.75 and 0.73) and R^2 (0.88 and 0.87) values when compared to those by the SWAT model (NSE values were 0.69 and 0.0.67 and R^2 values were 0.8 and 0.78) during calibration and validation respectively. Based on their statistical indicators, namely R^2 and NSE, Sith and Nadaoka (2017) have compared SWAT and GSSHA models, Golmohammadi et al. (2014) has compared MIKE-SHE, APEX and SWAT using R^2, RMSE; NSE and PBIAS and Shi et al. (2011) were also compared the performance of the SWAT and XAJ models by using the values of R^2.

Table 4.10: Comparison of model performance evaluation results

Performance rating	Model	Calibration (1990_2000)	Validation (2001_2007)
R^2	HMS	0.88	0.87
	SWAT	0.80	0.78
NSE	HMS	0.75	0.73
	SWAT	0.69	0.67

Thirdly when SWAT compared to HEC_HMS, SWAT needs extra software SWAT_CUP for Sensitivity analysis, calibration, and validation purposes but HEC_HMS has its optimization algorism for calibration, validation, and sensitivity analysis.

In general, the results show that the HEC-HMS model is the most suitable model for hydrological modeling with high precision than SWAT for the Katar river basin Ethiopia. In line with this, Golmohammadi et al. (2014) was tested three Hydrological Distributed Watershed Models MIKE-SHE, APEXand SWAT at Grand River Basin, Canada. As the result, they reported as MIKE SHE predicted the streamflow slightly better than either SWAT and APEX. Similarly, Shi et al. (2011) were also compared the performance of the SWAT and XAJ models and showed that both models performed well in the Xixian River Basin, with NSE > 0.69 and R^2 > 0.72 for both calibration and validation periods. SWAT and HEC-HMS model were compared for their applicability on the Central Highlands of Vietnam by Khoi (2016) and reported that both models could simulate fairly well the streamflow for the study area.

4.4.1 Model comparison in the time domain

The performance results based on the time-domain comparison of the two models are given in Table 4.10; these results show that the HEC-HMS model yields better results than the SWAT models. For the SWAT model, this poor result may be related to the insensitivity of the flow parameters. In addition, the poor performances of the two models may be attributed to the capability of the models to reproduce the streamflow in mountainous areas that lack robust data sets due to spatially insufficient observations (only one station exists). The table 4.10 present the variation of the two hydrological models' performances for each fold in terms of the values of the objective function (NSE) for all watersheds. As shown by these table, the HEC_HMS model produces better NSE values for the Katar river basin.

4.4.2 Model comparison in the quantile domain

From the quantile domain-based model comparison results, the HEC_HMS model performed better than (SWAT) for the simulation of mid-range, dry, and low flows in the Katar river basin. In general, two of the models performed better for the simulation of high and moist flows,but the performances were relatively poor for the simulation of mid-range, dry, and low flows. This is due to using the NSE values to calibrate the model. The NSE method applies more weight to the high flows than the low flows, therefore, the calibration process will focus more on the high flows. If a different objective function were used (e.g. square root or log transformed NSE), this would change the emphasis towards lower flows. However, the results of this investigation of a specific study basin with day-to-day flow comparisons may not be applicable for the selection of racy rainfall–runoff models for simulation studies. Figure 4.7 presents the flow duration curve for each category of flow range based on the quantile-domain model comparison.

