Addis Ababa University
Addis Ababa Institute of Technology
School of Graduate Studies

HYDROLOGICAL MODELLING IN UNGAUGED CATCHMENT

(IN CASE SULUH), TIGRAY

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A Thesis submitted to
The school of civil and Environmental Engineering

Presented in fulfillment of the Requirements for the degree of Master of Science in Civil and Environmental Engineering (Major Hydraulic Engineering)

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This is to certify that the thesis prepared by Tewele G/tsadkan, entitled: Hydrological Modelling in Ungauged Catchment (In Case Suluh), Tigray and submitted in partial fulfillment of the requirements for the degree of Master of Sciences in Civil and Environmental Engineering (Major Hydraulic Engineering) complies with the regulations of the university and meets the accepted standards with respect to originality and quality.

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DEDICATION

I Dedicate This Work to My beloved family, especially to my Father and Grand mom who are the reasons for who I am!

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Abbreviations

CART- Classification and Regression Tree

CN -Curve Number

CN- Curve Number

DA_RCHG-Deep aquifer Recharge

DEM -Digital Elevation Model

DMC -Double Mass Curve

ENS -Nash-Sutcliffe Efficiency

ET-Actual Evapotranspiration

FAO -Food and Agricultural Organization

GDEM -Global Digital Elevation Model

GIS - Geographic Information System

GLUE -Generalized Likelihood Uncertainty Estimation

GW_RCHG- Ground Recharge

GWQ -Ground Water Flow

HBV -Hydrologisika Bayraans Vattenbalans-avediling

HEC-HMS Hydraulic Engineering Centre-Hydrologic Modeling System

HRUs- Hydrologic Response Units

LAT -Latitude

LATQ- Lateral flow

LONG -Longitude

LULC -Land Use Land Cover

MCMC -Markov Chain Monte Carlo

MoWIE- Ministry of Water Irrigation and Electricity

ParaSol -Parameter Solution

PCCs -Physical Catchment Characteristics

PERC-Percolation

PET -Potential Evapotranspiration

PPU -Percentage Prediction Uncertainty

PRECIP-Precipitation

R^2 -Coefficient of Determination

REVAP - Revap

SCS -Soil Conservation Service

SOLAR- Solar Radiation

SRTM -Shuttle Radar Topography Mission

SUFI2-Semi-Automated Sequential Uncertainty Fitting ver.2

SURQ -Surface runoff

SW_END- Final Soil water content

SW_INIT-Initial Soil water content

SWAT- Soil and Water Assessment Tool

SWAT-CUP- Soil and Water Assessment Tool-Calibration and Uncertainty Program

TMP_MN-Minimum Temperature

TMP_MX- Maximum Temperature

USDA-ARS- United State Department of Agriculture Agricultural Research Service

UTM -Universal Transverse Mercator

WXGEN -Weather Generator

WYLD- Water Yield

Abstract

The study area of suluh catchment have the scarcity of record data, but the Suluh River have the capability of feeding the society nearby as source of small scale hydropower and irrigation. In addition to that since it is ungauged catchment it has no representing model of Rainfall-runoff relation and water harvesting structure. The work described here will attempt to solve these problems using the regional approach whereby statistically homogeneous regions are identified and the parameters of choosing distribution are estimated from the regional averages so that the flow quantile for the ungauged catchment within that region can easily be computed. So that the necessity of this study arises from the weight to improve site specific estimates based on limited data and to make inference about ungauged catchments.

In ungauged catchments, model parameters have to be estimated from other sources of information. An appealing way to estimate model parameters in ungauged catchments is to glean the model parameters from hydrologically similar catchments. Hydrological modeling in ungauged catchments often involves the transfer of calibrated model parameters from donor (gauged) catchments to the receiver (ungauged). However, in any hydrological modeling, some parameters tend to be more sensitive to the objective function, whereas others are insensitive. Sensitivity analysis was performed to choose the most sensitive flow parameters that influence the catchment represented by SWAT to be used for calibration. This was achieved using the global sensitivity approach in semi-automated Sequential Uncertainty Fitting (SUFI2) algorithm. The global sensitivity analysis method takes into consideration, the sensitivity of one parameter relative to the other in order to give their statistical significances. The t-statistics and p-values of the parameters were used to rank to the different parameters considered to influence flow and the final selection done based on the significance of the ranked values. Table4 shows stream flow parameters that were tested for their sensitivity. These are useful in estimating the amount of flow from a catchment. The global sensitivity analysis of 21 flow parameters showed that, only eight were very sensitive to flow. Although, the rest of the parameters were found not to be sensitive to flow in the catchment as their p-values were greater than 5%. The Time period of 2000-2009 is used for SWAT model Calibration, and the 2009-2014 period for validation. Time series plots, as well as statistical measures, such as the coefficient of determination (R2) and the Nash-Sutcliffe efficiency (NS) parameter between observed and simulated stream flows are computed on monthly time scales and indicate a good performance of the final calibrated SWAT model. From the SWAT model output around 85% of the Suluh flow indicates surface runoff.

The maximum rainfall of the catchment is about 331mm during a month of August and Similarly with surface runoff of 98.3mm.

Keywords: Ungauged Catchment, Suluh, Transfer, SWAT, Calibration, Validation, Stream flow.

1. Introduction

There are many reasons why we need to model the rainfall–runoff processes of hydrology. The main reason is a result of the limitations of hydrological measurement techniques. We are not able to measure everything we would like to know about hydrological systems. We have, in fact, only a limited range of measurement techniques and a limited range of measurements in space and time. We therefore need a means of extrapolating from those available measurements in both space and time, particularly to ungauged catchments (where measurements are not available) and into the future (where measurements are not possible) to assess the likely impact of future hydrological change. Models of different types provide a means of quantitative extrapolation or prediction that will hopefully be helpful in decision making. The ultimate aim of prediction using models must be to improve decision making about a hydrological problem, whether that be in water resources planning, flood protection, mitigation of contamination, licensing of abstractions, or other areas. With increasing demands on water resources throughout the world, improved decision making within a context of fluctuating weather patterns from year to year requires improved models.

1.1 General

Modelling the rainfall–runoff behavior of ungauged catchments is of interest both for understanding systems behavior and as a basis of sustainable water resources management. The main challenge with rainfall–runoff modelling in ungauged catchments is the lack of local runoff data to calibrate the model parameters. Parameter calibration is important because most model equations are empirical in nature, model output depends on the initial and boundary conditions that are poorly known and, probably most importantly, because most of the flow processes take place in the subsurface where media characteristics are heterogeneous and unknown. Soil properties can change dramatically in space but change very little in time, so parameter calibration can significantly enhance model performance.

In ungauged catchments, model parameters have to be estimated from other sources of information. An appealing way to estimate model parameters in ungauged catchments is to glean the model parameters from hydrologically similar catchments. The concept of hydrological similarity assumes that the runoff response to a given rainfall input in two different catchments will be similar if similar rainfall–runoff processes occur. The process of transferring parameters from hydrologically similar catchments to a catchment of interest is generally referred to as regionalization (Blöschl & Sivapalan, 1995). The two most widely used concepts for regionalizing model parameters are hydrological similarity as a function of spatial proximity and similarity as a function of catchment attributes.

