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ADDIS ABABA INSTITUTE OF TECHNOLOGY



School of Civil and Environmental Engineering
Independent Project work Submitted for the approval in Partial
fulfillment of Degree of Master of Engineering in Hydraulic Engineering
**Flow Estimation in
Zarima May Day Dam watershed using SWAT Model**





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APPROVAL PAGE

Flow Estimation in Zarima May Day Dam watershed using SWAT Model.

The Independent Project Work Submitted to School of Graduate Studies Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Master of Science in Hydraulics Engineering.

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Certification

I, the undersigned, certify that I read and hear and recommend for acceptance by Addis Ababa Institute of Technology a Project entitled “flow Estimation using SWAT Model, the case of Zarima May Day Dam Watersheds at Zarima Sub Basin, in the upper Semin mauntain of zarima river from tekeze basin in Ethiopia.” in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Major Hydraulic Engineering).

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Adviser

Declaration

I, Haftom Tekay Welu, declare that this Independent Project is my own original work and that it has not been presented and will not be presented to any other University for similar or any other degree award.

Haftom Teklay Welu

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ACRONYMS

LULC	land use land cover
LU	land use
GIS	Geographical Information System
SWAT	soil and water assessment tool
DEM	digital elevation model
NMSA	national meteorological services agency
STRM	shutter topography radar mission
MoWE	ministry of water resources
ET	evapotranspiration

ABSTRACT

Estimation of flow on the hydrological regime of river basins is one of the most concerns in the river sub basin of zarima. With plethora of tools available in the literature choosing of an appropriate tool that can quantify and analyze the impact of flow on the hydrological regime in a systematic and planned manner is important. Soil and Water Assessment Tool (SWAT) integrated with Geographic Information System (GIS) based interfaces and its easy linkage to sensitivity, calibration and uncertainty analysis tools made its applicability more simple and has great potential in simulation of the past, present and future scenarios.

A number of standards were used to appraise the model set-up, model performances, physical representation of the model parameters, and the accuracy of the hydrological model balance to assess the models that are defined in journal papers. On the basis of performance indicators, the mainstream of the SWAT models were categorized as providing satisfactory to very good. This review debates on the application of SWAT in analyzing land use land cover and run of estimation for the case study of Zarima May Day dam watershed. The Application of SWAT and land use land cover change in simulation models for Zarima May Day dam watershed is to improve accuracy, reduces costs, and allows the simulation of a wide variety of conservation practices at watershed scale. It is also observed that different researchers and/or model versions bring about in different outcomes while a comparison of SWAT model applications on similar case study was applied. This review determines the interactive role of SWAT and GIS technologies in improving integrated watershed management in Runoff Estimation and land use land cover for the topic of the study area.

CHAPTER 1

1.1. INTRODUCTION

1.2. General over view

Ability to make hydrological predictions has become an essential part of sustainable management of water resources, water quality and water related natural hazards, especially in environments where climate or human induced land use changes are under way. Catchment undergoing transition from one state to a different state through climatic change and land use changes can be considered as inadequate indicators of the future.

LULC change and rainfall have a significance influence on the hydrological responses of the river basin; watershed management implies the proper use of all land and water resources of a watershed for optimum production with a minimum hazard to natural resources. Runoff is one of the important hydrologic variables used in the water resources application and management planning. Precipitation and hydrological processes maintain water balance in a river basin. Land surface performs a role in the hydrological cycle, as water availability is generally a consequence of precipitation redistributed in to evaporation, run off and soil moisture storage (Doman and Verhagen 2003).

Estimation of surface run off is essential for the assessment of water yield potential of the watershed, planning of water conservation measures and reducing the sedimentation and flooding hazards downstream (Subramanian 2008). Rainfall and LULC are the important parameter of runoff estimation by hydrological modeling. There are a number of integrated physically based distributed models. Among which, researchers have identified SWAT as one of the most promising and computationally efficient model (Arnold et al., 1998; Neitsch et al., 2005; Gassman et al., 2007). Therefore, to test the capability of the model in determining the effect of special variability of the watershed on stream flow, SWAT with Arc GIS was selected. The time series data on runoff yield were available at the gauging station of the catchment and these were used to calibrate and validate the SWAT model and to assess its applicability in stimulating runoff yield from Zarima catchment.

1.3. Background

Land cover change commonly is highly pronounced in the developing countries that are characterized by agriculture based economics and rapidly increasing human population. Meyer and Turner (1994) discussed that land cover changes are caused by a number of natural and human deriving forces. Whereas natural effects such as climate changes are only over a long period of time, the effects of human activities are immediately and often direct. From the human factors, population growth is the most important in Ethiopia (Hurni, 1993 as cited in Tekele and Hedlund, 2000), as it is common in developing countries. Some 85% of the population lives in rural areas and directly depend on the land for its livelihood. This means the demands of lands are increasing as population increases.

Population growth causes degradation of resources that relay on the available land and the interaction between them is very complex. Interactions can make positive or negative effects to the resources. People demand land for food production as well as for housing and it is common practice to clear the forest to make farming area and housing. The result is that land cover and land use change due to daily human intervention. Hence, understanding how the land use cover change influence the river basin hydrology will enable planners to formulate policies to minimize the undesirable effects of future land cover changes.

Zarima basin is frequently exposed to intense and rapid orographic storms that produce high flash floods along the steep topography. Since; the high Simien mountain range ensures that; relatively high runoff in the river Zarima at the dam Site. The land and water resources of the watershed are in danger due to the rapid steep slope topography flooding, deforestation and overgrazing, soil erosion, sediment deposition, storage capacity reduction, drainage and water logging. There is a need for hydrological and land use land cover change research that can improve the catchment management program. Appropriate decision support tools are needed for better assessment of the hydrology and land use planning and implementations of soil and water conservation measures. The tools concern various hydrological models and geographical information system (GIS). The modeling tools will finally help to save the physical quality of the land.

1.4. Statement of the problem

Resource management is very complex phenomena. This complex nature of sustainable natural resource management demands research that uses a systems approach; research that is interdisciplinary - combining biophysical and socio-economic dimensions. In the same way Zarima river and its tributary sub basin of dukuko is located at a lower basins of semine terara mountain is highly susceptible to LULC change due to high runoff sediment, natural and manmade drivers such as rapid population growth, over exploitation of resources.

Rapid population growth together with new land use planning and new sugar cane plantation practices leads pasture land areas to be cultivated, forest land clearance; woody land and shrub lands are converted to crop lands and also, Intensive and extensive production of fire wood and wood charcoal by pastoralists for supplements of income generation is seriously affecting the plant biodiversity and associated elements in the lower course of the basin.

Therefore, Flow estimation is one of the most important hydrologic variables used in the water resource applications and management planning. Estimations of surface run of is essentials for the assessments of water yield potential of the watershed , planning of water conservation conservations measures and reducing the sedimentation and flooding hazards is part of removing the soils, these effects have in turn will be one of the greatest challenger threatening the dam reservoir with siltation. So estimating the run of from the catchment and land cover change are the unforeseen problem of the area.

1.5. Research question

1. What amount of Flow could be expected monthly from the catchment?
2. What are general trends of maximum temperature, minimum temperature and precipitation scenario in the future compared to the present condition and how this is reflected on hydrology of the Zarima sub-basin?

1.6. Research Objectives (Aim of the Study)

1.6.1. General objective

- ✓ The study aims to estimate Flow and identify and compare Gauged stream flow with estimated flow in Zarima May Day dam catchment area

1.6.2. Specific objective

- ✓ To estimate Stream flow using SWAT

1.7. Significance of the study

Continuous runoff data is prerequisite for hydrological forecasting and water resource management. The reliability of hydrological decision-making increases as the accuracy of the runoff time series increases. However, because of the limitations of monitoring technology and the cost of monitoring, continuous runoff data is not always available, and frequently there are inadequate or no measurements. Therefore estimating the stream flow will help us in Water resource appraisal and allocations for water supply plans, As part of interstate agreements, compacts, and court decrees, Engineering design (Reservoirs, Bridges, roads, culverts, Treatment plants), Operations (Reservoirs, Power production,, Navigation), Identifying changes in stream flows due to changes in (Land use, Water use, Climate), Flood planning and warning(Flood forecasts, Flood plain mapping), Stream flow forecasting, Support of water quality sampling, Water quality conditions and trends, Contaminant transport, Total Maximum Daily Loads (TMDLs), Characterizing and evaluating in-stream conditions (Habitat assessments, In-stream flow requirements, Recreation)

1.8.Proposal outline

This research proposal is arranged in 6 chapters. Chapter 2 tries to include the views of different literatures on key points of the study especially the theories behind the software's and models applied in this research and major factors considered on hydrological and hydraulic modeling are presented. In Chapter 3, the methodologies and procedures used for the development of hydrologic and hydraulic modeling are presented in detail. In chapter 4 expected output of the research and predicting problem facing with recommendation. On Chapter 5 the work program will be discussed. On the final chapter, which is a chapter 6 reference used for this Proposal mentioned.

CHAPTER 2

2.1. Literature review

This chapter reviews the various relevant literatures, which are referred to in this study. First hydrological process, the flow of Zarima River and hydrological models are discussed. Then the hydrological Models with the emphasis on soil and water assessment tool (SWAT) and the application of GIS in hydrological modeling.

2.2. Hydrological process

Hydrologic process can be defined as the natural system in which water moves between land, atmosphere and the ocean cyclically. These cycles and the consequences of which now threaten the living existence of the hydrologic process of any typical watershed. Hydrologic cycle is composed of several natural processes which have interactions and they can be represented or simplified using a mathematical model. The following are the processes that are represented in hydrological cycle; precipitation, interception (including utilization by ecosystems, man and irrigation), absorption into earth materials and uptake by plants (including percolation), water movement from shallow to deep aquifers, surface flow, subsurface flow and water losses in the form of evaporation, transpiration and seepage. The runoff comprises all the surface and shallow subsurface water flows caused by precipitation events. The surface runoff always occurs if more water is applied to the soil than it can absorb by infiltration. Overland flow can be grouped into three different classes, being distinguished by three physical processes (Morgan, 2005) cited in (Junker, 2012). The first type is the Hortonian overland flow (named after scientist Robert E. Horton, who made the first detailed studies of this type of runoff), which occurs if the rainfall intensity is higher than the soil infiltration rate. This phenomenon often occurs during heavy rainstorms.

The second type of surface runoff occurs if the soil is saturated and as a consequence further uptake of water by soil is not possible. Soil saturation is the result of periods with much rain. After the soil reaches a saturated state, following rainfall events cause runoff. Furthermore, soil properties (depth, particle distribution, texture) have effects on the absolute water storage capacity of the soil. Basically sandy soils usually have a lower storage capacity where up on the

soil depth always plays an important role. Logically the absolute capacity decreases due to less soil depth and consequently runoff occurs more often on shallow soils.

The third type of runoff is caused by deposition of silt-sized particles transported by the Hortonian overland flow. These particles can form an impermeable crust that reduces the infiltration rate of the soil dramatically. Subsequent rainfall events then cause surface runoff. Stream flow includes not only overland runoff, but also subsurface runoff. In hydrology stream flow is generated by the three component's surface (and shallow subsurface) flow, interflow and groundwater flow. The three components can also be distinguished regarding their time of response to the precipitation events. In this case they are separated into two classes, the fast reacting flows (surface flow, fast interflow and rain directly falling into flowing water) and the slow reacting flows or so called base flows (groundwater flow or slow interflow).

2.3. Impact of land use on water resource

With regard to the hydrologic regime, impacts on surface and ground water resources can be distinguished. Impacts of land use practices on surface water can be divided into (i) impacts on the overall water availability or the mean annual runoff, and (ii) impacts on the seasonal distribution of water availability. With regard to the latter, impacts on peak flows and impacts on dry season flows are of importance. With regard to groundwater, the effect of the land use on groundwater recharge has to be examined.

2.3.1. Mean surface runoff

The impact of land use on the mean runoff is a function of many variables, the most important being the water regime of the plant cover in terms of evapotranspiration (ET), the ability of the soil to hold water, and the ability of the plant cover to intercept moisture. A change of land cover from lower to higher ET will lead to a decrease in annual stream flow. From a review of 94 catchment experiments, Bosch and Hewlett (1982) concluded that the establishment of forest cover on sparsely vegetated land decreases water yield. Coniferous forest, deciduous hardwood, brush and grass cover have (in that order) a decreasing influence on water yield of the source areas in which the covers are manipulated. Conversely, a change from higher-ET plants to lower-ET plants will increase the mean surface runoff: reduction in forest cover increases water yield (Bosch and Hewlett, 1982; Calder, 1998).

An exception to this rule are cloud forests, which can intercept more moisture (fog drip) than consumption by ET and very old forests, which, depending on the species, may consume less water than the vegetation that establishes itself after clear-cutting (Calder, 1998). Stream flow gains decline over time with establishment of new plant cover, but time scales can vary greatly. In humid warm areas, the effect of clear-cutting is shorter lived than in less humid areas, due to rapid re-growth of vegetation (Falkenmark and Chapman, 1989). Increasing water yield from changing plant cover does not necessarily increase water availability downstream. Stream flow might decrease because of other factors, e.g. water consumption by riparian vegetation or through transmission losses (Brooks *et al.*, 1991).

2.3.2. Peak flow/Runoff

Peak flows can increase as a result of a change in land use if the infiltration capacity of the soil is reduced, for example through soil compaction or erosion, or if drainage capacity is increased. Peak flow may increase after trees are cut down (Bruijnzeel, 1990). Relative increases in storm flow after tree removal is smallest for large events and largest for small events. As the amount of precipitation increases, influence on storm flow of soil and plant cover diminishes (Bruijnzeel, 1990).

In larger basins, effects of land use practices on peak flow are offset due to time lag between different tributaries, different land use and variations in rainfall (Bruijnzeel, 1990). In larger watersheds, this de-synchronization effect can lead to a reduction in peak discharge, although overall storm flow increases due to land use changes in individual sub watersheds (Brooks *et al.*, 1991).

2.3.3. Base flow (dry season flow)

In tropical areas, a forestation can lead to decreased dry-season flows due to increased evapotranspiration. In the MaeThang watershed (Thailand), afforestation programs led to water shortages downstream, which resulted in a seasonal closure of a water treatment plant and lower availability for irrigation (Chomitz and Kumari, 1996). Similarly, in the Fiji Islands, large-scale pine afforestation (60 000 ha) in watersheds previously covered by grassland led to reductions in dry-season flow of 50-60 percent, putting the operation of a hydro-electric plant and drinking water supply at risk (FAO, 1987).

2.3.4. Ground water recharge

The groundwater recharge may be increased or decreased as a result of changing land use practices. The major driving forces are the ET of the vegetative cover and the infiltration capacity of the soil. Groundwater recharge is often linked with dry-season flows, as groundwater contributes much of the river discharge during the dry season. The water table may rise as a result of decreased evapotranspiration, e.g. following logging or conversion of forest to grassland for grazing. Recharge may also increase due to an increased infiltration rate, e.g. through afforestation of degraded areas (Tejwani, 1993).