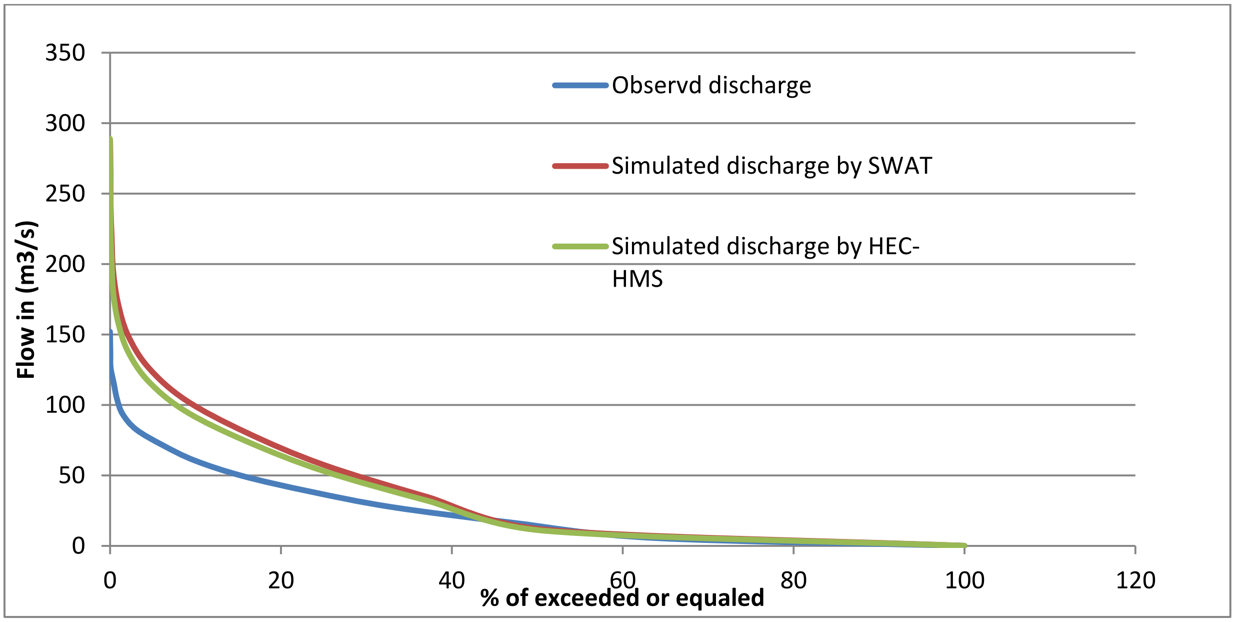


Figure 4.7:Flow duration curves of the observed and simulated flow in a basin.

Both models reproduce the peak discharge of the Katar river basin.

4.5 Impact of LULC Change on Runoff _rainfall simulation

Rainfall is the most important parameter that influences all of the water balance components such as runoff. The total rainfall in the Katar river basin for the years 1990 and 2001 was 888.2 mm and 926.6 mm respectively. The runoff value depends on the rainfall. The LULC change analysis was carried out for all the watersheds for the years 1990 and 2001 the Kata river basin was found to have undergone the major LULC change in terms of decrease in forest cover; decrease in grassland; increase in built-up land, increase in agricultural land; decrease afro_afline (Table 4.1). Based on the determined land use land cover change result of the area, the simulated hydrology (complex relationship of rainfall-runoff) for the Katar river basin is determined for the years 1990 and 2001 (Figure 4.7).