1.2 Problem statement

The study area of suluh catchment have the scarcity of record data, but the Suluh River have the capability of feeding the society nearby as source of small scale hydropower and irrigation. In addition to that since it is ungauged catchment it has no representing model of Rainfall-runoff relation and water harvesting structure. Suluh River is the tributary of Geba and still now Geba have the problem of hydrological yield then the tributary of Geba have to be study. The evolution of hydrologic knowledge and methods brings a continual improvement in the scope and accuracy of solutions to hydrologic problems. One of the most important inputs for determining the size of the water harvesting structure is the volume of water that will be expected to be generated from the catchment. Moreover, most of Tigray river basins have sparse network of observation sites with short record length of observed flow that makes the use of single site analysis to estimate design parameters at many potential project sites unreliable. There are also river basins, which are totally ungauged. In such instant, the design of any structure within the region is difficult unless data transposing from gauged site is done which requires a lot of effort. The work described here will attempt to solve these problems using the regional approach whereby statistically homogeneous regions are identified and the parameters of choosing distribution are estimated from the regional averages so that the flow quantile for the ungauged catchment within that region can easily be computed. So that the necessity of this study arises from the weight to improve site specific estimates based on limited data and to make inference about ungauged catchments.

1.3 Research Objectives

1.3.1 General objective

The main objectives of this study is to test the rainfall-runoff model for the catchment under study, and estimating daily runoff for the ungauged catchments.

Specific objective of the study:

- To test the model for hydrological processes.
- To evaluate meteorological and hydrological data of Suluh
- To estimate regional hydrological model parameters.
- To estimate the monthly runoff series of suluh catchment.

1.4 Scope of the study

The research work covers the development of model for the focused area, calibration and validation of the developed model, and its application to future land use prediction in order to determine its impact on hydrological parameters.

1.5 Structure of the Thesis

It comprises five chapters, which are briefly outline below.

Chapter one: Introduction, This chapter discusses background information, problem of statement, general and specific objective

Chapter two: is Literature review and talks about methods how to do hydrological model and describes the SWAT model applications. Besides, the general condition and previous studies conducted in Ethiopia.

Chapter Three: Methodologies and Materials

This chapter recapitulates the description of the study area and the methods step by step for the hydrological modelling and data preparation the entire input for the SWAT model.

Chapter Four: Result and discussion

This chapter grants the outcome of the model application to assess the hydrological process.

It gives a detail justification of the model setup, sensitivity of model parameter, calibration, validation and model prediction uncertainty.

Chapter Five: Conclusion and Recommendation

This chapter summarizes the contributions of this research and suggests related future research issues.

2 Literature review

2.1 Hydrological Models

A **hydrologic model** is a simplification of a real-world system (e.g., surface water, soil water, wetland, and groundwater) that aids in understanding, predicting, and managing water resources. Both the flow and quality of water are commonly studied using hydrologic models.

All Rainfall-Runoff models and, in the broader sense, hydrologic models are simplified characterizations of the real world system. A wide range of rainfall runoff models are currently used by researchers and practitioners, however the applications of these models are highly dependent on the purposes for which the modeling is made. Many Rainfall runoff models are used merely for research purposes in order to enhance the knowledge and understanding about the hydrological processes that govern a real world system. Other types of models are developed and employed as tools for simulation and prediction aiming ultimately to allow decision makers to take the most effective decision for planning and operation while considering the interactions of physical, ecological, economic, and social aspects of a real world system. Examples of some of the implications of latter type of Rainfall runoff models are: real-time flood forecasting and warning, estimating flood frequencies, flood routing and inundation prediction, impact assessment of climate and land use change and integrated watershed management. The development of Rainfall runoff models could be recognized based on the importance of available data which provides the learning data set for calibrating the nonlinear behavior of these models. These data are used as a priori knowledge in the model with the logic that gives the flexibility to the model to extrapolate the Rainfall runoff process for some future time. This line of thinking, known as batch model calibration (using batch of data for calibration), has been challenged by another philosophy that availability of observation continuously gives the opportunity to the model components (state variables and even parameters) to be updated (corrected) sequentially. This is thought to give more flexibility for taking advantage of the temporal organization and structure of information content for better compliance of the model output with observed system response.

Water is an essential element for survival of living things. It is vital factor for economic development and augmenting growth of agriculture and industry especially in the perspective of rapidly increasing population and urbanization. Many zones face scarcity of freshwater or subject to pollution. Thus, the availability and the sustainable use of the water resources become the core of the local and national strategies and politics in these regions. To deal with water management issues, one must analyze and quantify the different elements of hydrologic processes taking place within the area of interest. Obviously, this analysis must be carried out on a watershed basis because all these processes are taking place within individual micro watersheds. Hydrological processes and their local scattering have always direct relation to weather, topography, geology and land use of watershed in addition to the impact of human activities. A watershed is comprised of land areas and channels and may have lakes, ponds or other water bodies. The flow of water on land areas occurs not only over the surface but also below it in the unsaturated zone and further below in the saturated zone, Singh and Frevert (2002). The use of a watershed model to simulate these processes plays a fundamental role in addressing a range of water resources and environmental and social problems.

The development of Geographic Information System (GIS) capabilities has encouraged and improved the expanded use of watershed models worldwide. GIS is a suitable tool for the efficient management of large and complex database and to provide a digital representation of watershed characteristics used in hydrologic modeling. It has added confidence in the accuracy of modeling by providing more practical approach toward the watershed conditions, defining watershed characteristics, improving the efficiency of the modeling process and ultimately increasing the estimation capabilities of hydrological modeling, Bhuyan et al. (2003).

Hydrological models have been used in different River basins across the world for better understanding of the hydrological processes and the water resources availability. It is important to use hydrological model today to assess and predict the water availability of river basins due to land use change to develop a strategies in order to cope up with the changing environment.

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 meet one of the two primary objectives. The one objective of the watershed hydrologic modelling is to get a better understanding of the hydrologic processes in a watershed and of how changes in the watershed may these phenomena. The other objective is for hydrologic prediction. They are also providing valuable information for studying potential impacts of changes in land use and land cover or climate. On the basis of process description, the hydrological models can be classified in to three main categories (Cunderlik, 2003).

2.1.1. Lumped models

Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. The parameters often do not represent physical features of hydrologic processes and usually involve 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.

2.1.2 Distributed models

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

2.1.3 Semi-distributed models

Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin in to a number of smaller sub-basins. The main advantage of these models is that their structure is more physically-based than the structure of lumped models, and they are less demanding on input data than fully distributed models. SWAT (Arnold, et al., 1993), HEC-HMS (US-ACE, 2001), HBV (Bergström, 1995), are considered as semi-distributed models. Hydrologic models can be further divided into event-driven models, continuous-process models, or models capable of simulating both short-term and continuous events. Event-driven models are designed to simulate individual precipitation-runoff events. Their emphasis is placed on infiltration and surface runoff. Typically, event models have no provision for moisture recovery between storm events and, therefore, are not suited for the simulation of dry-weather flows. On the other hand, continuous-process models simulate instead a longer period, predicting watershed response both during and between precipitation events. They are suited for simulation of daily, monthly or seasonal stream flow, usually for long-term runoff-volume forecasting and for estimates of water yield (Cunderlik, 2003). Generally for this study, semi-distributed models are selected because of their structure is more physically-based than the structure of lumped model, and they are less demanding on input data than fully distributed models.

2.2 Introduction to SWAT Model

SWAT (Soil & Water Assessment Tool) is 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). SWAT is a public domain software enabled model actively supported by the USDA Agricultural Research Service (Arnold et al., 1998) at the Backland Research & Extension Center in Temple, Texas, USA. It is a hydrology model with the following components: weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer. SWAT can be considered a watershed hydrological transport model. This model is used worldwide and is continuously under development.

The interface of SWAT model is compatible with ArcGIS that can integrate numerous available geospatial data to accurately represent the characteristics of the watershed. In SWAT model, the impacts of spatial heterogeneity in topography, land use, soil and other watershed characteristics on hydrology are described in subdivisions. There are two scale levels of subdivisions; the first is that the watershed is divided into a number of sub-watersheds based upon drainage areas of the attributes, and the other one is that each sub-watershed is further divided in to a number of Hydrologic Response Units (HRUs) based on land use and land cover, soil and slope characteristics. 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 (Arnold et al., 1998).