In contrast, the water table may fall as a result of decreased soil infiltration, e.g. through non-conservation farming techniques and compaction (Tejwani, 1993). And also, heavy grazing may lead to reduced infiltration and groundwater recharge (Chomitz and Kumari, 1996). If the infiltration capacity is substantially reduced, this can lead to water shortages in dry seasons, even in regions where water is usually abundant, like in the case of shifting cultivation in Cherapunji province, India (FAO, 1999). Likewise, groundwater recharge can be reduced as a result of planting of deep rooting tree species, e.g. eucalyptus (Calder, 1998).

2.4. Impact of land use on erosion

Forests are checkers of soil erosion. Protection is largely because of under story vegetation and litter, and the stabilizing effect of the root network. On steep slopes, the net stabilizing effect of trees is usually positive. Vegetation cover can prevent the occurrence of shallow landslides (Bruijnzeel, 1990). However, large landslides on steep terrain are not influenced appreciably by vegetation cover. These large slides may contribute the bulk of the sediment, as for example in the middle hills of the Himalayas (Bruijnzeel and Bremmer, 1989).

A forestation does not necessarily decrease soil erosion. Splash erosion may increase substantially when litter is cleared from the forest floor (Bruijnzeel, 1990). The spectrum for the size of the drops that are formed by the canopy varies widely among different species, resulting in large differences in the potential of splash erosion (Calder, 1998).

Deforestation may increase erosion. In Malaysia, streams from logged areas carry 8-17 times more sediment load than before logging (Falkenmark and Chapman, 1989). The actual soil loss, however, depends largely on the use to which the land is put after the trees have been

cleared. Surface erosion from well-kept grassland, moderately grazed forests and soil-conserving agriculture are low to moderate (Bruijnzeel, 1990). Road construction may be a major cause for erosion during timber harvesting operations. In the USA, forest roads are estimated to account for 90 percent of the erosion caused by logging activities (Brooks *et al.*, 1991; Bruijnzeel, 1990).

2.5. Effect of land use, soil type on runoff

Runoff is that balance of rain water, which flows or runs over the natural ground surface after losses by evaporation, interception and infiltration.

The rainfall loss through infiltration depends upon the intensity and duration of rainfall, weather (temperature), soil characteristics, vegetal cover, land use, initial soil moisture content (initial wetness), entrapped air and depth of the ground water table. The vegetal cover provides protection against rain drop impact and helps to increase infiltration. (Raghunath, 2006).

2.6. Metrological data

There are different Techniques for estimating missing daily and monthly rainfall data

2.6.1. The Inverse Distance Weighting (IDW) methods

Estimate the rainfall amount of a location as a weighted average of the rainfall amount of adjacent stations and the weights are considered as a function of the distance.

2.6.2. Spatial interpolation methods

Yield non-zero rainfall amounts for a station if even just one of the neighboring stations has rainfall, and hence, due to the poor sampling by rainfall gauge networks, tend to significantly overestimate the number of rainy days. Moreover, the errors in estimating the missing records due to the faulty measurement process of rainfall at neighboring stations can't be ignored.

2.6.3. Regression based methods

It is also used for estimating missing precipitation values. Regression models consider climate data, elevation, topography to coastal area etc. some regressive techniques explored in filling missing daily rainfall series include: simple substitution, parametric regression, ranked regression, and the theil methods, neural network algorithms are also explored for imputation of missing precipitation values. Regression based methods also underestimate the number of days with no rainfall.

2.6.4. Simple Arithmetic Mean Method/Local Mean Method/

This is the simplest method commonly used to fill in missing meteorological data in meteorology and climatology. If the normal annual precipitations at surrounding gauges are within the range of 10% of the normal annual precipitation at station X, then the Arithmetic procedure could be adopted to estimate the missing observation of station X. this assumes equal weights from all nearby rain gauge stations and uses the arithmetic mean of precipitation records of them as estimate.

$$P_x = \frac{1}{m} [P_1 + P_2 + \dots + P_m] \dots \dots \dots (Eq - 1)$$

Where, P_x is the estimated value of the missing data, P is the value of same parameter at nearest weather station, and m is the number of the nearest station. The A.A method is satisfactory if the gauges are uniformly distributed over the area and the individual gauge measurement do not vary greatly about the mean.

2.6.5. Normal ratio method

This method is used if any surrounding gauges have the normal annual precipitation exceeding 10% of the considered gauges. This weights the effect of each surrounding station. If the normal precipitations vary considerably then P_x is estimated by weighting the precipitation at various stations by the ratios of normal annual precipitation. The normal ration method gives P_x as:

$$P_x = \frac{N_x}{m} \left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \dots + \frac{P_3}{N_3} \right] \dots \dots \dots (Eq - 2)$$

Where, P_x = Estimate for the ungagged station P_i =Rainfall values of rain gauges used for estimation N_x = Normal annual precipitation of X station N_i = Normal annual precipitation of surrounding stations m =No. of surrounding stations.

2.6.6. Modified normal ratio method

Normal ratio method is modified to incorporate the effect of distance in the estimation of missing rainfall. It is Modified by Young (1992) is a common method for estimation of rainfall missing data. This method is used if any surrounding gauges have normal annual precipitation exceeding 10% of the considered gauge. This weighs the effect of each of surrounding station. The

estimated data is considered as a combination of parameters with different weights, as shown below;

$$V_o = \frac{\sum_{i=1}^n W_i V_i}{\sum_{i=1}^n W_i} \dots \dots \dots (Eq - 3)$$

Where, V_o is the estimated value of the missing data W_i is the weight of nearest weather station expressed as:

$$W_i = \left[R_i^2 \left(\frac{N_i - 2}{1 - R_i^2} \right) \right] \dots \dots \dots (Eq - 4)$$

Where, R_i is the correlation coefficient between the target station and the i^{th} surrounding station, and N_i is the number of points used to derive correlation coefficient.

2.6.7. Inverse distance method

In this method, weights for each sample are inversely proportionate to its distance from the point being estimated. The inverse distance method has been advocated to be the most accurate method as compare to other methods discussed above as it is a function of;

- 1). Rainfall measured at the surrounding index station
- 2). Distance to each index station from the ungagged location

The Inverse distance (reciprocal-distance) Weighting method (IDWM) is the method most commonly used for estimating missing data. This weighting distance method for estimating the missing value of an observation, which uses the observed values at other stations, is determined

by; $X_m = \frac{\sum_{i=1}^n X_i d^{-2m_i}}{\sum_{i=1}^n d^{-2m_i}} \dots \dots \dots (Eq - 5)$

Where, X_{mi} is the value of precipitation at the base station, n is the number of station, X_i is the value at station i , d_{mi} is the distance from the location of station i to station m .

2.7. Hydrological model

Hydrologic models have become an indispensable tool for the study of hydrological processes and the impact of modern anthropogenic factors on the hydrologic system. The broad classification of hydrologic models is as shown in Figure 1.

Hydrologic models can be classified into the following categories based on the presence of random variables, their distribution in space, and temporal variation (Chow, Maidment, & Mays, 1988)

(1). Deterministic models: Randomness is not considered; a given input always produces the same output. Therefore, these models can be used for forecasting.

(A). Deterministic lumped model: A lumped model is generally applied to a single point or a region without dimension for the simulation of various hydrological processes (Niel, Paturol, & Servat, 2003). The parameters used in the lumped model represent spatially averaged characteristics in a system. The conceptual parameterization in the models is simple and computationally efficient.

(B). Deterministic semi-distributed model: It divides the whole catchment into Hydrologic Response Units (HRUs) based on other variables in addition to land use and land cover, soil type, and slope and simulates the various hydrological processes in each HRU.

(C). Deterministic distributed model: It considers the hydrological processes taking place at each grid and defines the model variables as functions of the space dimensions (Beven, Warren, & Zaoui, 1980; Feyen, Vázquez, Christiaens, Sels, & Feyen, 2000).

Watershed-scale models can further be categorized on a spatial basis as lumped, semi-distributed, or distributed models. The lumped modeling approach considers a watershed as a single unit for computations where the watershed parameters and variables are averaged over this unit (Cheng, 2011; Magar & Jothiprakash, 2011; Niel et al., 2003). The semi-distributed models partition the whole catchment into sub-basins or HRUs (Daofeng, Ying, Changming, & Fanghua, 2004). In contrast, the spatial heterogeneity is represented by grids in the case of distributed models. Compared to lumped models, semi-distributed, and distributed models better account for the spatial variability of hydrologic processes, input, boundary conditions, and watershed characteristics (Elfert & Bormann, 2010; Legesse et al., ; Lin, Wu, & Hong, 2008; McColl & Aggett, 2007; Thanapakpawin et al., 2006).

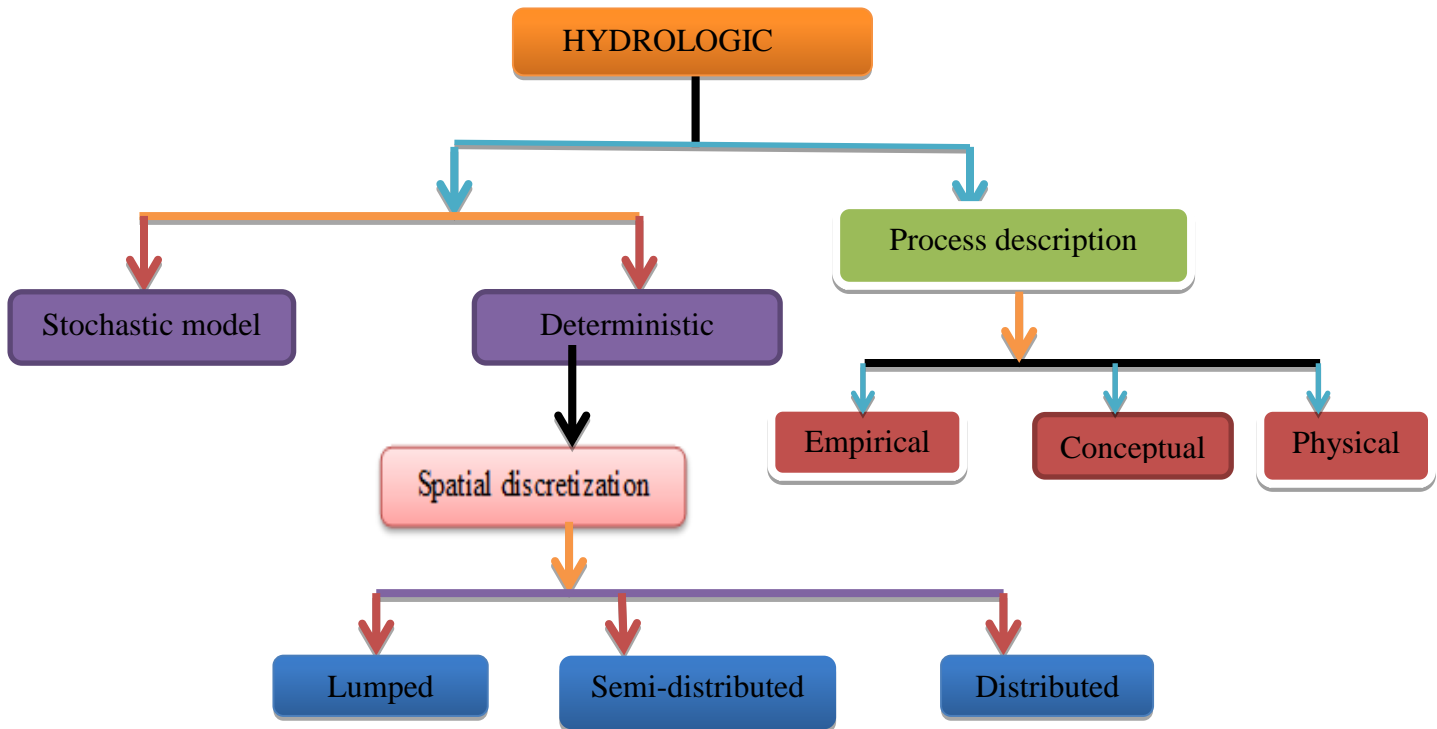


Figure2. 1. Classification of hydrologic model

(2). stochastic models: The output of these models is at least partially random. Therefore, these Models make statistical predictions. Stochastic models are classified as space independent or space correlated depending on whether random variables in space influence each other.

The hydrological models can also be classified according to whether the hydrological processes are described as conceptual, empirical, or fully physically based (Figure 1). Empirical models, such as Artificial Neural Networks (ANNs), Fuzzy Logic, Genetic Algorithm (GA) etc., are used to establish a relationship between rainfall and runoff to predict runoff in different catchments (Chen, Wang, & Tsou, 2013; Halff, Halff, & Azmoodeh, 1993; Shirke et al., 2012). Empirical models contain no physical transformation function to relate input to output; such models usually build a relationship between input and output based on hydro-meteorological data (Sarkar & Kumar, 2012; Sudheer, Gosain, & Ramasastri, 2002).

2.8. Theoretical consideration of SWAT

The soil and water assessment tool (SWAT) is a result of USDA -ARs continuing effort in non-point source pollution modeling and evolution. SWAT is a physically based continuous time and distributed parameter model (Neitsch et al., 2002). The model has been widely used to simulate runoff and sediment yield in small water sheds. (Triphati et al 2003, Sprwill et al, 2000). It has the capability of simulate long term effect of best management practices (BMP) (Neitsch et al, 2002).

The large scale spatial heterogeneity of the study area is represented by dividing the watershed in to sub basins. Each sub basin is further discredited in to a series of Hydrologic of response unites (HRUs), which are unique soil land use combinations. Soil water content, surface runoff, nutrient cycles, sediment yield, crop growth and management practices are stimulated for each HRU and then aggregated for the sub basin by a weighted average

Physical characteristics such, as slope, reach dimensions, and climatic data are considered for each sub basin. Fore climate, SWAT uses the data from the station nearest to the centric of each sub basin. calculated flow sediment yield and nutrient loading obtained for each sub basin are then routed through the river system channel routing is stimulated using the variable storage or Muskingum method. The water in each HRU in SWAT is stored in for storage volumes: snow: soil profile (0-2 meter) shallow aquifer (typically 2-20 m), and deep aquifer. Surface run off from daily rain fall is estimated using a modified SCS curve number method which estimates the amount of run off based on local land use, soil type and antecedent moisture condition. Peak run off predictions are based on a modification of the rational formula (chow. et al., 1988). The water shed concentration time is estimated using manning's formula considering both over land and channel flow.

2.9. Application of GIS in Hydrological modeling

GIS is an organized collection of computer hard ware and software with supporting personnel that captures, stores, analyses and displays all forms of geo- referenced information (sub in, 1996). A primary role of GIS in hydrological modeling is to integrate the ever- increasing volume of diverse spatial and non-spatial data. This can be the model input or output. Recent advances in GIS (Hard ware and Software) technology offer un precedence capability for storing and manipulating large amount of detailed, spatially- distributed watershed data (ASCE, 1999). In SWAT, GIS software called ARC View is used to prepare input date and display the model output as spatial maps, charts or time series date. This make easy to study and display the information.