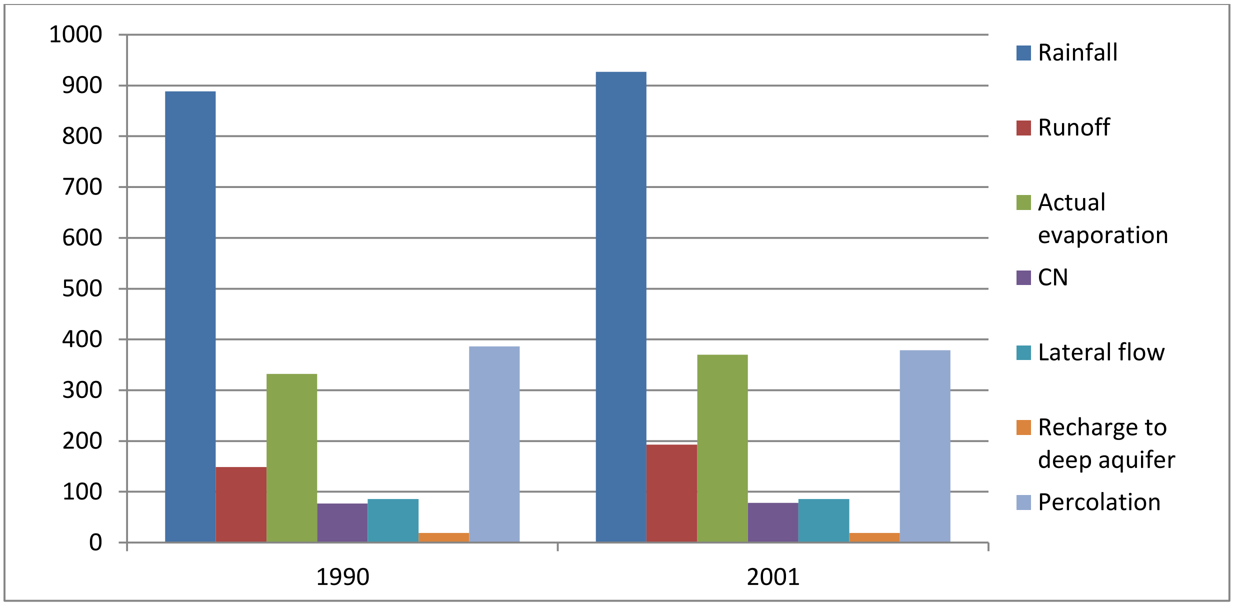


Figure 4.8: Simulation of the rainfall-runoff relationship in the year of 1990 and 2001

Figure 4.7 shows the distribution of runoff for 1990 and 2001 for the kata river basin. The trend of runoff was found to be highly dependable on the amount of rainfall received, types of land use, and soil types of the entire basin. In summary, a decrease in the natural cover of the forest over some time caused a significant rise in the surface runoff. The surface runoff increases were due to the decrease in infiltration, and hence groundwater recharge processes. The increase in built-up, which was due to urban expansion and intensive cultivation (increase in agricultural land), will loosen the soil, leading to soil erosion, as well as a decrease in the surface roughness, and thereby ultimately increase the surface runoff.

5. SUMMARY AND CONCLUSION

5.1 Summary

Rainfall-runoff modeling is very important for simulating the response of basin to rainfall and produce flow hydrograph, which is extensively used for flood forecast and water resources planning. In this study, HEC-HMS and SWAT model was used to model the streamflow of the Katar river basin. The Soil Conservation Service Curve Number, Soil Conservation Service Unit Hydrograph, constant base flow, and channel routing method were used to compute the rainfall loss component, runoff component, base flow modeling, and Muskingum respectively.

The models (HEC-HMS and SWAT) were calibrated and validated using 11 years (1990-2000) and 7 years (2001-2007) daily observed streamflow data respectively. The Nash-Sutcliffe Efficiency (NSE), and Coefficient of Determination (R^2) were used to assess the performance of both models and it ranges between 0.67_0.75 and 0.78_ 0.88 respectively, during calibration and validation, indicating good to very good performance for simulation of streamflow data from rainfall data of the study area. Based on the above statistical error test criteria's HEC-HMS model performance rating is more acceptable than the SWAT model.

For Katar river basins, the expansion of agricultural land and the reduction of forest land was maximum than other land-use types. With this regard, there was also a remarkable loss of Grassland and afro_afline in the years 1990 and 2001. For the land-use change periods, the increment of annual surface runoff from 148.68 mm to 193.5 mm has resulted from the Katar river basin. This situation has revealed that the land-use changes are the main contributors to the increment of surface runoff on the Katar river basin.