Stream flow is determined by its components (surface runoff and ground water flow from shallow aquifer).

2.3 SWAT Model Application in Ethiopia

The SWAT model application was calibrated and validated in some parts of Ethiopia, frequently in Blue Nile basin. Through modelling of Gumara watershed (in Lake Tana basin), Awulachew et al. (2008) indicated that stream flow and sediment yield simulated with SWAT were reasonable accurate. The same study reported that similar long term data can be generated from ungauged watersheds using the SWAT model. A study conducted on modelling of the Lake Tana basin with SWAT model also showed that the SWAT model was successfully calibrated and validated (Setegn et al., 2008). This study reported that the model can produce reliable estimates of stream flow and sediment yield from complex watersheds. Gessese (2008) used the SWAT model performed to predict the Legedadi reservoir sedimentation. According to this study, the SWAT model performed well in predicting sediment yield to the Legedadi reservoir. The study further put that the model proved to be worthwhile in capturing the process of stream flow and sediment transport of the watersheds of the Legedadi reservoir.

In addition to the above, the SWAT model was tested for prediction of sediment yield in Anjeni gauged watershed by Setegn et al., (2008). The study found that the observed values showed a good agreement at Nash-Sutcliff efficiency (ENS) of 80 %. In light of this, the study suggested that the SWAT model can be used for further analysis of different management scenarios that could help different stakeholders to plan and implement appropriate soil and water conservation strategies. The SWAT model showed a good match between measured and simulated flow and sediment yield in Gumara watershed both in calibration and validation periods (Asres and Awulachew, 2010). Tekle (2010) through modelling of Bilate watershed also indicated that SWAT Model was able to simulate stream flow at reasonable accuracy.

The literature reviewed and presented above showed that SWAT is capable of simulating hydrological and soil erosion process with reasonable accuracy and can be applied to large and complex watersheds.

2.4 Model operation

SWAT is a continuous time model that operates on a daily time step at basin scale. The objective of such a model is to predict the long-term impacts in large basins of management and also timing of agricultural practices within a year (i.e., crop rotations, planting and harvest dates, irrigation, fertilizer, and pesticide application rates and timing). It can be used to simulate at the basin scale water and nutrients cycle in landscapes whose dominant land use is agriculture. It can also help in assessing the environmental efficiency of best management practices and alternative management policies. SWAT uses a two-level disaggregation scheme; a preliminary sub basin identification is carried out based on topographic criteria, followed by further discretization using land use and soil type considerations. Areas with the same soil type and land use form a Hydrologic Response Unit (HRU), a basic computational unit assumed to be homogeneous in hydrologic response to land cover change.

2.5 Uncertainty Analysis

Most important issue with calibration of watershed models is that of uncertainty in the predictions. Watershed models suffer from large model uncertainties. These can be divided into: conceptual model uncertainty, input uncertainty, and parameter uncertainty.

1. Conceptual model uncertainty (or structural uncertainty)
2. Input uncertainty is as a result of errors in input data such as rainfall, and more importantly, extension of point data to large areas in distributed models.
3. Parameter uncertainty

The packages like SWAT-CUP can help decrease model uncertainty by removing some probable sources of modeling and calibration errors. On a final note, it is highly desirable to separate quantitatively the effect of different uncertainties on model outputs, but this is very difficult to do. The combined effect, however, should always be quantified on model outputs (Abbaspour, 2007).

2.5.1 SWAT-CUP (SWAT Calibration and Uncertainty Procedures) is a program designed to integrate various calibration/uncertainty or sensitivity programs for SWAT (Soil & Water Assessment Tool) using the same interface. To create a project, the program guides the user through the input files necessary for running a calibration program. Each SWAT-CUP project contains one calibration method and allows user to run the procedure many times until convergence is reached. User can save calibration iterations in the iteration history for later use. Many computer programs have been developed by hydrologists for parameters uncertainty analysis in river basin model, such as, generalized likelihood uncertainty estimation (GLUE; Beven & Binley 1992), sequential uncertainty fitting (SUFI-2; Abbaspour et al. 2004), parameter solution (ParaSol; Van Griensven & Meixner 2006) and Markov chain Monte Carlo (MCMC; Kuczera & Parent 1998; Vrugt et al. 2008).

The Generalized Likelihood Uncertainty Estimation (GLUE) (Beven and Binley, 1992) was introduced partly to allow for the possible non uniqueness of parameter sets during the estimation of model parameters in over parameterized models. The procedure is simple and requires few assumptions when used in practical applications. GLUE assumes that in the case of large over parameterized models, there is no unique set of parameters, which optimizes goodness of fit criteria. The technique is based on the estimation of the weights(probabilities) associated with different parameter sets, based on the use of a subjective likelihood measure to derive a posterior probability function, which is subsequently used to derive the predictive probability of the output variables.

The ParaSol method aggregates objective functions (OF's) into a global optimization criterion (GOC), minimizes these OF's or GOC using the shuffle complex evolution (SCE-UA) algorithm and performs uncertainty analysis with a choice two statistical concepts (Van Griensven and Meixner, 2006).

The MCMC (Markov Chain Monte Carlo) generates samples from a random walk which adapts to the posterior distribution (Kuczera and Parent, 1998).

In this particular study it was preferred to use sequential uncertainty fittings (SUFI2). It is automated model calibration requires that the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to measured data) are extracted from the model output files. The main function of an interface is to provide a link between the input/output of a calibration program and model.

2.5.2 Calibration and Uncertainty Analysis Procedure SUFI-2

The program SUFI-2 was used for calibration and uncertainty analysis. In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data. The degree to which all uncertainties are accounted for is quantified by a measure referred to as the P-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). The 95PPU is calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling. As all forms of uncertainties are reflected in the measurements (e.g., discharge), the parameter uncertainties generating the 95PPU account for all uncertainties. Breaking down the total uncertainty into its various components is of some interest, but quite difficult to do. Another measure quantifying the strength of a calibration/uncertainty analysis is the so called R-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. SUFI-2, hence seeks to bracket most of the measured data (large P-factor, maximum100%). Another measure quantifying the strength of a calibration/uncertainty analysis is the R-factor which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. The calibrated parameter ranges can be generated with an acceptable value of the R-factor and P-factor.

The concept behind the uncertainty analysis of the SUFI-2 algorithm is depicted graphically in Fig. 2. This Figure illustrates that a single parameter value (shown by a point) leads to a single model response (Fig. 2a), while an uncertain parameter (shown by a line) leads to the 95PPU illustrated by the shaded region in Fig. 2b. As parameter uncertainty increases, the output uncertainty also increases (not necessarily linearly) (Fig. 2c). Hence, SUFI-2 starts by assuming a large parameter uncertainty (within a physically meaningful range), so that the measured data initially falls within the 95PPU, then decreases this uncertainty in steps while monitoring the P-factor and the R-factor. In each step, previous parameter ranges are updated by calculating the sensitivity matrix (equivalent to Jacobian), and equivalent of a Hessian matrix, followed by the calculation of covariance matrix, 95% confidence intervals of the parameters, and correlation matrix. Parameters are then updated in such a way that the new ranges are always smaller than the previous ranges, and are centred on the best simulation. The goodness of the fit and the degree to which the calibrated model accounts for the uncertainties are assessed by the above two measures. An ideal situation would lead to a P-factor of about 100% and an R-factor near zero. When acceptable values of R-factor and P-factor are reached, then the parameter uncertainties are the desired parameter ranges. Further goodness of fit can be quantified by the R2 and/or Nash Sutcliff (NS) coefficient between the observations and the final best simulation. If initially a set of parameter ranges cannot be found where the 95PPU brackets most of the data, for example, if the situation in Fig. 1d occurs with the parameter uncertainties at physically meaningful limits, then the problem is not one of parameter calibration and the conceptual model must be re-examined.