3.0. Model Performance Evaluation

Successful application of hydrologic model is highly dependent on the sensitivity analysis and calibration of the model parameters. The matches between simulated and observed results were assessed via graphical and statistical techniques. The SWAT plus package, was applied for sensitivity analysis, calibration and validation of the model.

The package provides tools for linking SWAT project with R, thereby enabling the execution of SWAT simulations and controlling changes in model parameters, simulation periods and time steps. The goodness of fit between the simulated and measured data was evaluated by the equations representing these relationships are as shown below.

3.1. Coefficient of Determination (R^2)

Coefficient of determination measures both the strength of the linear relationship between observed and estimated values. This is calculated by equation (1).

$$R^2 = \left[\frac{\sum_{i=1}^n (Q_{oi} - Q_o)(Q_{ei} - Q_e)}{\sqrt{\sum_{i=1}^n (Q_{oi} - Q_o)^2} \sqrt{\sum_{i=1}^n (Q_{ei} - Q_e)^2}} \right]^2 \dots \dots \dots \text{Equation(1)}$$

Where, Q_o = Observed Annual Average Flow (m^3/s)

Q_e = Estimated Annual Average Flow (m^3/s)

Q_{oi} = Observed Monthly Average Flow of month i

Q_{ei} = Estimated Monthly Average Flow of month i

n = Number of data. As number of months are 12, $n = 19$ in this case.

The coefficient of determination (R^2) is the square of the coefficient of correlation.

Criteria: Larger the value of R^2 , better the performance.

Hydro-Sim, WECS1990, NEA1997, DHM2004, DAR and GT methods are 0.97, 0.67, 0.95, 0.67, 0.74 and 0.92 respectively, then the respective numerical values these methods get are 6, 1.5, 5, 1.5, 3 and 4. The WECS1990 and DHM2004 methods have equal values of NSE i.e., 0.67, and therefore both these methods are assigned 1.5 (average of 1 and 2). The mean value of performance of each method was then calculated as Global Performance Index (GPI) as given by Equation (7).

$$GPI_j = \frac{R^2_j + MAE_j + RMSE_j + PBIAS_j + NSE_j + KGE_j}{6} \dots\dots\dots \text{Equation (7)}$$

Where j represents the estimating method, say, for hydrological simulation method j = 1 while for DAR method, j = 5.

Based on the GPI value, the six considered methods are ranked from first to sixth such that higher the GPI value, better method for monthly flow estimation.

Model performance was evaluated by a criteria suggested by as shown in table below

Table 2.1. General performance ratings for Nash-Sutcliffe efficiency (NSE), coefficient of correlation, PBIAS and RMSE.

Performance rating	R ²	NSE	PBIAS	RMSE
Very good	>0.85	>0.80	< ±5%	
Good	0.75<NSE<=0.85	0.70<NSE<=0.80	±5% ≤ PBIAS ≤ ±10%	
Satisfactory	0.60<NSE<=0.75	0.5<NSE<=0.70	±10% ≤ PBIAS ≤ ±15%	SI < 1
Unsatisfactory	<0.60	<=0.5	≥15%	SI > 1
Acceptable	>0.60	0<NSE<=1	<±15%	
Unacceptable	<=0.60	<0	>±15%	

CHAPTER 3

3.1. Research Methodology

This chapter describes the input data, their sources and the methodology adopted to estimate runoff and land use land cover change in Zarima river basin. The overall methodology involved scenario simulation using soil and water assessment tool (SWAT) and ARC GIS to develop soil textural map of the study area.

3.2. Description of the study area

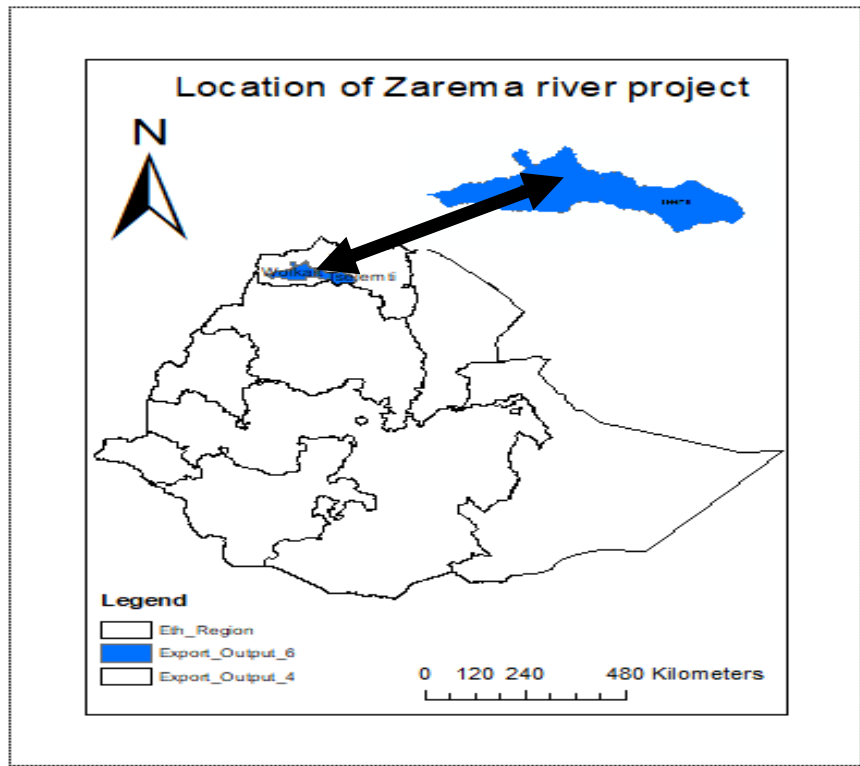


Figure 3. 1. Location of Zarima Rivers

Zarima project is located in the Tigray region of Ethiopia, Western zone, within the borders of Wolkaiyte and Tselemti districts or “weredas” (third-level administrative divisions).

The Zarima May Day Dam harnesses the water potential of the river Zarima and its tributary Dukuko, approximately 6 km upstream from the left bank confluence with the Tekeze River. The overall catchment area is around 2072.9 km² of which 701 km² in the Zarima sub-catchment and 1140 m² in the Dukuko sub-catchment.

3.2.1. Tekeze Basin

The Zarima basin represents an important part of the overall Tekeze basin. Tekeze River, is a major river in Ethiopia (760 km long), drains northward toward the Nile. The Tekeze basin within the Ethiopian borders is approximately 63 000 km².

The upper course of the Tekeze flows on the Ethiopian highlands, which cover almost the 70 % of the basin, at elevation above 1500 m a.s.l.. The basin is surrounded by high mountain ranges, from 2000 up to 4600 m a.s.l. at the mountain of Anuca. In this region the river receives some tributaries, among which the Tserare, Gheba, Zarima and Insia contributes with relevant flows. These rivers originate from the eastern and western slopes of the Simien Mountain and flow toward North, North-West. The upper course of the tributaries is characterized by a fairly fan shaped area, whereas the lower course is excavated in narrow and relatively deep valleys. The lower portion of the Tekeze basin is a 150 km long and narrow strip of land along the Sudan border, laying between elevation 500 and 1000 m, with an almost flat topography.

The rainfall pattern within the basin is relatively variable, ranging from a total amount of 1100-1200 mm/yr at the south-eastern boundary to a small 700-800 mm/yr on the lower course toward the north-western plains. The western area including the Simien mountain range represents a local exception, where the rainfall amount reach the highest peak up to 1500-1600 mm/yr, being one of the wettest area in Ethiopia. The minimum rainfall is recorded north of Gheba valley, 500 mm/yr, in the north-eastern corner of the basin.

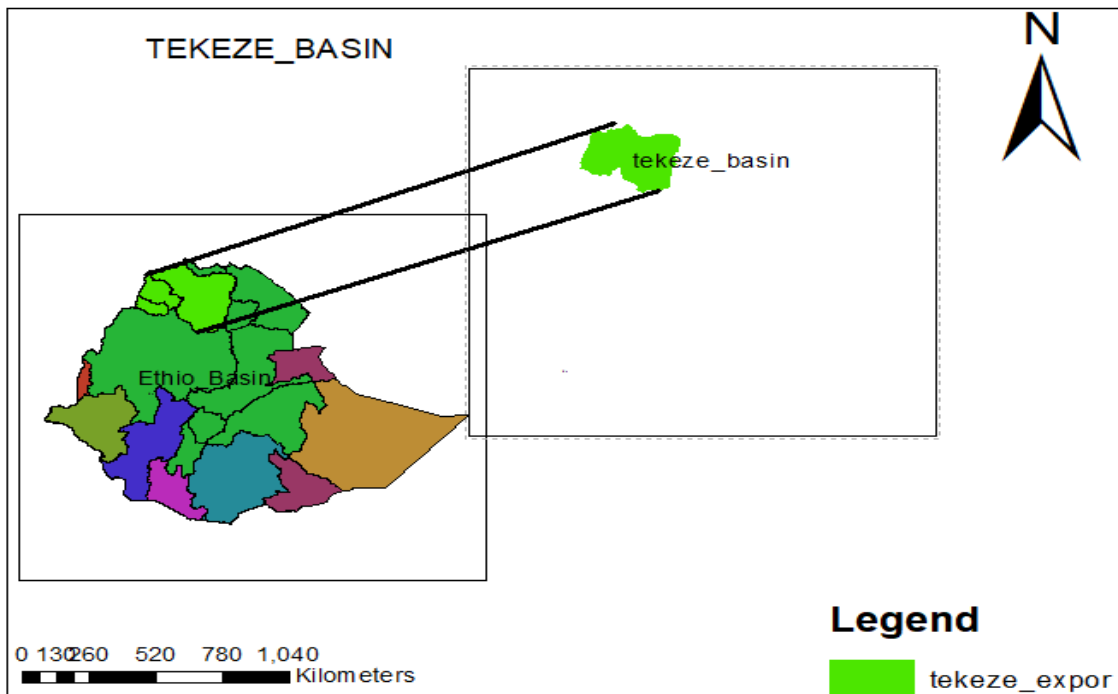


Figure 3. 2. Location of Tekeze Basin

3.2.2. Zarima Basin

The project area exhibits the highest rainfall amount in the region. The Zarima River, indeed, originates from the eastern slope of Simien Mountains, in between Debarke and Zarima towns.

The Dukuko river, the main tributary of Zarima river, originates westerly of the Simien mountains approximately at the same elevation above the sea level, however with sensibly lower rainfall totals.

Zarima and Dukuko, after the confluence, are named Zarima River. The Zarima May Day Dam has been strategically located downstream of this confluence to maximize the available water resource. The overall catchment area at the dam section is around 2072.9 km², being the Zarima sub-catchment of 701 km² and the Dukuko sub-catchment of 1140 km² (upstream from the confluence).

The Zarima sub-catchment receives a larger amount of rainfall compared to the Dukuko sub catchment, totals higher than 2000 mm/yr have been recorded in the past. Frequent storms occur generally between June and September and precipitation up to 120 mm may fall within 24-hours. The Zarima sub-catchment, due to the presence of the Simien mountain range, is

frequently exposed to intense and rapid orographic storms, which produce high flash floods along the steep topography.

The great variability in the rainfall pattern is depicted by the isohyets along the Zarima valley. The stream crosses contours ranging from 1400 mm/yr in the mountain divide down to 900 mm at the confluence with Dukuko River, over a 50 km course. The orographic effect of the Simien Mountains is clearly a predominant source of rainfalls.

The Dukuko sub-catchment is characterized by lower rainfall amounts. The stream crosses isohyets ranging from 1000 mm/yr to 900 mm/yr at the confluence with Zarima River, over approximately 73 km course.

The remaining sub-catchment, downstream from the confluence toward the dam site, has a drainage area of about 328 km². The Zarima River flows for about 37 km prior to reach the Tekeze river confluence. The average rainfall over this sub-catchment is around 900 mm/yr, however, high rates of potential evaporation, up to 1900 mm/yr, define a climate predominantly arid. The contribution to the overall annual runoff due to this area is small.

The topography of the Zarima basin is predominantly mountainous, characterized by highlands and ranges. The river flows in a relatively narrow valley, descending from an elevation of about 3000 m to 810 m at the dam site in a distance of 87 km (along Zarima stream). The basin is partially covered by woodlands and bushes in the upper portion, whereas the lowlands are arid and semiarid, also due to the increasing demand of valuable land for agriculture and pasture.

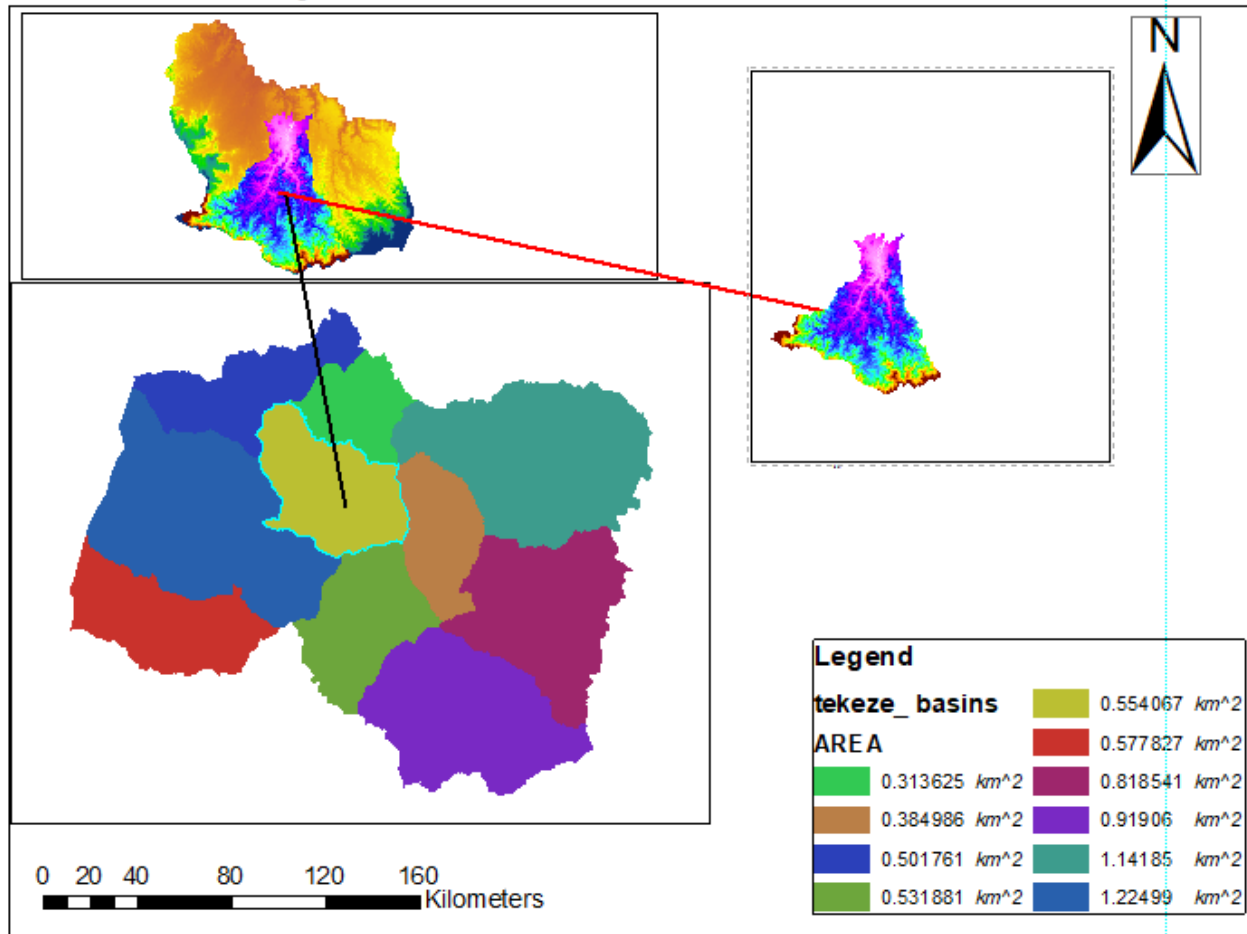


Figure 3. 3. Location of Zarima Sub Basin

3.2.3. Climatic Region

The NMSA (National Meteorological Service Agency, 1996) has provided a classification of the rainfall patterns over Ethiopia. Several different climatic zones have been defined across the country, essentially depending on the influence of the ITCZ (Inter-Tropical Convergence Zone) and the orography/elevation above the sea level.