5.2 Conclusion

This study evaluates the performances of two hydrologic models, namely, HEC-HMS and SWAT, to find a suitable model for hydrological modeling in the Katar river basin, Ethiopia. The two models require almost the same data input and model parameters. Both models were calibrated using the observed daily streamflow at Abura gauging station for the period of 1990 to 2000 and validated from 2001 to 2007. The results of calibration and validation indicated that, for River Basin Katar, both models could simulate fairly well the streamflow. SWAT gave the model performance with the $R^2 > 0.78$ and NSE > 0.67; and the HEC-HMS model provided the model performance with the $R^2 > 0.87$ and NSE > 0.73 for the calibration and validation periods. In general, the simulated streamflow given by the HEC-HMS model is more satisfactory than that provided by the SWAT model.

6. RECOMMENDATION

Based on the findings of this study, the following recommendations are forwarded.

- During evaluating the performance of two models for simulating rainfall-runoff factors like LULC, topography, Antecedent Moisture Condition and soil types can greatly affect Curve Number (CN) value which mainly determines the amount of Runoff generated. So, it is recommended to take great attention to this factor while determining CN.

- The river gauging station at Abura was installed at the outlet of the Katar river basin but a huge amount of runoff stored in a natural reservoir and marshland before inter to the outlet. For this reason; there was an overestimated flow during the simulation. Therefore, it best to add a stream gauge station above the natural and artificial reservoir.

- During the comparison of hydrological models, I considered only two models HEC_HMS and SWAT model to simulate streamflow the coming researchers should use most models to compare the rainfall-runoff simulation was best.

- It is recommended that for better simulation and management purposes, future research should be done considering the different sources of uncertainties like water abstraction and water detention in the basin.

- In addition to the above recommendation, the comer researches should be done on flood detection and mapping of the Katar river basin.

- Study on model evaluation/assessment/ is so limited in the country Ethiopia. So researchers should evaluate the models rather than directly applying

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Appendices

Appendix A; Table 1: Mean monthly streamflow data at the outlet of Abura gauging station

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1990	2.68	10.95	20.02	21.31	5.30	4.31	3.85	59.52	46.83	12.59	3.65	2.39
1991	2.16	2.24	3.76	5.39	2.77	3.44	14.05	45.78	36.07	6.14	2.56	2.31
1992	2.02	2.46	1.76	3.04	3.07	3.23	8.18	65.98	53.99	25.08	4.56	2.83
1993	2.71	6.55	2.19	5.10	11.51	11.56	16.41	52.83	35.71	20.12	7.17	2.70
1994	2.14	1.92	1.64	1.56	2.36	4.27	22.93	68.87	49.09	7.02	2.81	2.04
1995	1.56	1.58	7.94	7.23	5.44	2.54	12.60	48.41	59.32	4.59	2.35	2.11
1996	2.48	1.69	2.86	3.93	6.74	17.94	21.50	64.12	24.38	8.54	2.44	2.16
1997	2.91	1.67	1.56	6.00	2.60	2.73	13.57	20.98	11.05	5.58	6.96	2.94
1998	2.19	3.45	5.01	2.38	5.99	3.66	13.40	69.19	49.60	28.12	6.76	2.36
1999	1.99	0.43	1.71	1.65	1.69	3.19	17.00	33.86	21.21	44.47	7.45	2.34
2000	1.58	1.58	1.56	1.49	4.67	2.75	9.73	49.31	28.69	25.27	8.70	2.51
2001	1.76	1.55	2.17	2.57	7.57	13.82	34.32	80.05	37.86	10.45	2.45	1.79
2002	1.84	1.90	2.77	2.08	2.80	3.43	7.29	26.57	13.45	3.33	1.48	1.92
2003	2.44	1.39	1.55	3.93	3.80	2.44	16.62	51.94	28.99	7.49	1.84	1.85
2004	1.47	1.34	1.35	8.71	3.52	3.32	20.03	38.03	26.83	13.57	2.22	1.41
2005	1.51	1.39	2.29	2.74	13.87	2.86	25.92	59.26	38.91	10.39	2.33	1.54
2006	1.65	1.40	2.15	11.56	7.50	4.70	38.20	79.89	41.37	8.34	3.01	1.79
2007	1.16	1.89	1.01	3.62	3.85	11.76	28.83	67.17	58.43	12.16	2.26	1.09