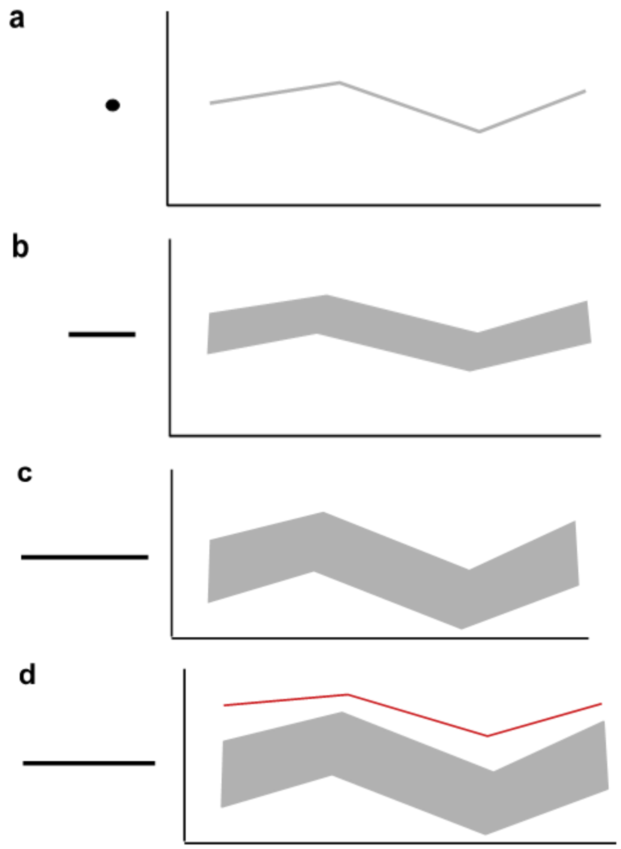


Figure 2. A conceptual illustration of the relationship between parameter uncertainty and prediction uncertainty. (Source: Abbaspour et al., 2007)

2.6. Transfer of Hydrological Model Parameters

All hydrologic models can to some degree benefit from calibration to improve their Q simulations, due to (i) lack of process understanding, (ii) possibly overly simplistic process representations, (iii) the spatiotemporal discretization of highly heterogeneous rainfall-runoff processes, and (iv) the impossibility of measuring all required model parameters at the model application scale [Beven, 1989; Bl€ oschl and Sivapalan, 1995; Duan et al., 2001, 2006; McDonnell et al., 2007; Nasonova et al., 2009; Rosero et al., 2011; Minville et al., 2014]. Since

Q observations are unavailable for the majority of the Earth’s land surface [Sivapalan, 2003; Hannah et al., 2011], hydrologic models often rely on regionalization approaches to transfer information from gauged (donor) to ungauged (receptor) catchments [see He et al., 2011; Hrachowitz et al., 2013; Razavi and Coulibaly, 2013; Bl€ oschl et al., 2013; Parajka et al., 2013 for reviews]. Six regionalization approaches have been used most frequently. First, the earliest regionalization approach consisted of catchment-by-catchment calibration and subsequent construction of a regression model that related the calibrated model parameters to catchment characteristics [e.g., Seibert, 1999; Yokoo et al., 2001; Young, 2006]. However, this approach generally met with limited success due in large part to the loss of model parameter interaction and the problem of equifinality [e.g., Kokkonen et al., 2003; Hundecha and McIntyre et al., 2005; Wagener and Wheater, 2006; Oudin et al., 2008; Kim and Kaluarachchi, 2008]. Second, another widely used approach is to simultaneously construct the regression model and perform the calibration [e.g., Hundecha and Samaniego et al., 2010], although this approach involves the nontrivial task of formulating a priori parsimonious yet effective parameter predictor relationships. Third, in another common approach, calibrated parameter sets are transferred to nearby regions based only on geographic proximity [e.g., Merz and Bl€ oschl, 2004; Oudin et al., 2008]. However, this approach requires a dense network of gauging stations, and geographic proximity cannot necessarily be equated to similarity in rainfall-runoff behavior, particularly in climatically, geologically, or topographically highly heterogeneous regions [Vandewiele and Elias, 1995; Shu and Burn, 2003; Oudin et al., 2008; Reichl et al., 2009; Ali et al., 2012]. Alternatively (and fourthly), it is possible to transfer calibrated parameter sets based on explicit consideration of climatic and/or physiographic similarity [e.g., Kokkonen et al., 2003; McIntyre et al., 2005], or fifth simultaneously calibrate multiple catchments with similar climatic and/or physiographic characteristics to obtain more generalizable parameter sets [e.g., Fernandez et al., 2000; Parajka et al., 2007; Kim and Kaluarachchi, 2008]. However, these last two approaches are complicated by the need for a priori selection of characteristics representing the rainfall-runoff behavior. Sixthly and finally, various approaches have recently used Q signatures (measures that quantify the hydrograph shape such as slope of the flow duration curve and baseflow index) estimated using, for example, regression to condition model parameters [e.g., Yadav et al., 2007; Zhang et al., 2008; Troy et al., 2008; Castiglioni et al., 2010]. However, this Q-signature approach is affected by: (i) the poor quality of daily meteorologic data in many regions which, after calibration against the estimated Q signatures, might lead to unrealistic model parameters producing the right results for the wrong reasons; (ii) the inherent difficulty in estimating Q signatures for ungauged regions [Beck et al., 2015]; and (iii) the fact that measures related to Q signatures by themselves are generally less effective at conditioning model parameters than goodness-of-fit measures.

Numerous studies have applied these approaches and demonstrated their respective advantages and limitations (see the aforementioned reviews). However, most studies had a regional (subcontinental) focus, employed a relatively small number of catchments, and used a variety of hydrologic models, forcing data, regionalization approaches, objective functions, and evaluation methodologies, resulting in findings with questionable generalizability [Razavi and Coulibaly, 2013]. In general, approaches that transfer calibrated parameter sets according to a certain measure of climatic and/or physiographic similarity performed better than (or gave comparable results to) other approaches [Kokkonen et al., 2003; McIntyre et al., 2004, 2005; Parajka et al., 2005; Oudin et al., 2008; Li et al., 2009; Reichl et al., 2009; Bao et al., 2012; Wallner et al., 2013; Singh et al., 2014; Sellami et al., 2014; Garambois et al., 2015]. There have been, however, several studies that obtained better results using approaches that transferred calibrated parameter sets based on geographic proximity [Oudin et al., 2008; Zhang and Chiew, 2009; Samuel et al., 2011; Patil and Stieglitz, 2014; Petheram et al., 2012], although the first four of these studies were conducted in regions with relatively dense gauging networks which tends to favor the spatial proximity approach (France, southeastern Australia, Ontario, and the conterminous USA, respectively). Kay et al. [2006] compared three regionalization approaches for two hydrologic models but obtained effectively inconclusive results: similarity-based regionalization performed best when using one hydrologic model, but performance was poorest in combination with the other model.