The project area is classified as Mono-Modal, i.e. dominated by a single maxima with wet period clearly marked from June/July to August/September. The zone of convergence affects this season with low-pressure systems accompanied by the oscillations of the ITCZ extending from West Africa through North-Ethiopia to India. The major rain cells are generated by the northward migration of the ITCZ together with the persistence of the Arabian and Sudanese

thermal low - high-pressure systems over the Atlantic and Indian oceans and the occurrence of complex jet streams along the ITCZ boundaries.

The dry season extends from October to January under the influence of dry and cool northeasterly winds. The sporadic interaction between the Mediterranean low and the equatorial/tropical system may occasionally produce erratic rainfalls. A small rainy season can be defined from February to May, however, exhibiting inter-annual variations. This season of transition is influenced by the low-pressure system over the Mediterranean Sea and the tropical troughs produced by Subtropical jets.

Mean monthly sunshine hours range between 6.5 and 8.5 hrs/day. Highest monthly values, up to 10 hrs/day, occur during the dry season. Low values, less than 4 hrs/day, occur during the rainy season and especially in July and August.

An average wind intensity of 12 km/h is observed during the wet season.

3.2.4. Gauging Stations

The project area, as well as the lower part of the Tekeze basin, critically lacks of gauging stations for direct measurements of rainfall and river discharge. The available records are extremely poor in quantity (short series length) and scarcely consistent (excessive gaps). The network of stations is under designed and can hardly be implemented to describe the basin hydrology.

New and automatic gauges should be early installed along with the development of the project area to beneficially increase the dataset of records in the next years. A structured network of stations may, indeed, allow to gather valuable data which would result decisive to efficiently operate the irrigation system at the command area.

The stations available within the project area are:

- the stream flow gauge (hydrometric) coupled with a rainfall gauge (pluviometric) installed at Zarima (close to Zarima town), along the Zarima stream upstream from the confluence with the Dukuko river;
- The rainfall gauge installed at Adi-Remets within the command area.

Both the stations, however, present relatively short series of records and intermittent gaps which strongly affect the data reliability.

To integrate and enhance the available rainfall records some gauging stations located outside, although fairly close, from Zarima basin have been considered. These stations are listed in

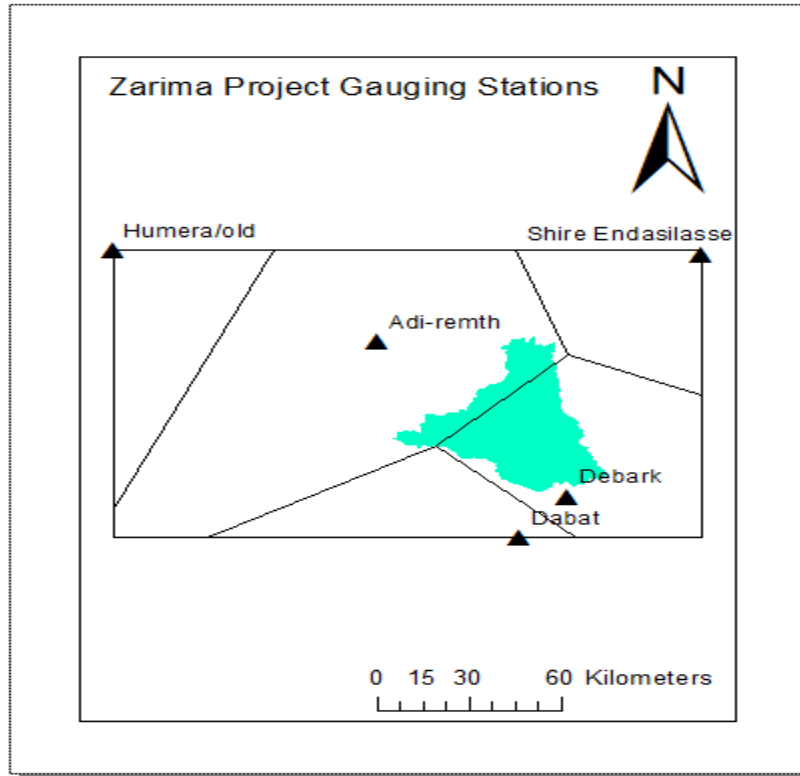


Figure 3.4. Zarima Project Watershed with Gauging Stations.

Table 3. 1. Zarima Gauging stations.

Station	Easting(m)	Northing(m)	Record length(year)
Humera	213945.68	1568147.83	1992 - 2010
AdiRemets	318582.98	1520513.42	1992 - 2010
Debark	340639.47	1448657.81	1992 - 2010
Shire Endaselasie	435543.24	1563107.4	1992 - 2010
Dabat	331625.54	1392292.59	1992 - 2010

Other interesting climatic features, such as temperature, humidity, wind speed and sunshine hours, have been collected from Debark, Humera, Shire Endaselasie, Dabat and Adi –Remets stations. Unfortunately neither Zarima station, located within the project area, are equipped with such specific gauges.

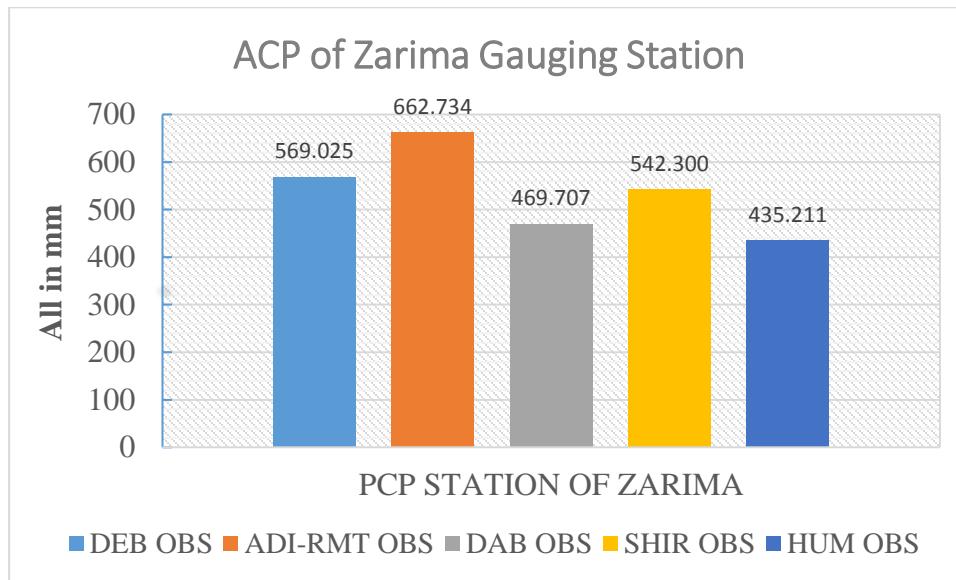


Figure 3.5. Annual Cumulative Precipitation of Zarima Gauging Stations.

3.2.5. Precipitation

The annual precipitation in the project area has been defined based on the rainfall records of Zarima, Debark, Dabat Shire endaselasie, Humera and Adi-Remets stations (19 years). The Annual cumulative rainfall pattern varies between the maximum 662.734 mm/yr and 435.211 mm/yr in the command area. The maximum annual rainfall has been recorded in 2010 (Adi-Remtse station), with a 197 mm/yr. These results show a large variability in the rainfall totals over the years, as some exceptionally long rainy seasons of high rainfalls are soon followed, on the other hand, by persistent dry seasons with critical scarcity of rainfalls (up to 7 month of drought).

The highest precipitation is normally recorded in July and August, when the total amount roughly corresponds to the 52 % of the annual average. December and January are conversely the driest months and frequently exhibit little or no rain.

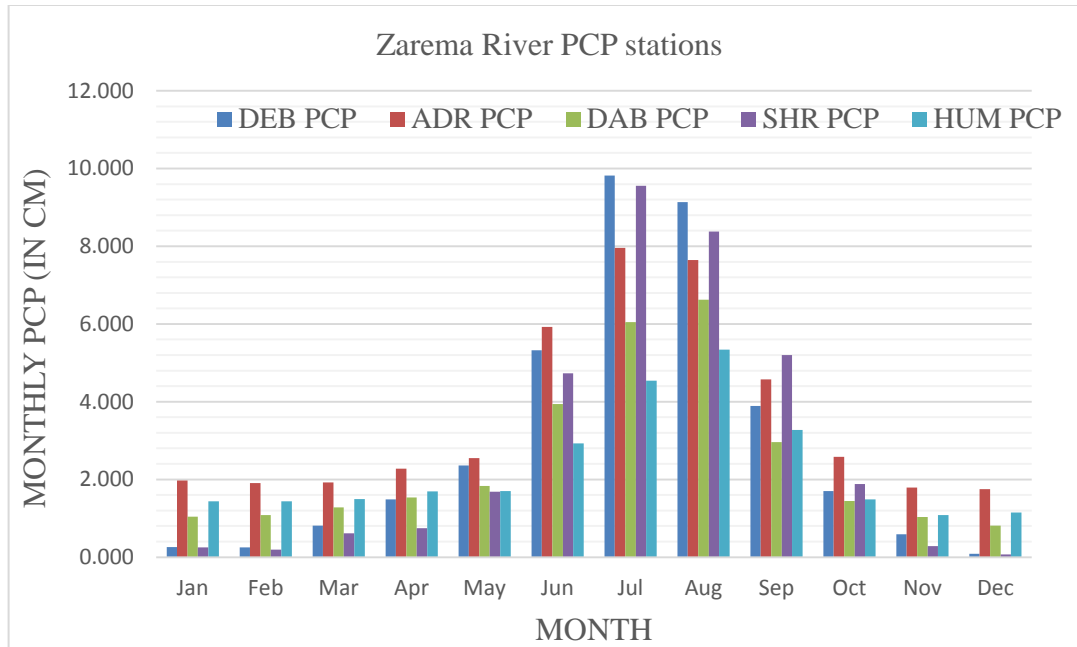


Figure 3.6. Long term monthly rain fall around zarima watershed (1992 – 2010)

3.2.6. Evaporation

The previous studies on the Tekeze basin (*Tekeze River Master Plan*, NEDECO [3]) suggest that the annual potential evaporation would range between 2200 mm in the lowlands (Humera station), located west of the project area, to less than 1000 mm in the Simien mountains. On average the annual evaporation is higher than the mean precipitation.

3.2.7. Temperature

The temperatures in the project area are mainly determined by the elevation above the sea level. In the lowlands (600 m a.s.l.) the annual average is around 26 °C, while in the Simien Mountains are below 10 °C. In the project area, which is essentially a highland region, the annual average is around 22 °C. Minimum monthly temperatures are recorded in December-February, ranging between 3 °C and 21 °C, and maximum monthly temperatures in March-April, ranging between 19 °C and 43 °C.

The mean temperature at the project area (950 m a.s.l.) has been computed by interpolating the records of Humera (600 m a.s.l.), Shire Endaselasia (1913 m a.s.l.) and Debark (950 m a.s.l.) based on the elevation of the different gauging stations.

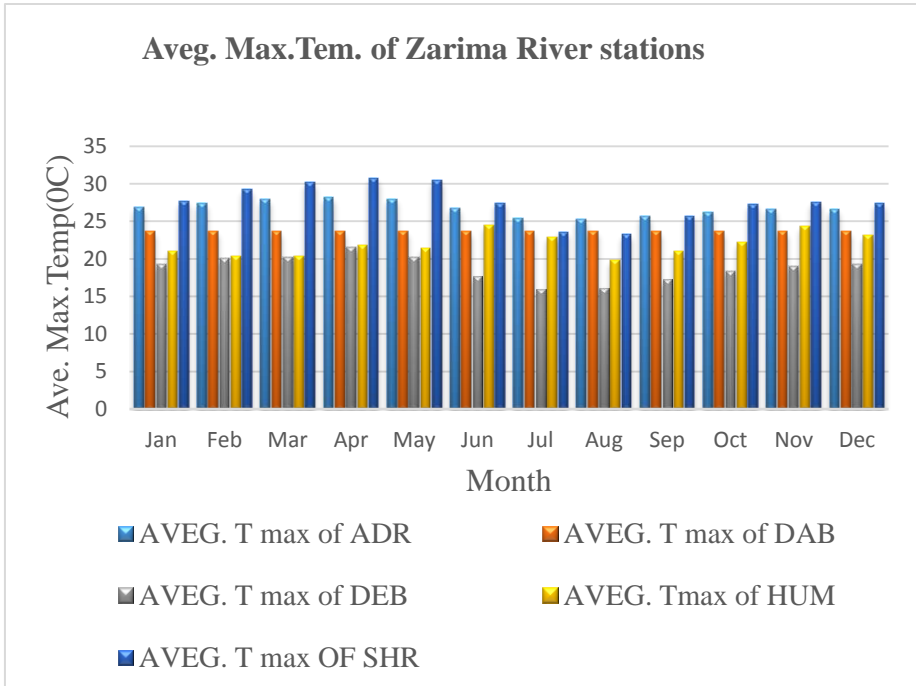


Figure 3.7. Long term mean monthly maximum temperature around zarima watershed (1992 – 2010)

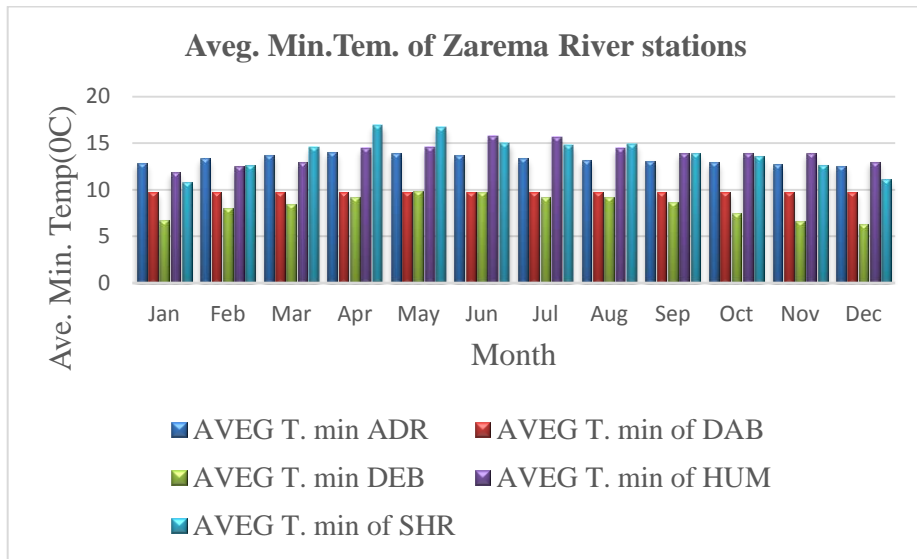


Figure 3. 8. Long term mean monthly minimum temperature around zarima watershed (1992 – 2010)

3.3. Input data and their sources

The required input data for this study were digital elevation model (DEM), Land use land cover map, soil map, stream flow and weather data. These data were available from various sources, which include; internet, Ethiopian national meteorological services agency (NMSA), Ethiopian ministry of water resources and others from GIS database. All the input data obtained for this study are discussed briefly in the following sub-section.