Appendix A; Table 2: Consistency analysis of rainfall data of Katar river basin

year	Arata	Assela	Kulumsa	Bokoji	Ketera genet	Ogolcho
1987	735.6	915	775.5	967.1	863.1	735.6
1988	717	908	874.4	1161.4	909.4	717
1989	670.9	1162.6	916.3	1078	797.5	970.1
1990	747	967.7	984	1056.3	910.1	939.4
1991	743.9	784	796.3	1039.7	795.2	704.7
1992	839.2	986.2	809.5	1153.8	743.9	739.8
1993	841.7	1056.8	930.6	1186.2	705.6	928.7
1994	638	1107.2	727	1051.4	668.8	589.2
1995	1016.9	1080.3	866.9	1030.9	703.8	734.3
1996	922.4	1241.4	877	1063.5	728.9	816
1997	882.6	1154.9	911.6	692.7	660.2	747.2
1998	928.3	1142.1	874.7	756.5	917.6	824.5
1999	668.7	857.2	746.6	631	747.2	626.5
2000	805.2	1061.8	797.5	765.8	933.1	719.7
2001	837	1438.8	938.9	953.1	788.4	703.7
2002	575.2	779.5	708.4	678	545.9	583.3
2003	771.2	978.7	758.6	658.6	610.5	775.5
2004	602.2	1077.2	728	743.6	748.8	571
2005	785.4	1082.8	743.3	727.1	359.2	537.4
2006	726.1	1034.1	805.7	957.9	719.5	499.2
2007	791.8	1194.1	835.9	791.2	713.6	820.1
2008	848.9	960.1	810.9	664.1	837	1277
2009	651.7	1091.4	789.4	975.1	1050.1	657.8
2010	961.4	1139.1	917.8	1469.8	1325.4	907.7
2011	739.2	1032.7	849.7	1210.75	809.2	747.2
2012	806.4	855.2	961.2	1002.9	950.1	875.2
2013	788.9	1107.7	749.8	1011.6	948.1	706.9
2014	806.5	1196.6	868.3	1260.9	811.3	522.9
2015	439.6	851.7	613.6	842.6	602.5	365.7
2016	784.5	1195.4	892	925	1061.3	769.5
2017	727.9	922.2	753.5	1060.2	958.9	727.9
2018	739.6	1018.8	854.1	565.6778	948.1	739.6

Appendix B; Table1: Definition of Hydrologic soil Groups (Source: Subramanya, 2008)

HSG	Its Characteristics
A	Soils having high infiltration rates, even when thoroughly wetted and consisting chiefly of deep, well to excessively-drained sands or gravels. These soils have a high rate of water transmission.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to a fine texture. These soils have a slow rate of water transmission.
D	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Appendix B; Table 2: Summary of Morphological Characteristics for the Major Soils in Katar river basin (source: MOWR,2010)

Soil group	Depth	Colour	Texture	Structure	Consistency	Drainage	HSG
Andosol (AN)	Deep to very deep	very dark grey to brown,	Loam, sandy loam	Weak to moderate, fine and medium, crumb and subangular blocky structure	Very friable to friable; slightly sticky and none plastic	Well to excessively drained	A
Cambisols (CM)	Shallow to very deep	Very dark Gray to dark reddish-brown	Sandy loam, sandy clay, loam, silty loam	Moderate to strong fine to coarse, subangular,	Very friable to the firm, none sticky to very sticky, none	well to excessively drained	A