Due to the lack of a commonly accepted approach for parameter regionalization, hydrologic models typically applied at continental to global scales (hereafter called macroscale) rarely use regionalized parameters [Sooda and Smakhtin, 2015; Kauffeldt, 2014; Bierkens et al., 2015]. Instead, they tend to rely on a priori parameterizations based on expert opinion, case studies, field data, hydrologic theory, or data sets of questionable quality. For example, the Community Land Model (CLM) [Oleson et al., 2010], among many other models, uses a fixed value for the baseflow recession constant (k), although it has long been recognized that k varies spatially [Hall, 1968; Beck et al., 2013b]. Although the PCRaster Global Water Balance (PCR-GLOBWB) model [Van Beek and Bierkens, 2009] determines k based on drainage theory and hydrogeologic data, observational studies have reported weak links between k and current hydrogeologic data sets [Van Dijk, 2010; Pe~ na-Arancibia et al., 2010; Beck et al., 2013b]. Similarly, several models (e.g., the Noah land surface model with Multi-Parameterization options—Noah-MP) [Niu et al., 2011] have adopted concepts from the TOPography based hydrologic MODEL (TOPMODEL) [Beven and Kirkby, 1979] to simulate surface runoff and baseflow, thus confounding model performance in regions where surface topography represents a poor proxy of the aquifer flow gradient and/or where other variables exert stronger controls on the flow response [Beven, 1997; Devito et al., 2005; Li et al., 2011]. Furthermore, in many models, including LISFLOOD [Burek et al., 2013], the generation of infiltration and saturation-excess runoff is implicitly linked to soil hydrologic properties that are impossible to measure at the model application scale [Bl€ oschl and Sivapalan, 1995; Hop- mans et al., 2002]. Consequently, it is unlikely that current macro-scale hydrologic models have reached their full potential in terms of Q simulation [Duan et al., 2006; Nasonova et al., 2009; Rosero et al., 2011].

In addition, two macroscale studies [Troyet al., 2008] used regionalization approaches based on spatial proximity or interpolation which should not be applied at macroscales, given that the majority of the land surface is ungauged or poorly gauged [Siva-palan, 2003; Hannah et al., 2011]. Moreover, three global studies [Nijssen et al., 2001; D€ oll et al., 2003] used only large catchments (>>10,000 km^2), which typically tend to be more strongly affected by human activity (river regulation, diversions, water abstraction and extraction, and urbanization) and routing processes (evaporation from the river surface, riverbed leakage losses, and travel time delays) and thus are less likely to yield valid parameters at the grid-cell scale. Note that Rakovec et al. [2016] used large catchments as well, but explicitly accounted for the scale discrepancy problem.

Recently, using data from thousands of catchments around the globe, Beck et al. [2015] identified several climatic and physiographic characteristics that are strong predictors of Q signatures, ensuring that these characteristics are hydrologically relevant and that their data quality is sufficient. The hypothesis tested in the present study states that, at the global scale, similarity in these climatic and physiographic characteristics reflects (to a certain degree) similarity in rainfall-runoff response.

2.6.1 Regionalization

Regionalization based on spatial proximity the rationale of this group of methods is that catchments that are close to each other will have a similar response as the climate and catchment conditions will only vary smoothly in space. The notion of spatial proximity is by no means trivial as it can be defined in a number of ways and the choice of method in any particular case is usually not obvious. An example of this group is the delineation of spatially contiguous regions with approximately homogeneous model parameters. The regions are found from an analysis of a number of gauged catchments and available hydrological information using statistical tools such as cluster analysis, principal component analysis and multiple regression (Nathan & McMahon, 1990). Hydrological information to assist in delineating homogeneous regions may consist of hydrogeological maps, climate maps, soil and vegetation maps and process indicators such as the seasonality of hydrological processes (Merz et al., 1999). Yu & Yang (2000) propose to establish regional flow duration curves, which comprise a family of regression equations relating the flow of various exceedence percentages with catchment area. The regional flow duration curves can then be used to calibrate model parameters in ungauged catchments. An alternative to homogeneous regions are geostatistical methods, such as kriging. The main strength of kriging is that it is a best linear unbiased estimator (BLUE); best meaning that the mean squared error is a minimum, linear meaning that the estimate is a weighted mean of the data in the area, and unbiased meaning that the mean expected error is zero (Merz & Blöschl, 2004). Regionalization based on catchment attributes The analysis of observed hydrological behavior often reveals small scale variability but catchments that are far apart may still be hydrologically similar (e.g. Pilgrim, 1983), so alternatives to the spatial proximity concepts have been proposed. These concepts are often based on similarity of catchment attributes that are available in both gauged and ungauged catchments. Runoff is not considered as a catchment attribute that will make this group of methods applicable to the ungauged catchment case. Catchment attributes include catchment size, information on topography, land use, geology, elevation, soil characteristics, as well as climate variables such as mean annual precipitation, and are thought of as surrogates of the hydrological processes within a catchment. The rationale of this approach is that catchments with similar attributes may also behave hydrologically similarly (Acreman & Sinclair, 1986). The catchment attributes can be used in regionalization methods of various structures. The first type of methods use a distance measure of hydrological similarity which is a function of the differences in catchment attributes of two catchments. The distance measure is zero if the catchment attributes are identical and increases as the attributes get more dissimilar. The distance measure can be used in statistical methods such as cluster analysis, principal component analysis, and classification trees (Breiman et al., 1984; Nathan & McMahon, 1990; Bates, 1994) to group the catchments. Once the groups are identified, the model parameters can be transferred from an analogue gauged catchment within the same group to the ungauged catchment of interest. A particular variant is the Region of Influence approach (Burn & Boorman, 1993), where for each catchment of interest a separate pooling group is formed.

The second way of using catchment attributes are regression analyses between model parameters and catchment attributes. Regression relationships are black-box models, although some degree of process reasoning can come in. Due to the availability of catchment attributes in geographic information systems, correlations between model parameters and catchment attributes are widely used in regionalization (e.g. Sefton & Howarth, 1998, Seibert, 1999; Kokkonen et al., 2003; Merz & Blöschl, 2004).In multiple regressions, one may encounter the problem of multicollinearity, i.e. when at least one of the attributes is highly correlated with another attribute or with some linear combination of them. If multicollinearity is present, the regression coefficient can be highly unstable and unreliable (Hirsch et al., 1992). One therefore limits the number of catchment attributes used in the regression, sometimes combining a number of attributes into an index, which is assumed to be representative of one aspect of the rainfall–runoff relationship (such as the base flow index, IH, 1999). Sequential regression may assist in identifying robust parameter estimates (Lamb & Kay, 2004). Sometimes the delineation of homogeneous regions and regression analyses are combined (e.g. Burn & Boorman, 1993). A formal way of combining regression analyses and the delineation of homogeneous regions are Classification and Regression Tree (CART) models (Breiman et al., 1984; Laaha & Blöschl, 2006).

Predicting hydrological variables in ungauged catchments has been singled out as one of the major issues in the hydrological sciences (Sivapalan et al., 2003). Predictions are particularly difficult to make in alpine regions where data are sparse and the spatial variability of the hydrological environment is enormous. Transferring information from neighboring catchments to the catchment of interest is generally accomplished by hydrological regionalization methods

(Sivapalan, 1995). Among the most widely used techniques are regressions between the model parameters and physiographic catchment attributes. Typically, linear multiple regressions are used where each model parameter is estimated independently from the others (e.g. Post and Jakeman, 1996, 1999; Sefton and Howarth, 1998).

Relationships between lake percentage and soil parameters found by Seibert (1999) could not be explained by hydrologic reasoning while relationships between forest percentage and snow parameters supported the process basis of the model. Similar conclusions were drawn by Kokkonen et al. (2003). They used the IHACRES model with 6 parameters and found that high

Significance of regressions does not guarantee a set of parameters with a good predictive power. Care must hence be taken when interpreting the physical meaning of parameter descriptor relationships found by regressions.