3.3.1. Digital elevation model

The topography is defined by DEM that describes the elevation of any point in a given area at a specific spatial resolution. DEM was derived from the NASA 30-meter Shuttle Topography Radar Mission (STRM) dataset. This DEM was used to delineate the watershed and analyze the drainage pattern of the land surface terrain. Sub basin parameters such as slope gradient, slope length of the terrain and the stream network characteristics such as canal slope length and width were derived from DEM.

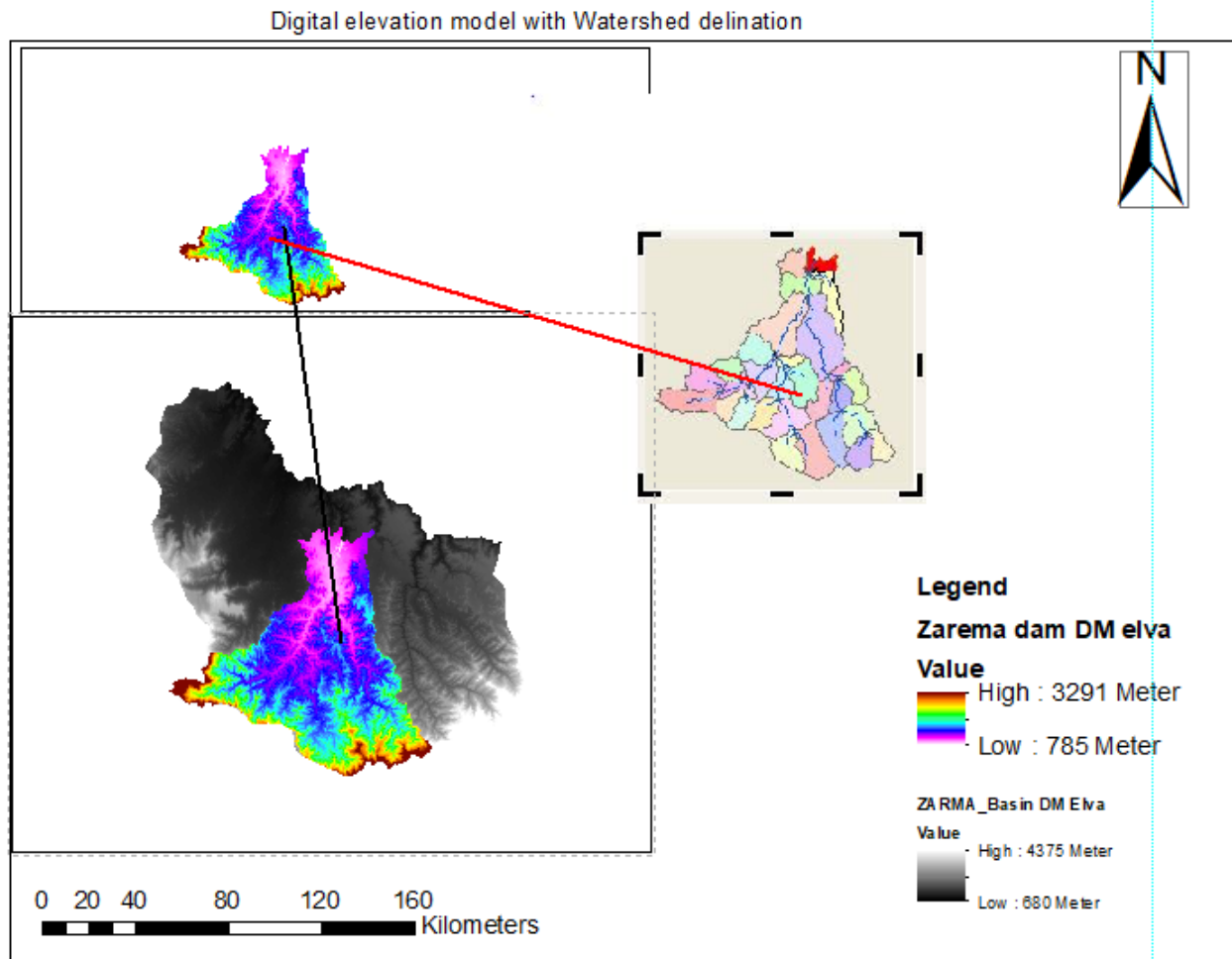


Figure 3. 9. Digital elevation model and Watershed delineation of project area.

3.3.2. Land use land cover map

The land use is one of the most important factors that affect runoff, evapotranspiration and surface erosion in a watershed. The land use map of the study area was obtained from Ministry of Water Resources. The reclassification of the land use map was done to represent the land use according to the specific land cover types and the respective crop parameter was selected from SWAT database.

Table 3. 2. Distribution and Area Coverage of land use/cover in Zarima Watershed

Land Use/Cover	Area in (ha)	(%) of Coverage Over the Watershed
Pasture (PAST)	664582	29.9335
Forest – Mixed (FRST)	92682	4.1745
Range – Grasses (RNGE)	378108	17.0304
Barren (BARR)	213686	9.62465
Forest – Deciduous (FRSD)	448803	20.2146
Agricultural Land Row Crops (AGRR)	422095	19.0116
Agricultural Land – Generic (AGRL)	239	0.0107648

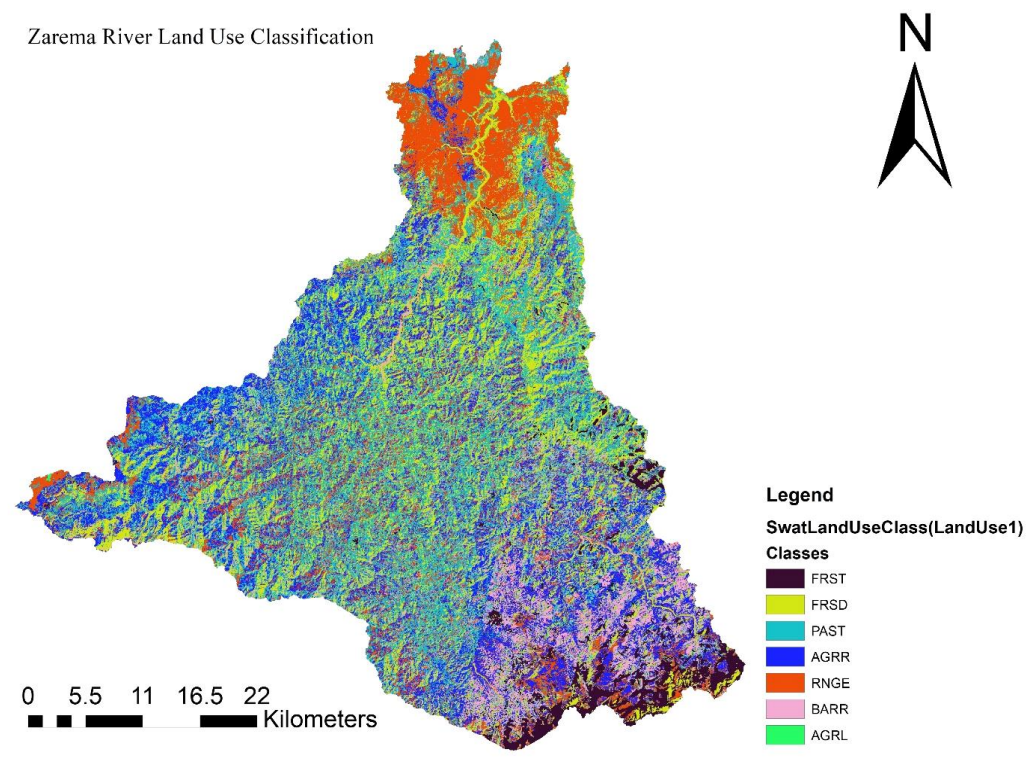


Figure 3. 10. Land Use Classification for Zarima River Project Area.

3.3.3. Soil map

The SWAT model requires different soil textural and physical-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of soil. These data were obtained mainly from the following sources: digital soil map from the Ministry of water and Energy (MOWE).

3.3.4. Stream network data

The stream network data set was digitized from topographic map of scale of the study area. The stream network dataset was superimposed onto the DEM to define the location of the stream network. Burning-in stream network operation is most important in situations where the DEM does not provide enough detail to allow the interface to accurately predict the location of the stream network.

3.3.5. Metrological data

Meteorological data is needed by the SWAT model to simulate the hydrological conditions of the basin. The meteorological data required for this study were collected from the Ethiopian National Meteorological Services Agency (NMSA) and MoWE. The meteorological data collected were precipitation, maximum and minimum temperature, relative humidity, and wind speed and sunshine hours.

Table 3. 3. List of Meteorological Stations in and around Zarima Watersheds

ID	Station Name	X-Coordinate(m)	Y-Coordinate(m)	ELEVATION(m.a.s.l)
1	Adi-Remtse	318435.37	1521096.3	2014
2	Debark	380612.58	1453362.83	2836
3	Humera	232657.28	1561948.05	760
4	Shire-endaselasi	424851	1558984.71	1897
5	Dabat	365160.88	1436217.8	2685

3.3.6. Techniques for estimating missing daily and monthly rainfall data

Spatial interpolation techniques are widely used methods for filling the gaps in daily rainfall series through estimating the unknown rainfall amount for a point from the known data from adjacent station. Paulhus and Kohler (1952) explored two methods of interpolation, the normal-ratio and 3-station-average, to fill the missing values in monthly rainfall data. Since, during my study spatial interpolation method were used.

3.3.7. Hydrological data

The hydrological data was required for performing sensitivity analysis, calibration and uncertainty analysis and validation of the model. The hydrological data were also collected from the Ethiopian MoWE hydrology section. It was the only hydrological data used for sensitivity analysis, calibration and validation.

3.3.8. Stream Flow in Zarima

The inflow at Zarima River has been extensively investigated in the previous studies. Two alternative and substantially different approaches have been adopted by WWDSE (Draft Feasibility Report [1]), using the flow data recorded by the stream gauge at Zarma station, implementing a long-term distributed hydrologic model based on multiple-gauge climatic records.

The present analysis is intended to consolidate the available information and summarize the relevant results. Recommendations on the inflow estimate to be adopted for the annual water balance are herewith included.

3.3.8.1. Stream Flow Gauge

The stream flow gauge installed at Zarima Station provides some stream flow records on the upper course of Zarima River. Two separate series, from 1972 to 1975 (with several gaps) and from 1992 to 2006 (again with important gaps) are available.

The data of Zarima River flow gauge presents several issues:

- i) A detailed survey of the control section is not available.
- ii) The rating curve has never been provided.

- iii) Potential modifications of the control section over the years, which may affect the rating curve, have not been reported.
- iv) The record book and the operational manual cannot be analyzed and certified.
- v) The measurement procedure and equipment's are unknown.

The records at Zarima station consist of 98 pairs of measurements concerning the water level or gauge height (m) and the flow discharge (m³/s). The analysis provides a reasonable correlation between the hydrometric measures, focusing on the set of pairs recorded in both the wet season (July to October) and dry season (November to June). As a result, the rating curve for the gauging station has been defined and adopted for further estimates. It must be noted that, along with the screening of the gauge records, a relevant discrepancy has been highlighted comparing the measurements collected in the period 1972–1975 with those of 1992-2006. This issue may be due to some modifications in the control section or a different measurement device. The set of pairs in the period 1972-1975 has been therefore discarded.

3.3.8.2. Flow Series at Zarima station

The rating curve at Zarima station has been used to obtain a 15 years long stream flow series, from 1992 to 2006. Nevertheless, within the available historical data several critical gaps exists. Such a short series is, moreover, not consistent with a reliable statistical analysis.

In the approach based on hydrologic correlations to be consistent data should be fill the gaps and extend the stream flow series. A bi-variate nonlinear (logarithmic) correlation has been investigated between the monthly average flow series and the monthly rainfall height recorded at Zarima station. A set of 60 pairs of records (flow-rainfall), successively screened into 45 significant data, was collected a processed. The analysis indicates a moderate correlation for the high flow season (July-October) and a relatively poor correlation for the low flow season (November-June), when the soil permeability and base flow storage are likely to affect the hydrologic response. Based on the available long series of rainfall records at Zarima station the flow series has been gap filled and extended.