				granular, and crumb structure	plastic to very plastic		
Fluvisols (FL)	Moderately deep to very deep	Black to dark yellowish-brown	Clay, clay loam, loam, sandy clay loam, sandy loam	Weak to moderate, fine and medium, granular and subangular blocky structure	Very Friable to the firm, none sticky to sticky, none plastic to plastic	Imperfectly to well-drained,	B
Luvisols (LV)	Moderately deep to very deep	Very dark Gray to dark red	Clay, clay loam, sandy clay loam silty loam	Moderate to strong, granular, crumb and subangular blocky structure	Very friable to the firm, slightly sticky to sticky; slightly sticky to very sticky	Moderately well to well-drained	C
Vertisol (VR)	Deep to very deep	Black to dark yellowish-brown	Clay, clay loam, loam	Moderate to strong, medium and coarse angular and subangular blocky structure	Firm, sticky, and plastic	Imperfectly to poorly drained	C

Appendix C; Table 1. Selected input parameter of the SWAT model

No	Input Parameter	Description of Parameter	Min and Max Range
1	CN2.mgt	SCS runoff curve number	35 - 98
2	SURLAG.bsn	Surface runoff lag time (days)	0.05 - 24
3	OV_N.hru	Manning's "n" value for overland flow	0.01 - 30
4	SL_SUBBSN.hru	Average slope length (m)	10-150
5	HRU_SLP.hru	Average slope steepness (fraction)	0-1
6	EPCO.bsn	Soil evaporation compensation factor	0 - 1
7	ESCO.bsn	Plant uptake compensation factor	0 - 1
8	CH_K2.rte	Effective hydraulic conductivity in main channel alluvium (mm/hr)	0.025 to 250
9	ALPHA_BF.gw	Base flow alpha factor (days)	0 - 1
10	GW_REVAP.gw	Groundwater "revap" coefficient	0.02 -0.2
11	GW_DELAY.gw	Groundwater delay (days)	0 - 500
12	GW_QMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0 - 5000
13	REVAP_MN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	0 - 500
14	RCHARG_DP.gw	Deep aquifer percolation fraction	0 - 1
15	SOL_AWC.sol	Available water capacity of the soil layer(mm H2O /mm soil)	0 - 1
16	SOL_K.sol	Saturated hydraulic conductivity(mm/hour)	0 to 2000

Appendix C; Table 2: Sensitivity Analysis of Parameters for daily by SWAT model

Parameter Name	t-Stat	P-Value
19:R__SOL_ALB(..).sol	-0.05	0.96
8:R__USLE_K(..).sol	0.08	0.94
9:R__OV_N.hru	0.15	0.88
6:R__REVAPMN.gw	0.18	0.85
12:R__ESCO.hru	-0.18	0.85
13:R__EPCO.hru	-0.21	0.84
2:V__ALPHA_BF.gw	-0.27	0.79
10:R__SLSUBBSN.hru	-0.70	0.49
20:R__SOL_BD(..).sol	-0.72	0.28
18:R__SOL_CBN(..).sol	0.85	0.14
14:R__SURLAG.bsn	-0.80	0.09
4:V__GWQMN.gw	-0.85	0.06
16:R__CANMX.hru	-0.89	0.05
7:R__SOL_AWC(..).sol	-0.92	0.04
5:R__GW_REVAP.gw	-1.01	0.03
11:R__HRU_SLP.hru	-1.48	0.03
15:R__CH_K2.rte	-1.49	0.02
3:V__GW_DELAY.gw	1.87	0.00
1:R__CN2.mgt	-17.78	0.00

Appendix C; Table 3: HEC-HMS optimized parameters of Katar river basin during model evaluation