The regression method is the most widely used regionalization technique but alternative methods are in use. Vandewiele and Elias (1995) examined two methods based on spatial proximity, the kriging method and the use of model parameter values from a few neighboring catchments in a Belgian case study. They found that the kriging approach provided a significantly better model performance than the nearest neighbor approach although the model performance for some of the catchments was rather poor. The question of whether or not homogeneous catchments tend to occur in close proximity to each other has been the subject of significant debate over the years. Shu and Burn (2003) suggested that geographically close catchments are not necessarily homogeneous in terms of hydrological response. In their case study in Great Britain, homogeneous spatial clustering patterns of the regional flood frequency distribution were found within a 62.5 km radius from a local clustering Centre. Burn and Boorman (1993) assigned donor catchments based on a similarity measure of physiographic catchment characteristics. In this method, the catchment characteristics are similar to those of the regression approach but the regionalization model structure is different as no assumption of linearity is made. Also, the complete set of model parameters is usually transposed from one or more donor catchments to the catchment of interest in this approach, while in the regression

Case, the parameters are usually regionalized independently from each other. Along similar lines, Campbell and Bates (2001) used a regional link function to estimate the parameters of a quasi-distributed, non-linear flood event model for 39 watersheds in Australia with good accuracy. Fernandez et al. (2000) proposed a regional calibration approach that involves a concurrent calibration of the model parameters and the relationships between model parameters and catchment attributes at many sites in a region. This approach has led to nearly perfect regional relationships between model parameters and catchment characteristics, however, these relationships did not improve the stream flow predictions at ungauged sites. A similar approach was applied in Hlavˇ cov´ a etal. (2000) and Szolgay et al. (2003), where they intended to

find regionally valid parameters of a monthly water balance model. They jointly calibrated a model using multi objective calibration, where the catchments were pooled together using cluster analysis of selected physiographic catchment attributes.

Merz and Bl ¨ oschl (2004) examined the performance of various methods of regionalizing the parameters of a conceptual catchment model in 308 Austrian catchments. They concluded that the methods based on spatial proximity performed better than those based on physiographic catchment attributes. The present paper builds on their analysis and examines the relative performance of regionalization methods. The present paper goes beyond Merz (2004) in three important aspects. First, Merz (2004) used a lumped catchment model. In an alpine country such as Austria there may be merits in allowing different model states in different elevations of the catchment to improve the overall predictive performance. Second, even though Merz (2004) tested the robustness of model parameters in a comprehensive way, further gains in robustness may be obtained by a multi-objective calibration where response data in addition to runoff are used. Third, Merz (2004) found that the regressions between model parameters and catchment attributes performed not as well as other methods but it was not clear whether this was due to the catchment attributes being poor hydrological indicators at the regional scale or due to problems with the linearity assumption of the multiple linear regressions used.

There are many definitions of regionalization available but a general definition as stated in Bloschl and Sivapalan [1995] is used most often. “Regionalization is the process of transferring

Information (hydrological information) from comparable catchments to the catchment of interest”. Usually watersheds with similar characteristics show similar hydrological treatments and therefore the hydrological parameters can be transferred from the same watersheds. Hydrological information can be either the model parameters or the general structure of models which estimate hydrological response (i.e. stream flows) according to this definition, the ungauged catchments should be located in a region of homogeneous with the gauged watershed. The assumption behind the homogeneous region of runoff response is similar climate, topography, vegetation, soil and geology in the homogeneous region would generally produce similar runoff response, but not necessary in geographically neighboring basins (Smarkhtin 2001).

There are different methods for this transformation including regression methods (Kokkonen et al., 2003; Bastola et al., 2008), spatial proximity (Merz and Blöshla, 2004) and physical similarity (McIntyre et al., 2005). One can also use the ratio method to predict river discharge in ungauged basins.6

The three regionalization Methods that are used to predict discharge from ungauged catchments are;

1. Similarity of spatial proximity: The transfer of catchment information was based on some sort of PCCs similarity between ungauged and gauged catchments. The PCCs were Determined using Arc GIS integrated with Arc SWAT. Therefore, calibrated model parameter Values from gauged catchments were transferred to the ungauged catchments based on PCCs Similarities.
2. Regional model: Catchments for which flow time series are to be estimated may not have Comparable gauged catchments. Thus, prohibiting extrapolation using similarity of spatial Proximity.
3. Catchment area (Area Ratio): This method assumes that in a specific gauging station catchment area the same quantity of runoff is generated on each km², independent of elevation. Thus outlet discharge is calculated as a function of the catchment areas. The method is a simple approximation, which works best when the gauging station is close to the respective outlet. This method does not consider the influences of vegetation, soil type, and geology on the flow in the investigated area.

Direct MP space transfer from a single donor catchment:

In the direct Model Parameter space transfer method, the median behavioral MP set from a single physiographically nearest donor catchment was applied to estimate the runoff at the ungauged catchment (Mulugeta B. Zelelewa & Knut Alfredsena 2014).

3 Materials and Methodologies

3.1 Description of the study area

The Suluh river basin is found in the highlands of the northeastern Tigray region. It is a tributary of the Geba River and drains from the mountains of Mugulat near Adigrat crest to the south. The drainage basin area of the Suluh River is about 967 km^2. Suluh is found in the eastern zone of Tigray region. Which is located (1508717.0854 m N 544662.4375 m E). It is the tributary of Geba River and originates from mugulat near adigrat. This is found about 18Km North West of the regional capital city of Mekelle the road between Mekelle and Hagereselam. The average altitude of the area is about 2321.0857 m m.a.s.l with 1777 and 3298 minimum and maximum elevation respectively. The topography of the area is not uniform. The catchment area consists of mountainous terrain and gentle slope. The mountain portion is covered with scattered bush and grass while the gentle slope is serving as agricultural land. The command is more or less flat it is and suitable for agriculture.it have 25000ha arable area. Areal precipitation of the Suluh catchment have calculated by Theissen polygon method and determined Average Annual rainfall of 641.5mm.

3.1.1 Climate

The geographic location and altitude characteristics of Ethiopia cause different climates (IAO, 2008). According to the National Strategy and Action Plan for the Implementation of the Great Green Wall Initiative in Ethiopia (2012) almost 90% of the Tigray region is characterized by a semi-arid climate. Rainfall occurs quantitatively and seasonally highly variable. The occurrence of rainfall periods is associated with the seasonal migration of the inter-tropical convergence zone (ITCZ) and the complex topography (HTSL, 1976; Nyssen et al., 2005; Abebe 2007). During the northern hemisphere winter, the ITCZ is located at the Equator; hot and dry winds from the Sahara reach the western highlands of Ethiopia and cause a dry season (Bega). From March to May, the ITCZ moves north allowing humid air masses from the Equator to reach Tigray and causing a short rainy season (Belg). From June to September (Kiremt), the ITCZ is localized in its northern position which is around 16 C (IAO, 2008). The south-east Monsoon and air masses from the Indic ocean cause the great rainy season (Kiremt).

Areal precipitation of the Suluh catchment have calculated by Theissen polygon method and annual rainfall of the catchment is highest in the north part, determined Average Annual rainfall of the basin is 645mm (Figure 3.1) below.