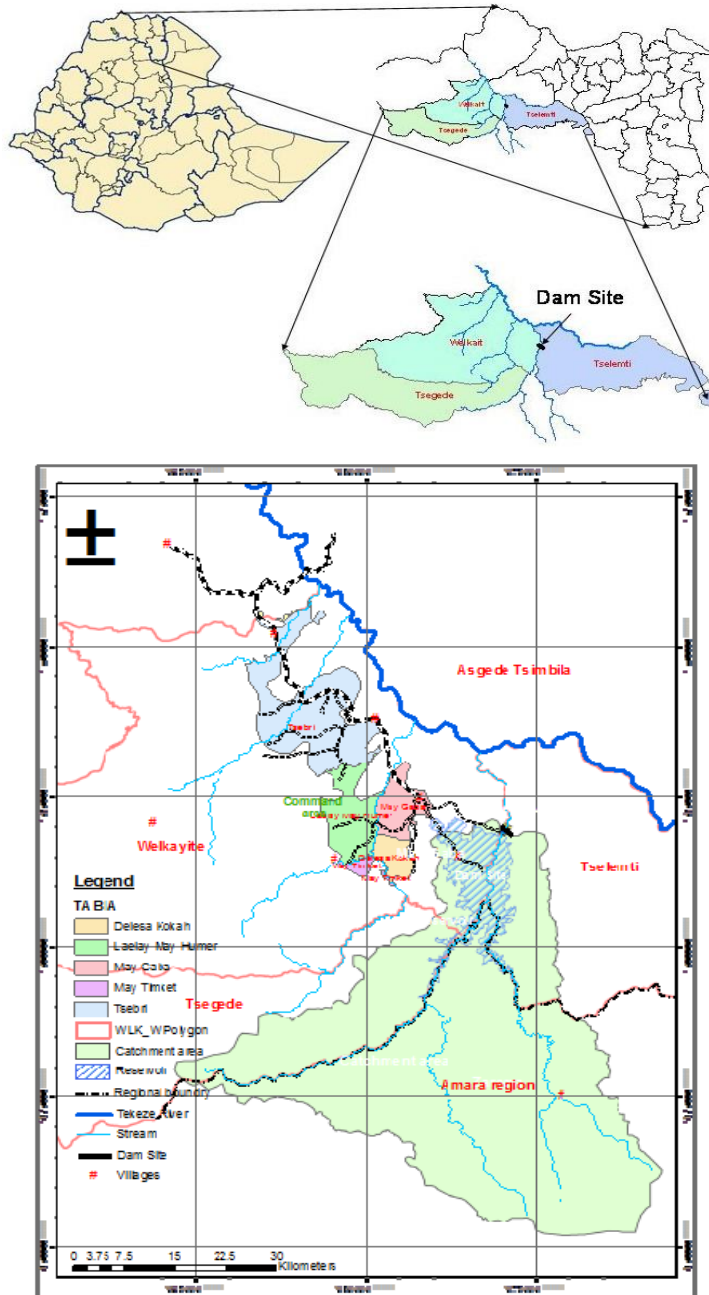


Figure 3. 4. Location of Zarima Dam Site and Its Watershed Delineation

3.3.9. Data Quality Analysis

Metrological observation data includes abnormal values and observation error caused by malfunctioning observation instruments.

Metrological data obtained indirectly through a process of conversion also includes errors caused by the analysis. Problems arise if users utilize hydrological data without being aware of the possibility of these observation (particularly when performing statistical analyses).

The quality of hydrological data is managed by performing reliability checks and by correcting missing data and abnormal values.

Methods of managing quality that are widely used include: obtaining ISO certification of observation instruments, system, organizations and having experts verify the hydrological data. Reliability checks with related data would be desirable for runoff.

It is possible to define a missing data detection function in a system, and although the detection of abnormal values can be partially automated, ultimately it must be done by expert check. It is essential to construct a data quality management system that can perform this task efficiently. And if an expert is to verify, supplement and correct the hydrological data, an extremely important aspect of the data quality management is the registration of auxiliary data in the database, defining when, how, by whom and why these tasks are performed.

3.3.10. The Data-Screening Procedure

The data screening procedure consists of four principal steps. These are:

1. Do a rough screening of the data and compute or verify the totals for the hydrological year or season.
2. Plot these totals according to the chosen time step (e.g. month, year, and season) and note any trends or discontinuities.
3. Test the time series for absence of trend with Spearman's rank-correlation method
4. Apply the F-test for stability of variance and the t-test for stability of mean to split, non-overlapping, sub-sets of the time series.

These steps form what we call the 'basic procedure'. If necessary, one can expand the basic procedure to include two additional steps. These are:

- ✚ Test the time series for absence of persistence by computing the first serial-correlation coefficient.
- ✚ Test the time series for relative consistency and homogeneity with double-mass analysis.

3.3.10.1. Rough Screening of the Data

The basic procedure begins with an initial, rough screening of the data. For rainfall totals, we advise tabulating daily observations by region (but observations from several collection stations should be available!). This will allow visual detection of whether the observations have been consistently or accidentally credited to the wrong day, whether they show gross errors (e.g. from weekly readings instead of daily ones), or whether they contain misplaced decimal points (Stol 1965). An analysis of the frequency distribution of one-day rainfall might also be useful. Other observations (e.g. of water levels) have their specific sources of error. One should be aware of these and the methods of detecting them.

Verifying the completeness of the data and checking the observer's arithmetic when computing totals is a useful exercise. One should particularly keep in mind the very real difference between 'no observation' and 'observation = 0'; both may have been entered as '-' (dash). Estimates of missing observations should be clearly marked as such.

In most cases, it is convenient - and perfectly acceptable - to use yearly totals as long as by 'year' one means 'water year' (hydrological year). This definition removes any risk of the seasons' being split over two years. Nevertheless, it can sometimes be better to analyze a specific period of a year (e.g. the wet or dry season, or even a particular month) if that period is a critical one in the envisaged water development scheme.

3.3.10.2. Plotting the data

After doing a rough screening of the data, one plots them on arithmetic or semi-logarithmic graph paper.

3.3.10.3. Test for Absence of Trend

After plotting a time series, one must be sure that there is no correlation between the order in which the data have been collected and the increase (or decrease) in magnitude of those data. It is common practice to test the whole time series for absence of trend.

Although one can choose to test only specific periods of the time series if these show signs of a possible trend, we advise against testing periods that are too short (ten to fifteen years).

3.3.10.4. Tests for Stability of Variance and Mean

The test for stability of variance is done first there are two reasons for this sequence:

Firstly instability of the variance implies that the time series is not stationary and, thus, not suitable for further use.

Secondly, the test stability of mean is much simpler if one can use a pooled estimate of the variances of the two sub-sets.

The test statistic is the ratio of the variances of two split, non-overlapping, sub-sets of the time series. The distribution of the variance-ratio of samples from a normal distribution is known as the F, or Fisher, distribution. Even if the samples are not from a normal distribution, the F-test will give an acceptable indication of stability of variance.

$$Ft = \frac{S1^2}{S2^2}$$

Where S^2 is Variance Note that, to compute Ft, it is irrelevant whether one uses the sample standard deviation, S, or the population standard deviation, S.

We give here two convenient formulae for computing the sample standard deviation, s, namely:

$$S = \frac{\left[\sum_{i=1}^n (Xi^2) - \left(\sum_{i=1}^n \frac{(Xi)^2}{n} \right) \right]^{0.5}}{n - 1}$$

Where x, is the observation, n is the total number of data in the sample, and X is the mean of the data.

3.3.10.5. The t-Test for Stability of Mean

The t-test for stability of mean involves computing and then comparing the means of two or three non-overlapping sub-sets of the time series (the same subsets from the F-test for stability of variance).

$$Tt = \frac{X1 - X2}{\left[\frac{[(n1 - 1)S1^2 + (n2 - 1)S2^2]}{n1 + n2 - 2} * \left(\frac{1}{n1} + \frac{1}{n2} \right) \right]^{0.5}}$$

Where n is the number of data in the sub-set, X the mean of the sub-set, and S^2 its variance.

The test statistic t, is valid for small samples with unknown variances. These variances can, however, differ only because of sampling variability if the t-test is applied in this form. This means that the variances of the sub-sets should not differ statistically: hence' the requirement that the time series must be tested for stability of variance before it is tested for stability of mean.

3.3.11. Tests for Relative Consistency and Homogeneity

3.3.11.1. Test for Homogeneity

This would require an analysis of the process that generated the data, including the observational practices (which are causes of inconsistency) and the physical changes (which are causes of non-homogeneity).

A time series of hydrological data is relatively consistent if the periodic data are proportional to an appropriate simultaneous time series (Chang and Lee 1974). In other words, Relative consistency means that the hydrological data at a certain observation station are generated by the same mechanism that generated similar (e.g rainfall/rainfall) or related (e.g rainfall/runoff) data at other stations.

Relative consistency is a true consistency only if there is physical evidence to support this.

Examples of a possibly true and relatively consistent relation are the proportionality between rainfall and rainfall, computed runoff and observed runoff, and rainfall and sediment concentration in a river.

To determine relative consistency, one compares the observations from a certain station with the mean of observations, the smaller the chance that inconsistent data from a particular one will influence the validity of the average of the pattern.

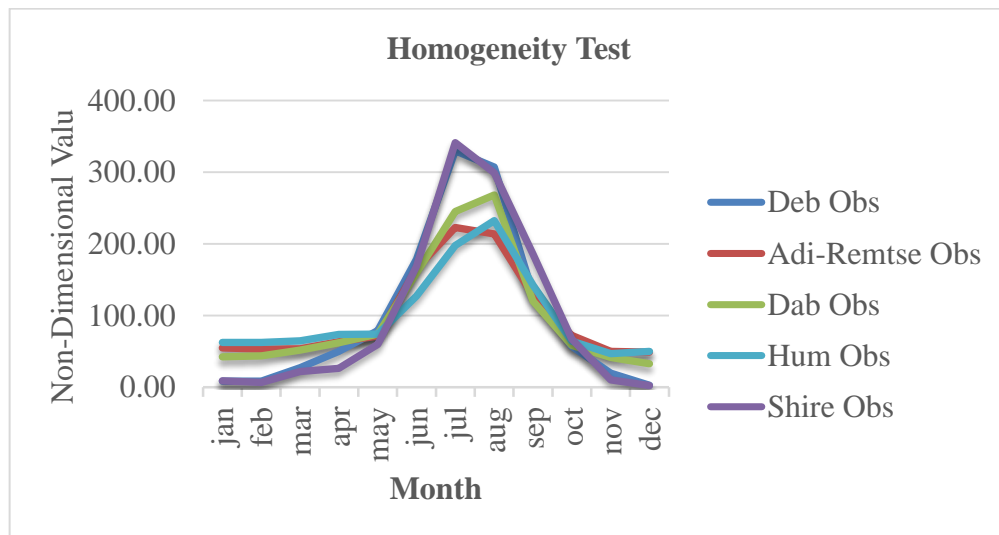


Figure 3. 5. Non – Dimensional Plot for Homogeneity Test of RF Stations

3.3.11.2. Double-Mass Analysis

Double-mass analysis assumes a linear relation between time series of hydrological data. As this assumption may not be valid at all rates of accumulation, it must be verified. Rainfall data are usually proportional to totals nearby stations in the same hydrological area.

A linear relation between two variables that include the pair $x = 0$ and $y = 0$ can be expressed as:

$$y = b * x$$

Where, b is a proportionality factor.

If y is the time series to be tested, x the time series of the pattern, and $i=0, \dots, n$ the number of data pairs and the index of the time steps, then the plot of $Y_i = \sum(y_i)$ (the mass of y) against $X_i = \sum(x_i)$ (the mass of x) will result in a broken line through the origin, with an average slope $B_{av} = \frac{Y_n}{X_n}$. The line passes through the origin because the sum of the data at time zero is zero for both X and Y.

Double-mass analysis is used not only to verify the relative consistency of a time series, but also to find correction factors for errors and fill in gaps.

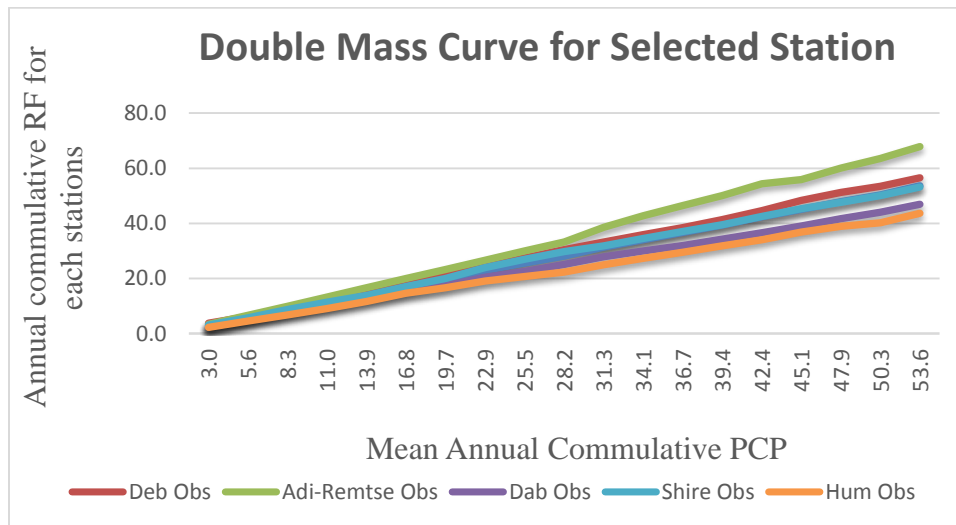


Figure 3. 6. Double Mass Curve graph for consistency test

3.4. Soil Water Relationship

Water that enters the soil may move along various path ways, including: removal from soil by plant uptake or evaporation, percolation past the soil profile to become aquifer recharge, or lateral movement in the profile and contribute to stream flow. SWAT uses a kinematic storage model developed by Sloan et al. (1983) to estimate lateral subsurface flow. This model simulates subsurface flow in a two-dimensional cross –section along a flow path down a steep hill slope. SWAT uses storage routing methodology to calculate percolation for each soil layer in the profile. If the soil is frozen during the simulation period, percolation in the soil layer is equal to zero (Neitsch et al., 2005).

3.4.1. SWAT model

3.4.2. Soil and water Assessment Tool (SWAT) Model Description

SWAT is a physically based, catchment scale, continuous model developed by the USDA Agricultural Research Service (ARS) to quantify the impact of land management practices on water, sediment, and agricultural chemical yield in large, complex water-sheds with varying soil, land use, and management conditions over a long period of time that runs on a daily time step. The major components of the model including hydrology, weather, soil erosion, plant growth, nutrients, pesticides, land management, and stream routing.

Spatial variability is integrated in the watershed by delineating the watershed into a number of sub watersheds based on the topography. Each sub-watershed is further discretized into hydrologic response unit (HRUs) based on threshold percentages. HRUs are distinctive combination of categorized land uses, soil types and slope in a sub-watershed. Surface runoff, sediment yield, soil water content, nutrient cycles, crop growth and agricultural management practices are simulated for each HRU and then aggregated for the sub-basin.

3.4.3. Reason for selection of SWAT

The reasons behind for selecting the SWAT model for this study area;

- The model was applied for modeling, watershed in different parts of the world.
- The model simulates the major hydrological process in the watersheds
- It is less demanding on input data, and time consuming
- It is readily and freely available.

SWAT is a semi-distributed model that can be applied at the river basin scale to simulate the impact of land management practices on water, sediment and agrochemical yields in large watersheds with varying soils, land use and agricultural conditions over extended time periods of time (Arnold et al., 1998). The model has been used to simulate runoff and the impact of alternative input data such as changes in land use, land management practices (Neitsch et al., 2005; Arnold et al., 1998).

SWAT is a continuous time model able to simulate long-term impacts of land use, land management practices and buildup of pollutants (Neitsch et al., 2005). These qualities of the SWAT model aid in the quantification of long term impacts of land use changes and variations in rainfall and air temperature on the hydrology of the Zarima River basin.