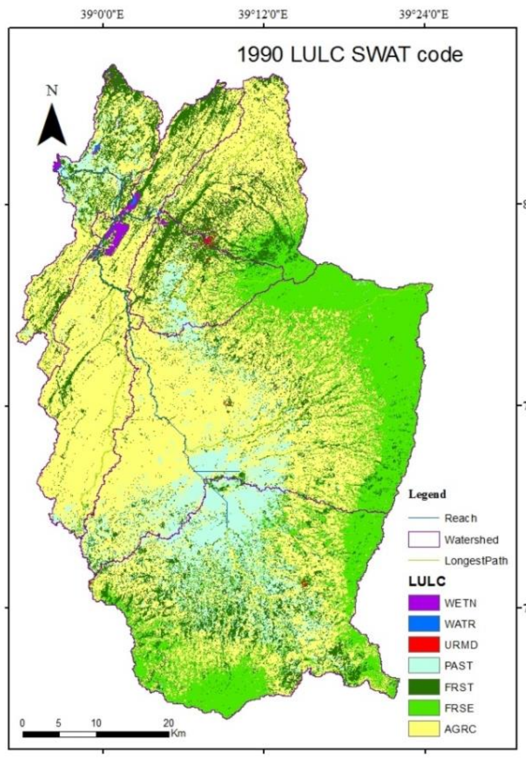
Element	Parameter	Units	Initial Value	Optimized Value	Objective Function Sensitivity
R70	Muskingum - K	HR	1.38	0.40889	0.00
R30	Muskingum - K	HR	1.07	0.69907	0.00
W460	SCS Curve Number - Curve Number		77.326	46.396	0.01
W470	SCS Curve Number - Curve Number		80.822	35.921	0.03
W490	SCS Curve Number - Curve Number		77.242	46.345	0.01
W600	SCS Curve Number - Curve Number		77.862	46.717	0.04
W710	SCS Curve Number - Curve Number		76.912	46.147	0.03
W710	SCS Curve Number - Initial Abstraction	MM	15.25	15.403	-0.00
R60	Muskingum - K	HR	0.13	0.0849333	0.00
W450	SCS Unit Hydrograph - Lag Time	MIN	5361.9	8082.3	-0.01
W470	SCS Unit Hydrograph - Lag Time	MIN	4042.5	9095.6	-0.02
W460	SCS Unit Hydrograph - Lag Time	MIN	3285.3	1460.1	0.00
W490	SCS Unit Hydrograph - Lag Time	MIN	2915.7	1295.9	0.00
W600	SCS Unit Hydrograph - Lag Time	MIN	4547.2	6854.8	-0.05
W710	SCS Unit Hydrograph - Lag Time	MIN	5124.7	5175.5	-0.03
R30	Muskingum - x		0.18	0.17287	0.00
R20	Muskingum - x		0.18	0.0800000	0.00
R70	Muskingum - x		0.18	0.11760	0.00
R80	Muskingum - x		0.18	0.11760	0.00
R60	Muskingum - x		0.18	0.26460	0.00
R100	Muskingum - x		0.18	0.17287	0.00
R110	Muskingum - x		0.18	0.17287	0.00

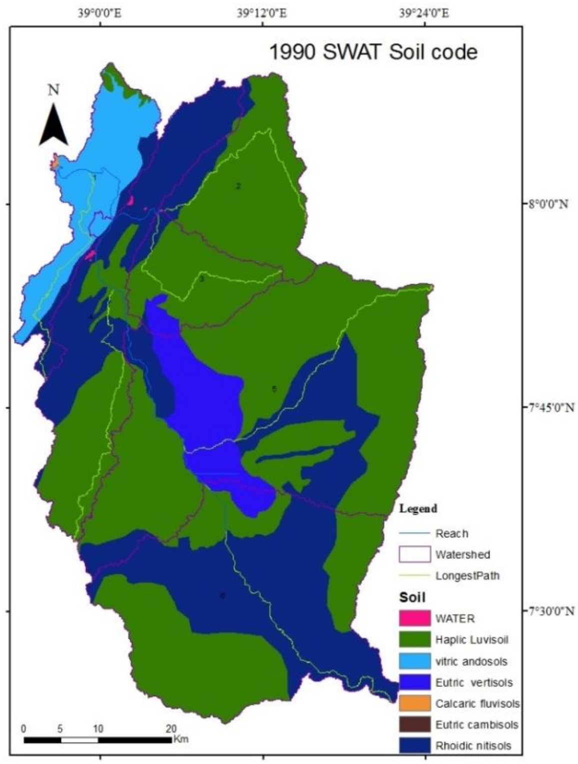
Appendix D; Table 1: revised classification of LULC (source: Subramanya, 2008)