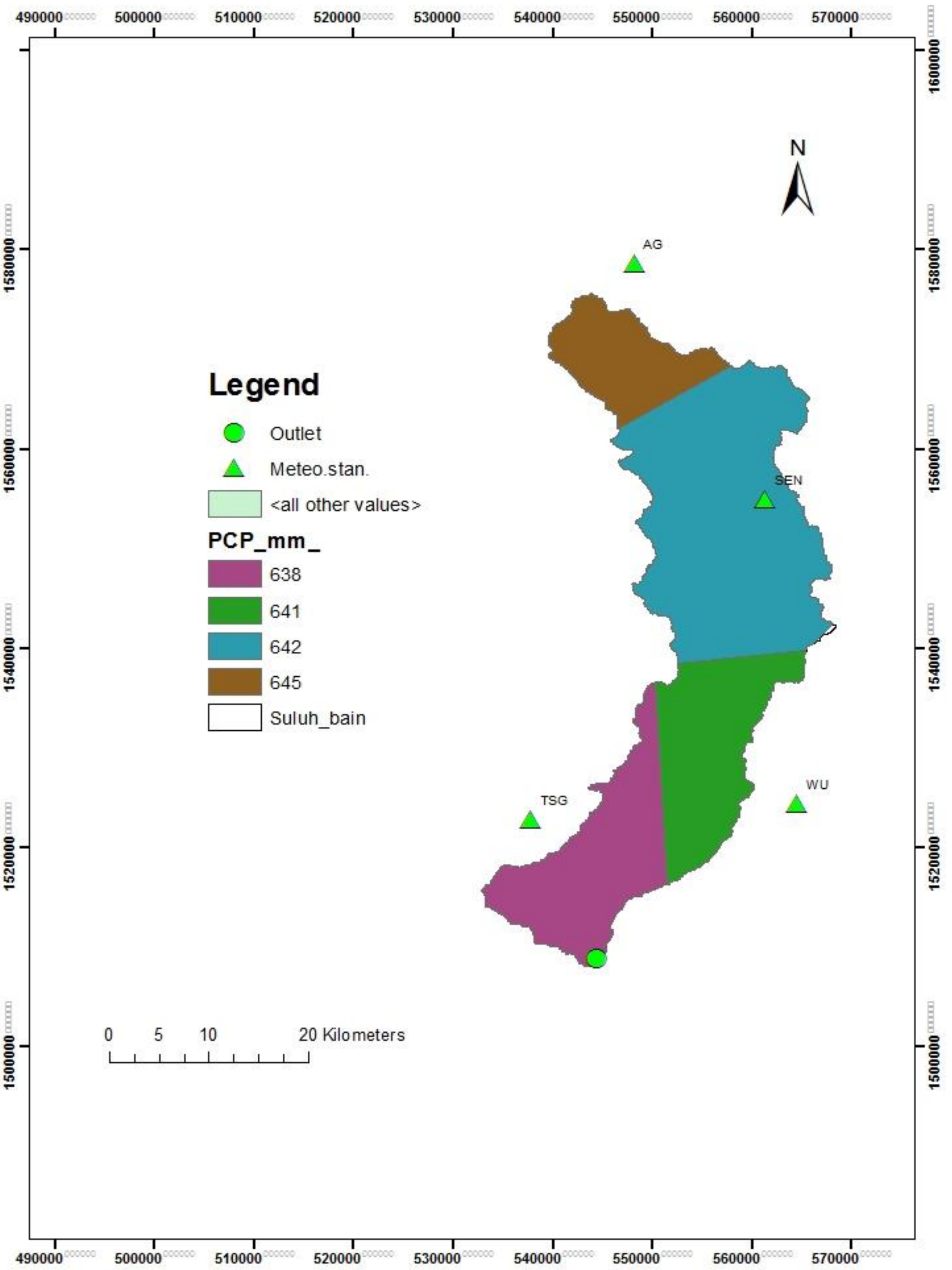


Figure 3.1 Theissen polygon of Suluh catchment

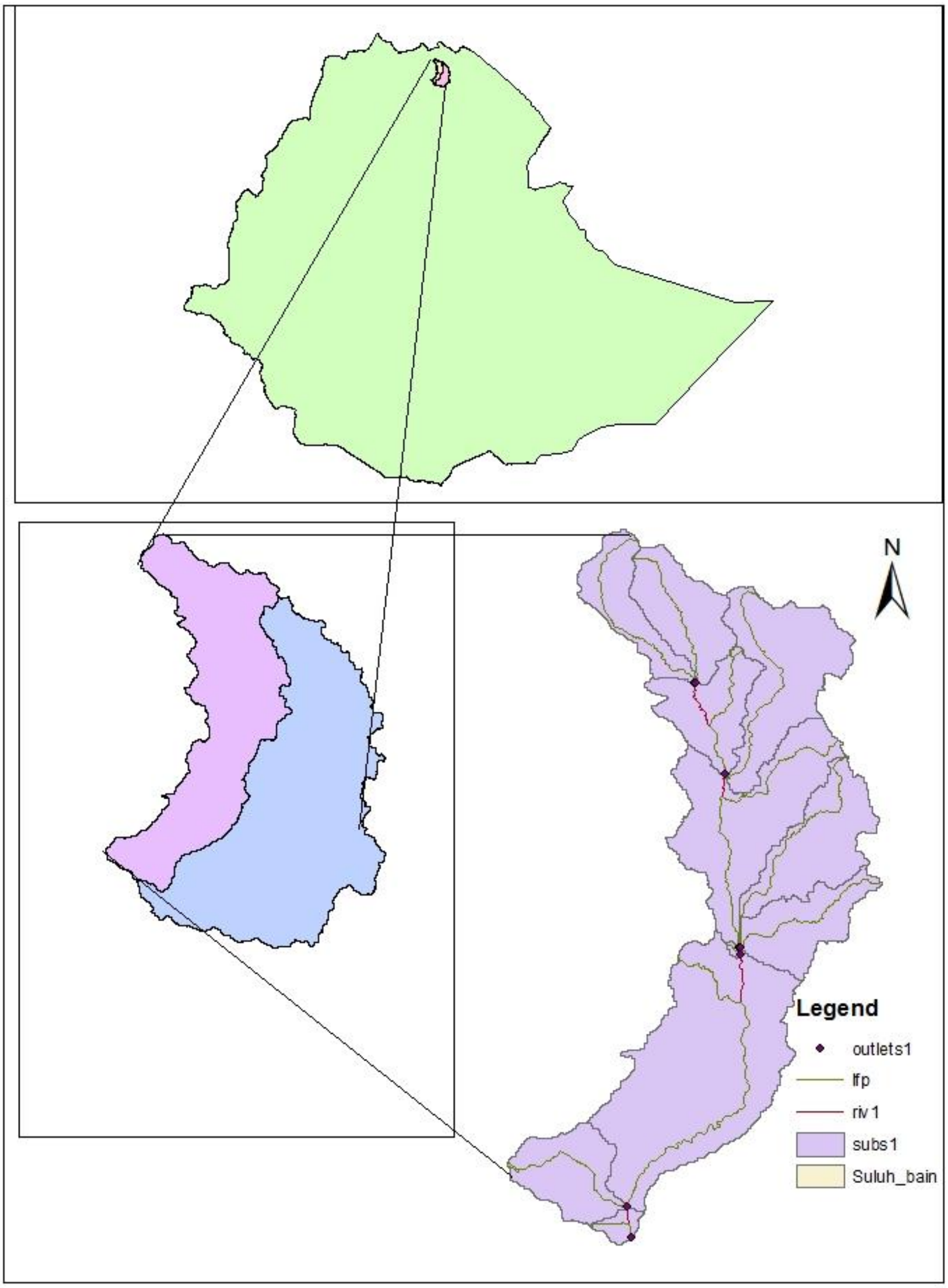


Figure3.2 Map of Ethiopia showing Suluh Watershed

3.2 Data preparation:

- ✓ Metrological and hydrological data (rainfall data ,stream flow data , minimum and maximum temperature ,wind speed ,relative humidity and sunshine hour);those data were collected from National Metrological Service Agency and Ministry of Water Irrigation and Electricity(MoWIE) and Hydrology department that is used input for catchment simulation, calibration and validation of the hydrological model.
- ✓ Catchment characteristic data (Land use, and topography data) could be collected from the MoWIE department of GIS and soil data from FAO.

3.3 Methods

3.3.0 Hydrological model and Component of SWAT

The simulation of the hydrology of watershed is done in two separate divisions. One is the land phase of the hydrological cycle that controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin. Hydrological components simulated in land phase of the hydrological cycle are canopy storage, infiltration, evapotranspiration, lateral sub surface flow, surface runoff and tributary channel flow. The second division is routing phase of the hydrological cycle that can be defined as the movement of water, sediments, nutrients and organic chemicals through the channel network of the watershed to the outlet.