The other core motive for the selection of SWAT model is sediment erosion from each hydrologic response unit (HRU) are stimulated using the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt 1977). Hence, this equation substitutes the normal Universal Soil Loss Equation's (USLE) rainfall factor with a runoff think about order to estimate event-based sediment yield estimates (Neitsch, S, Arnold, J and Kiniry, J & Williams, J, 2005). MUSLE predicts sediment erosion when there's surface water runoff and it reduces the erosion estimates when there's snow cover (Dar-Al Omran, 2011).

3.4.4. MODEL SET UP

SWAT2012 Version was used in this study to estimate all the components of watershed delineation. Sub-basin and stream definition were undertaken with the automatic delineation tool incorporated in Arc SWAT. The tool uses DEM information to define basin boundaries and stream flow direction. A total of 33 sub-basins were delineated for the study area. These sub-basins were further subdivided into 858 HRUs by fixing a threshold value of 0% for land use, soil type and slope. Slopes were divided into three classes of 1% to 10%, and greater than 10%. Agricultural management practices including crop rotations, planting and harvest dates, dates and implements used for tillage operations, and amounts and timing for fertilizer application were scheduled and used to build the management file for each field.

The model setup involved data preparation sub basin dis-cretization, HRU definition, parameter sensitivity analysis, and calibration uncertainty analysis. SWAT allows variety of various physical processes to be simulated during a watershed. So as to adequately simulate hydrologic

processes during a basin, the basin is split into sub basins through which streams are routed. The sub units of the sub basin are mentioned as hydrologic response units (HRU) which are the unique combination of soil and land use characteristics and are considered to be hydrological homogeneous. The model calculations are performed on a HRU basin and water quality variables are routed from HRU to sub basin and subsequently to the watershed outlet.

3.4.5. Watershed Delineation and HRU

The first step creating SWAT model input is watershed delineation from digital elevation model. Inputs entered into the SWAT model are organized to possess spatial characteristics. The SWAT model provides 3 spatial levels these are; The Watershed, the sub basin and hydrologic response units (HRUs). Each level is characterized by a parameter set and input file. The most important spatial level, the watershed, refers to the whole area being represented by the model. For modeling purposes, a watershed could also be partitioned into variety of sub watersheds or sub basins.

The utilization of sub basins during a simulation is especially beneficial when different areas of the watershed are dominated by land uses or soils dissimilar enough in properties to impact hydrology. By partitioning the watershed to at least one another spatially. Moreover, the choice and implementation of appropriate conservation measure are often aided by reliable predictions of watershed response under different land use scenarios.

The watershed delineation is supported an automatic delineation procedure employing 30m X 30m digital elevation model (MEM) setup, stream definition, outlet and inlet definition, watershed outlet selection and calculation of sub basin parameters. Hence, definition of watershed, sub basin boundaries and streams is set by selecting a threshold area was taken and therefore the watershed outlet is manually added and selected for finalizing the watershed delineation. With this information the model automatically delineates the watershed with 33 sub watersheds for simulations. HRU After the delineation of watershed is partitioned in to hydrologic response units (HRU)

➤ The SWAT model application can be divided into six steps:

- (1) Data preparation,
- (2) Sub-basin discretization,
- (3) HRU definition,
- (4) Parameter sensitivity analysis,
- (5) Calibration and validation, and
- (6) Uncertainty analysis the flowchart showing the modeling steps is given below

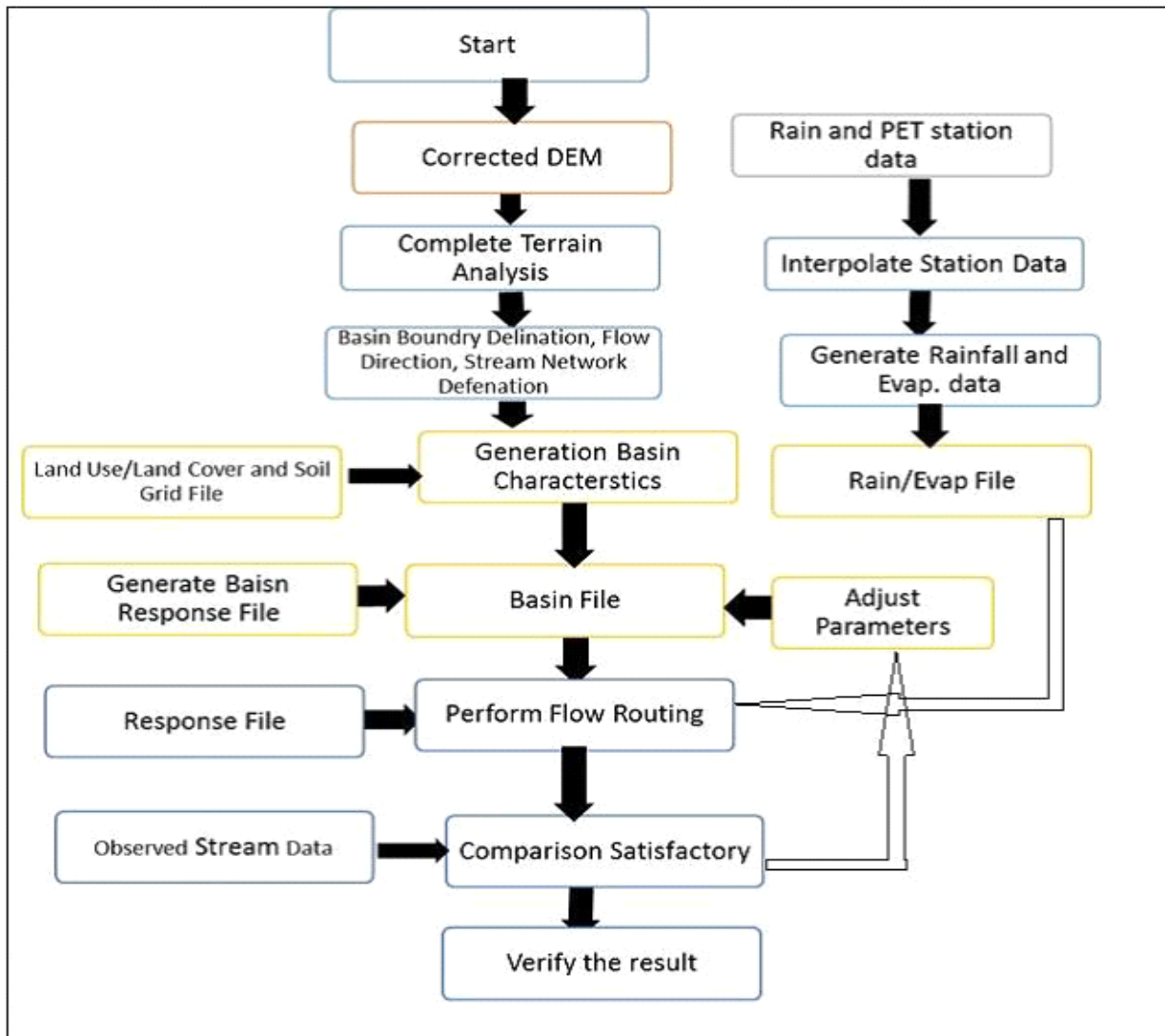


Figure 3. 7. Flow chart of the modeling process inputs and outputs.

3.5. Sensitivity Analysis

Sensitivity analysis is used to explain how the variation in model output can be attributed to Different sources of variation in the model input. However, it is important to note that some of the results of sensitivity analysis, depending on their placement in model algorithms, may not in fact have significant physical meaning. In this study the sensitivity analysis concerning daily flow rate was performed on different SWAT parameters.

Sensitivity analysis helps in identifying a series of parameters for the SWAT model calibration. In addition, performing sensitivity analysis and identifying sensitive parameters can help us to better explain why and how the model algorithm responds to land use change and why some parameters become more sensitive than the others under certain land use scenarios.

3.6. Calibration and validation

In hydrologic simulation there are two main exercises that must be successfully achieved before using the model; these are calibration and validation of the model. Calibration is an iterative exercise used to establish the most suitable parameter in modeling studies. The exercise is vital because reliable values for some parameter can only be founded by calibration (Beven.K, 1989). The model parameter changed during calibration is broadly classified into physical and process parameters. Physical parameters represent measurable properties of the basin such as area and slope of the basin. On the other hand, the process parameter represents watershed characteristics that are not directly measurable.

Model validation is the process of demonstrating that a given site specific model is capable of making sufficiently accurate simulation. This implies the application of the model without changing the parameter values that were set during calibration. According to (Refsgaard, 1996), there are four hierarchal schemes for systematic validation of hydrologic models: these are split sample test, differential-split sample test, proxy-basin test and proxy-basin differential split-sample test. The validation hydrograph is compared with the observed hydrograph for the validation period; if the fit is acceptable then the model prediction is valid. Therefore, based on the available data, I were select 70% of the data for calibration and 30% of the data is for validation will use in this study.

The model calibration data process were used from 1992 to 2002 and validation model data were used from 2003 to 2010.

3.6.1. Model Performance Evaluation

Successful application of hydrologic model is highly dependent on the sensitivity analysis and calibration of the model parameters. The matches between simulated and observed results were assessed via graphical and statistical techniques. The SWAT plus package, was applied for sensitivity analysis, calibration and validation of the model.

The package provides tools for linking SWAT project with R, thereby enabling the execution of SWAT simulations and controlling changes in model parameters, simulation periods and time steps. The goodness of fit between the simulated and measured data was evaluated by the equations representing these relationships are from the different performance measure in my study were used below.

3.6.1.1. Coefficient of Determination (R^2)

Coefficient of determination measures both the strength of the linear relationship between observed and estimated values. This is calculated by equation (1).

$$R^2 = \left[\frac{\sum_{i=1}^n (Q_{oi} - Q_o)(Q_{ei} - Q_e)}{\sqrt{\sum_{i=1}^n (Q_{oi} - Q_o)^2} \sqrt{\sum_{i=1}^n (Q_{ei} - Q_e)^2}} \right]^2 \dots \dots \dots \text{Equation(1)}$$

Where, Q_o = Observed Annual Average Flow (m^3/s)

Q_e = Estimated Annual Average Flow (m^3/s)

Q_{oi} = Observed Monthly Average Flow of month i

Q_{ei} = Estimated Monthly Average Flow of month i

n = Number of data. As number of months are 12, $n = 19$ in this case.

The coefficient of determination (R^2) is the square of the coefficient of correlation.

Criteria: Larger the value of R^2 , better the performance.

CHAPTER 4

4.1. RESULT AND DISCUSSION

The investigated period for this study of zarima watershed using a time series dataset of 18 years in between 1992 and 2010. The first two years which is from 1994 to 2010 of the modeling were used for ‘model warm-up period (used for flashing of precipitation in the watershed). The mean annual precipitation for zarima catchment during this period was 535.8 mm. the maximum annual precipitation was 662.734 mm (Adi-Remtse) observation station while the minimum precipitation was 435.211 mm (Humera) observation station. The mean maximum daily temperature was 27.525 °c and the men minimum daily temperature was 18.735 °c.

Data for the period from 1994 to 2002 were used for calibration and dataset from the period of 2003 to 2010 were used for validation. The watershed was subdivided into 33 sub basins based on a 2,072.9 km² threshold area.

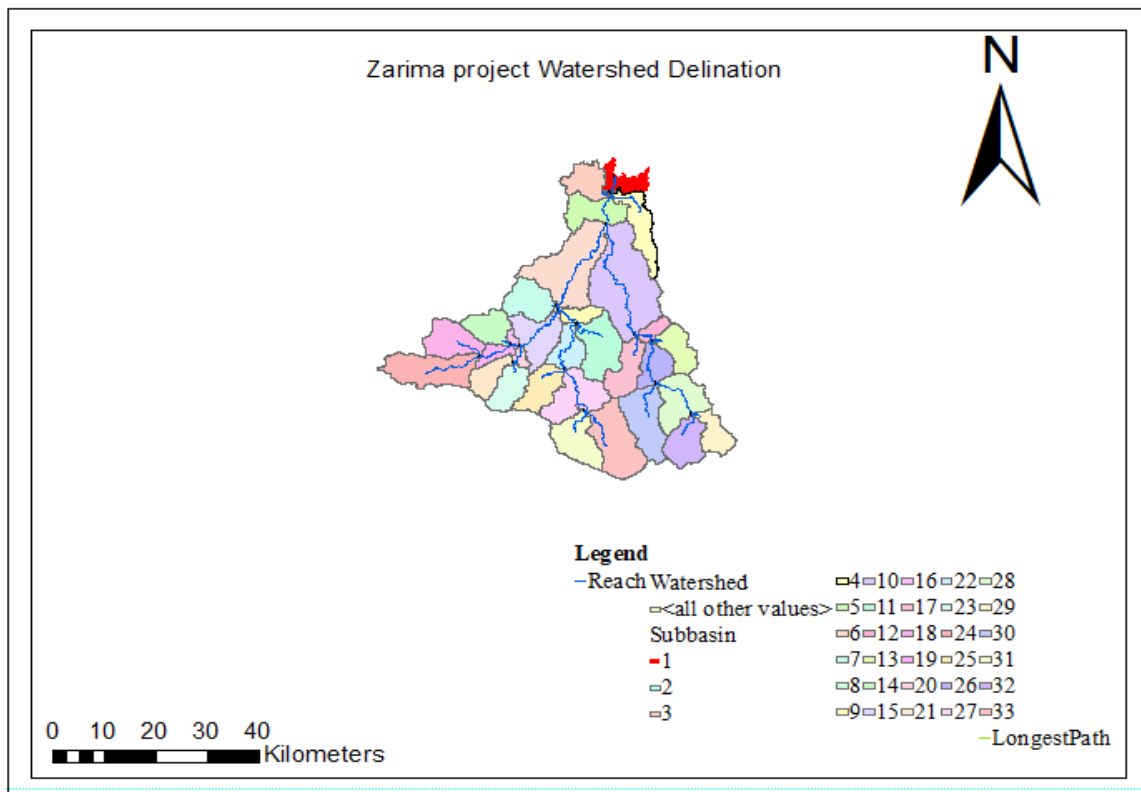


Figure 4.1. Zarma project watershed and it's subdivided into 33 sub basins.

4.2. Stream Flow Modeling

4.2.1. Sensitivity Analysis

Sensitivity analysis results showed SCS runoff curve number for moisture condition II (CN2), threshold depth for return flow of water in the shallow aquifer (GWQMN), available water capacity of soil layer (SOL_AWC) and peak rate adjustment factor (PRF) as the most sensitive parameters for surface runoff, ground water flow, soil moisture.

A total of 9 parameters were selected for stream flow drawn by SWAT model calibration based on the sensitivity analysis results.

Table 4. 1. Sensitivity analysis result for stream flow in Zarima Watershed.

No	Flow parameters	Definition	Value	Unit
1	CN2	Initial Soil conservation service(SCS) curve	12	%
2	Esco	Soil evaporation compensation factor	0.72	_
3	Alpha_Bf	Ground Water	0.33	Days
5	Gwqmn	Threshold water level in shallow aquifer for base flow	3450	mm
6	SOL_AWC	Available Water Capacity	0.38	%
7	CH_N2	Manning's 'n' Value	0.21	
8	SURLAG	Surface runoff lag coefficient	9	Days
9	SOL_K	Saturated hydraulic conductivity	0.02	%

For model predictions to be valid and reliable, the model parameter values need to accurately reflect the hydrological systems they represent. However, not all model parameters can be measured directly. The parameters selected during sensitivity analysis were used for model calibration and validation.