Original classification	re-classification
Open water	Water
Woody wetlands	
Emergent herbaceous wetlands	
Developed, open space	Medium Residential
Developed, low intensity	
Developed, medium intensity	
Developed, high intensity	
Deciduous forest	Forest
Evergreen forest	
Mixed forest	
Barren land	Agricultural
Shrub/scrub	
Grassland/herbaceous	
Pasture/hay	
Cultivated crops	

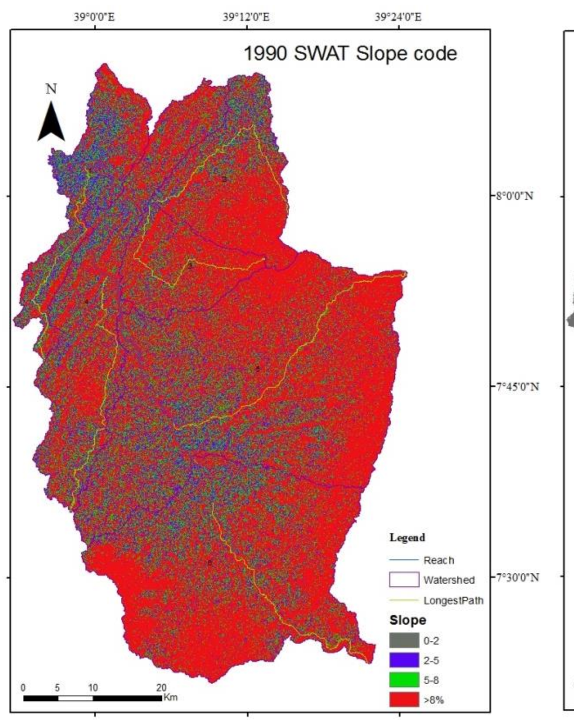
Appendix E; Figure 1:Katar river gauging station at Abura

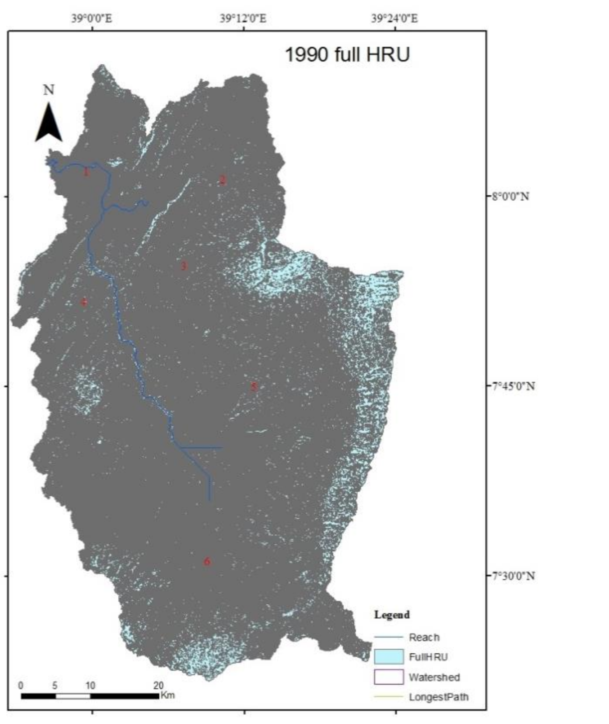
Appendix F: figure 1:artifical and natural landscape of Katar river basin





(a) (b)





(c) (d)

Appendix G: Figure 1: (a) LULC swat code; (b) major soil ;(c) slope classification and d) full hydrologic response unit 1990 of the study area