The R^2 value of 0.56, PBIAS of 12.8% and NSE value of 0.47. Based on the performance criteria table $\frac{3}{4}$ the coefficient of correlation (R^2) indicates unsatisfactory, while percentage volume bias (PBIAS) is acceptable, Nash Sutcliff efficiency (NSE) and other criteria performance is not reliable for validation and calibration, since, further suggest to be a good model performance.

4.2.2. Stream Flow Calibration

Stream flow was checked after every calibration step to evaluate the effect of each calibration step on total flow. The calibrated parameters for surface runoff, ground water flow and soil moisture were used for total stream flow calibration. Furthermore, after each calibration step, stream flow simulation was evaluated to ascertain the influence of calibration steps on the model stream flow simulation. The results of stream flow simulation in every step of calibration are shown in table below.

The final stream flow calibration results showed a good fit between the simulated and observed flow, with NSE, R^2 , KGE and RMSE of 0.998, 0.96426, 0.9897 and 0.433 L/s.

The hydrograph of the calibration period of the observed and simulated flow in monthly basis shows (Figure 4.1), the model slightly overestimates a number of monthly peak flows of the years; like May 1994, Dec 1994, Jul 2002 and Aug 1999. Also slightly underestimate the flows, like Mar 1993, Jul 1995 and Sep 1996 of the year's monthly mean flows.

This fluctuation might exist due to the model's low capacity to capture peak rainfall event, the information qualities occurred during filling missed data and error during measurement records.

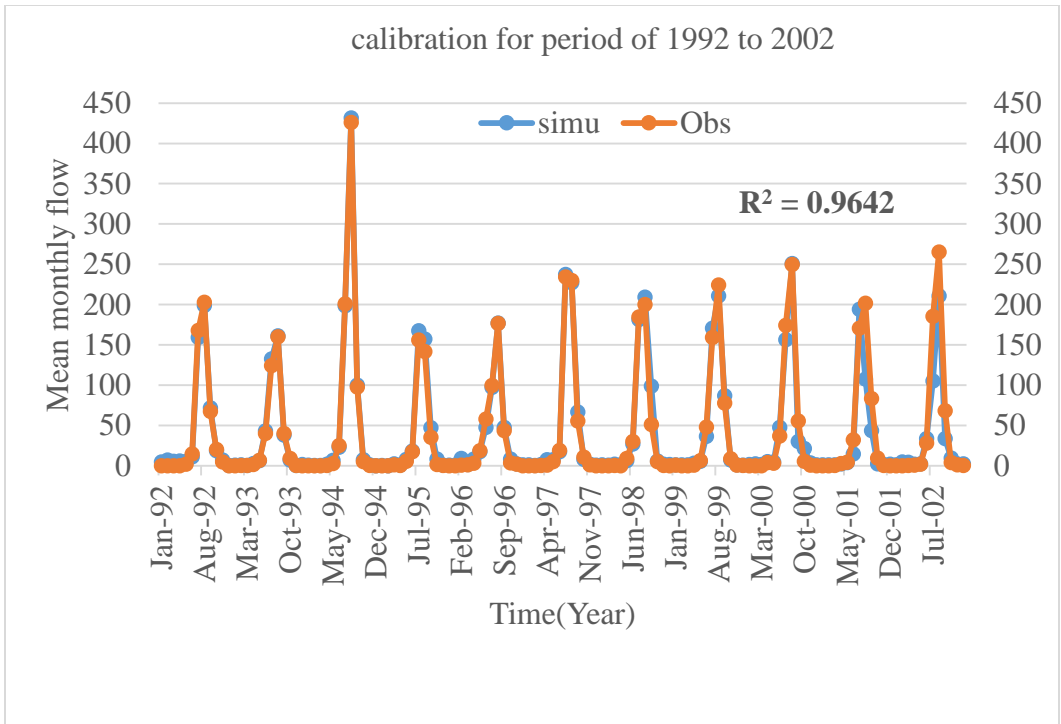


Figure 4.2. Observed and simulated stream flow hydrograph on mean monthly time step during the calibration period.

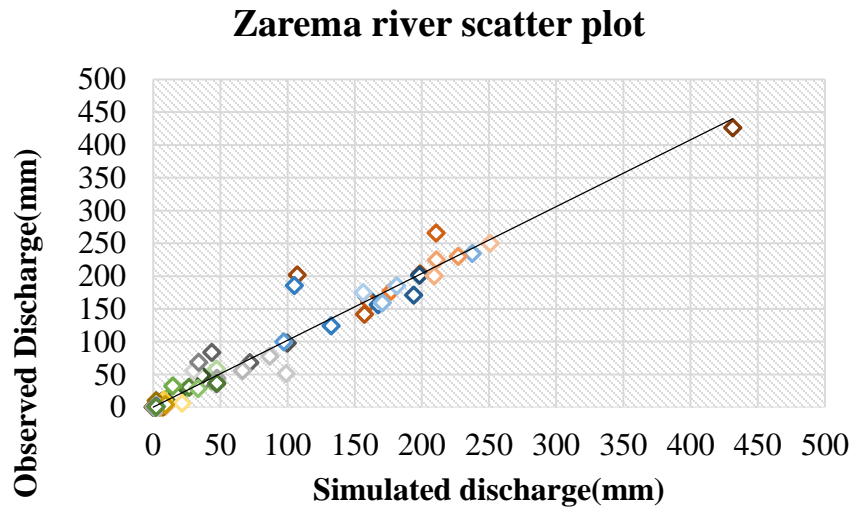


Figure 4.3. Regression and 1:1 line fit of observed and simulated monthly stream flow during the calibration period.

Observed data (OBS), Default model (DM), after runoff calibration (ARC)

Table 4. 2. Effect of each calibration on stream flow.

Calibration Step	Mean(m)	S.D(m)	NSE	R²	KGE	MAE(m)	RMSE(m)
Observed Data	41.978	76.36					
Default Model	52.35	89.42	0.47	0.56	0.973	18.74	
After Runoff Calibration	41.256	73.54	0.998	0.9642	0.9897	29.44	433.28

4.2.3. Stream Flow Validation

The model was validated for total stream flow at the outlet. The model performance was good for the validation period as shown in the figure below. The NSE and R² is greater than 0.75. The PBIAS was -8.586 with RMSE was 0.216 L/s.

The hydrograph of the validation period of the observed and simulated flow in monthly estimation, the model under estimates a number of the height flows of the months, like January 2003, November 2003, April 2004, February 2005, December 2005, march 2007, January 2008, April 2009, February 2010 and December 2010. A number of the medium and low flows were underestimated and over estimated by the model within the years because of the model's low capability to capture peak rainfall event, the information qualities occurred during filling missed data and error during measurement records.

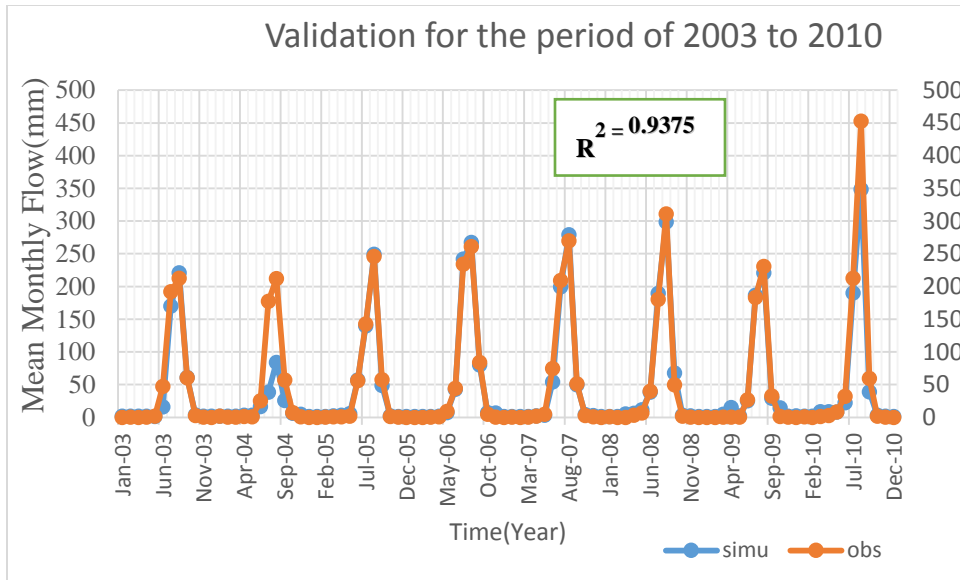


Figure 4.4. Observed and Simulated Stream Flow Hydrograph on Mean Monthly Time Step During Validation Period.

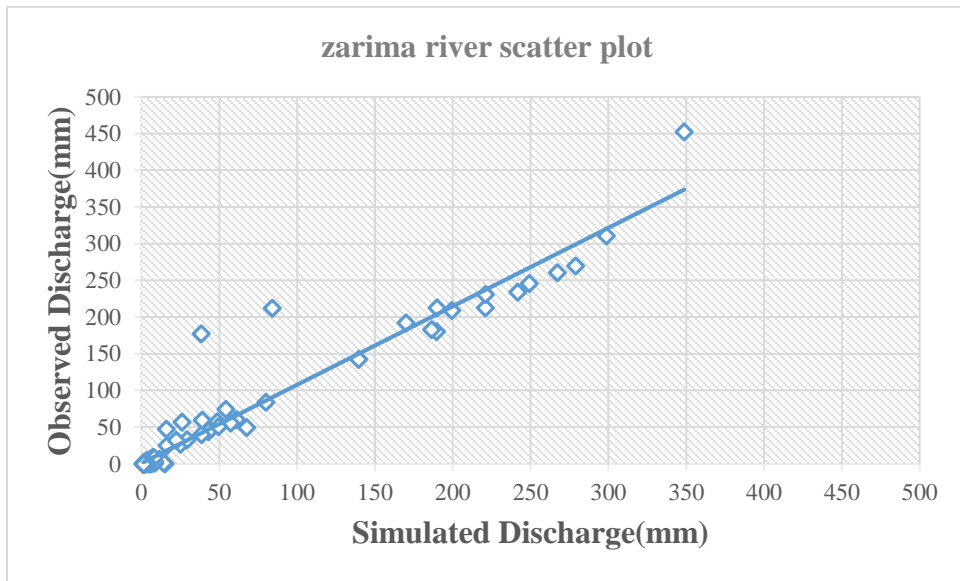


Figure 4.5. Regression and 1:1 line fit of observed and simulated monthly stream flow during the validation period.

Table 4. 3. Effect of each validation on stream flow.

Validation Step	Mean(m)	S.D(m)	NSE	R²	KGE	MAE(m)	PBIAS
Observed Data	47.948	86.463					
After Runoff Validation	43.832	81.148	0.999	0.9375	0.9997	20.8	-8.586

4.2.4. Effect of Calibration Step on Hydrological Components

The results of stream flow simulation after each calibration step are shown in Table 4/2.

The most significant improvement in stream flow results is observed after runoff calibration (ARC). The NSE value improved from 0.47 to 0.998, while R² value is 0.9642 from the default previous value was 0.56. Since, the curve number (CN2) was the most sensitive parameter for stream flow, these results suggest that adjusting CN2 value is sufficient to obtain a good flow calibration for the zarima catchment.

4.2.5. Flow Calibration and Validation

Both calibration and validation methods showed good results in stream flow simulation as shown in table below.

(Mean (M), Standard deviation (S.D), Nash – Sutcliffe efficiency (NSE), Coefficient of determination (R²), Kling – Gupta (KGE), and Mean Absolute Error (MAE).

Table 4. 4. Evaluation statistics for the calibration and validation long – term stream flow period.

Performance Criteria	Mean(m)	S.D(m)	NSE	R²	KGE	MAE(m)
Calibration (Monthly)	41.256	73.54	0.998	0.9642	0.9897	29.44
Validation (Monthly)	43.832	81.148	0.999	0.9375	0.9997	20.8

Table 4. 5 . Annual surface runoff simulated and observed flow.

No	Description	Annual Surface Runoff (m3/s)
1	Simulated flow	42.544
2	Observed flow	44.963

CHAPTER 5

2.1. CONCLUSION AND RECOMMENDATION

2.1.1. Conclusion

This study investigated the impact of incorporating runoff ground water flow, initial soil conservation service (CN2) and Soil evaporation Compensation factor data during SWAT model calibration and validation method is presented statistically and graphically.

The results of this study show that both methods can be successfully used in SWAT model calibration for stream flow. Since, in this simulation the performance index for calibration and validation method which is, R^2 , NSE and KGE values were greater than 0.75. Due to this

A reliable estimate of the inflow at Zarima River is a prime concern. The annual inflow volume, as well as, the flow regime over the year represent. In particular concerning the flow series computed by implementing the flow records of Zarima gauging station.

The study used the sample with different thresholds is a good method of estimate stream flow in zarima sub-basin because its limitation of data and difference of rainfall and condition of the basin. The model needs to use the data of the area close by the control of sub-basin, so the zarima sub-basin is distribute into many sub-basins (33) to make good proportion. Despite data limitation, the SWAT model produced good simulation results for monthly time steps.

In general, SWAT model predictions are acceptable and thus can be considered as a planning tool for watershed management. It is a capable tool for further analyzing of the hydrological processes and water resources in the study area.

2.1.2. Recommendation

The study area, as well as the lower part of the Tekeze basin, critically lacks of gauging stations for direct measurements of rainfall and river discharge. The available records are extremely poor in quality (short series length) and scarcely consistent (excessive gaps).

The uncertainties regarding the spatial representatives of meteorological and hydrological gauging stations end in uncertainties in estimates of areal rainfall estimation which is to be accounted so as to enhance the standard of selections made.

The network of station should be redesigned and can hardly be implemented to describe the basin hydrology. This important evidence and critical problem in this project should be addressed in the next studies for further detailed error correction, which is upgrade human skill capacity, modernized material resources and other basic necessary material will be fulfilled the model prediction output depends on those on the above reliable standard of input file data.

New and automatic gauges should be early installed along with the development of the project area to beneficially increase the dataset of records in the previous five years, but this good development would not supported by skilled man, consistent and series dataset record.

The station available new and automatic gauges are:

Zarima gauge (hydrometric) and rainfall gauge (pluvio_metric) installed at zarima.

The rainfall gauge installed at Adi_Remets. Both the stations, however, present relatively short series of records and intermittent gaps which is strongly affect the data reliability and consistency. One among the constraints in conducting this thesis work was lack of measured data series (continuous) gauging and stream flow data inside the catchment. To integrate and enhance the available rainfall records some gauging stations located outside, upon this fairly close and enough data availability from zarima basin have been considered. It had been clear that use of more accurate data will improve the modeling approach. So, responsible bodies should give due attention to possess enough hydrological and metrological data within the study area.

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