The SWAT model is a physically-based continuous time, spatially distributed model designed to simulate water, sediment, nutrient and pesticide transport at a catchment scale on a daily time step. It uses hydrological response units (HRUs) that consist of specific land use, soil and slope characteristics. The HRUs are used to describe the spatial heterogeneity in terms of land cover, soil type and slope class within a watershed. The model estimates relevant hydrological components such as evapotranspiration, surface runoff and peak rate of runoff, groundwater flow and sediment yield for each HRU. Arc SWAT ArcGIS extension is a graphical user interface for the SWAT model. The SWAT model is developed and refined by the U.S. Department of Agricultural Research Service (ARS) and scientists at universities and research agencies around the world. The water balance equation is the base of the hydrologic cycle simulation in SWAT:

$$swt = swo + \sum_{i=1}^{n}(Rday - Qsurf - Ea - Wseep - Qgw) \text{-------------equation 3.1}$$

Where, SWt is the final soil water content (mm H2O), SWo is the initial soil water content (mm H2O), t is time in days, Rday is amount of precipitation on day i (mm H2O), Qsurf is the amount of surface runoff on day i (mm H2O), Ea is the amount of evapotranspiration on day i (mm H2O), Wseep is the amount of percolation and bypass exiting the soil profile bottom on day i (mm H2O), Qgw is the amount of return flow on day i (mm H2O).

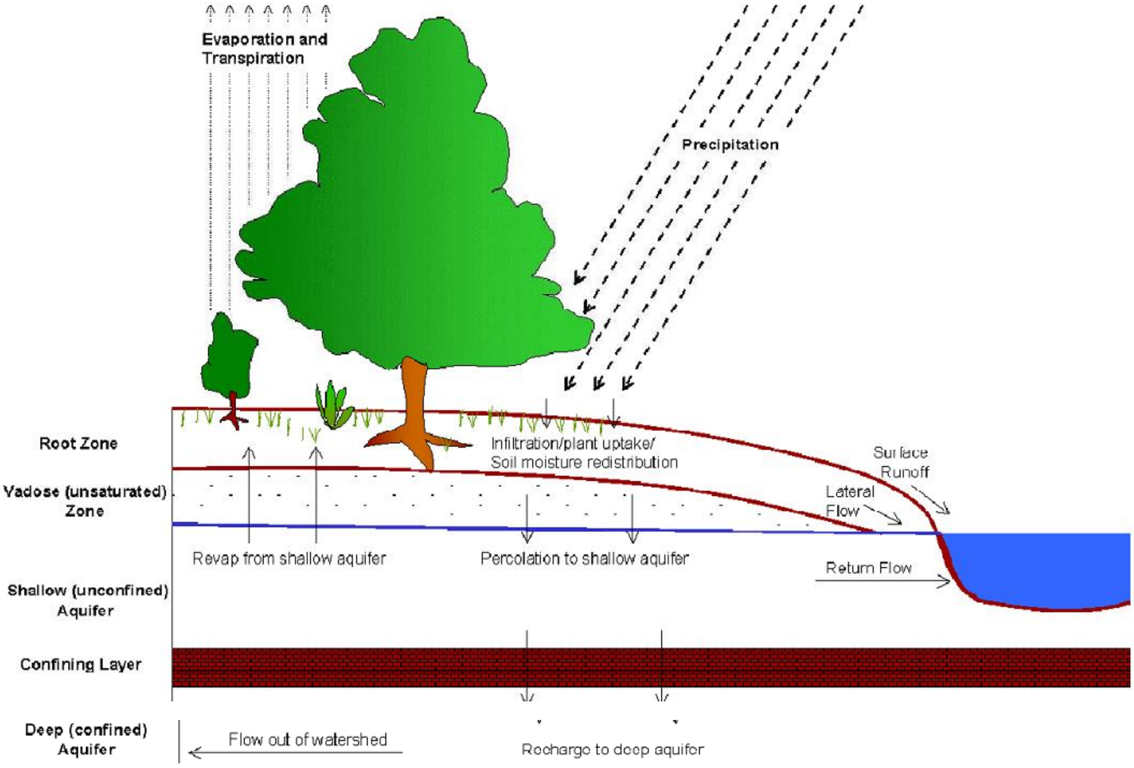


Figure3.3. Schematic representation of the hydrological cycle (Neitsch et al., 2005)

3.3.1 Surface Runoff Generation

Surface runoff also known as surface flow is that portion of precipitation that, during and immediately following a storm event, ultimately appears as flowing water in the drainage network of a watershed (Huggins, 1982). Surface runoff is influenced by soil type, rainfall intensity, topography of the watershed, and vegetation type.

SWAT model uses hourly and daily time step data to calculate surface runoff. The Green & Ampt method is used for hourly data and an empirical SCS Curve number is used for daily computation. SCS method stands for Soil Conservation Service method which is widely used for estimating flood on small to medium sized ungauged drainage basins. It was developed originally as a procedure to estimate runoff volume and peak discharge for design of soil conservation works and flood control project (Maidment, The Handbook of Hydrology). The SWAT model estimates runoff volume by using the Soil Conservation Service (SCS) curve number technique (USDA, 1972). The general equation for the SCS curve number method is expressed by equation as below

$$Qsurf = \frac{(Rday - Ia)^2}{(Rday - Ia + S)} \text{-------------------------------------equation 3.2}$$

Where, Qsurf is the accumulated runoff or rainfall excess (mm),

Rday is the rainfall depth for the day (mm water),

Ia is initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm water), S is retention parameter (mm water). The retention parameter varies spatially due to changes with land surface features such as soils, land use, slope and management practices. This parameter can also be affected temporally due to changes in soil water content. It is mathematically expressed as:

$$S = 25.4 * \left(\frac{1000}{CN} - 10 \right) \text{--------------------------------------Equation 3.3}$$

Where, CN is the curve number for the day and its value is the function of land use

Practice, soil permeability and soil hydrologic group.

The initial abstraction, Ia, is commonly approximated as 0.2S and the accumulated rainfall excess equation becomes: The entire database required by the SWAT model will be developed for the study area.

The main procedure and various steps followed in model application are explained below: SWAT project setup, Watershed delineation, HRU Analysis, Write input table, Edit SWAT Input, SWAT Simulation.

HRUs are the Hydrological response unit that divides the watershed into various homogeneous units based on the land use, soil type, and slope at each grid.

SWAT requires land use and soil data to determine the HRUs for each sub-basin. The land use and soil map have been imported in the model. Land use category is used to specify the land use layer and soil look up table is used to specify the type of soil to be modelled for each category.in the soil layer, linked to the SWAT database and reclassified land use and soil map. The soil map reclassified the database in 4 hydrological soil group (HSG) named A, B, C, D based on their infiltration rate.

3.3.2 Potential Evapotranspiration

Evapotranspiration is responsible for significant water losses from a watershed. Types of vegetation and land use significantly affect ET. Factors that affect ET include plant type, the plant’s growth stage or level of maturity, rooting depth, per cent soil cover, solar radiation, humidity, temperature, and wind speed. The amount of water transpired depends on the rooting depth of plants because water transpired through leaves is extracted by the roots from the soil in the root zone. Plants with deep-reaching roots can transpire more water than a similar plant with a shallow root system. Solar radiation is the major source of energy for ET and usually contributes from 80 to 100 per cent of the total ET.

Potential Evapotranspiration is a collective term that includes evaporation from the plant (transpiration) and evaporation from the water bodies and soil. Evaporation is the primary mechanism by which water is removed from a watershed. An accurate estimation of evapotranspiration is critical in the assessment of water resources and the impact of land use change on these resources. There are many methods that are developed to estimate potential evapotranspiration (PET). SWAT provides three options for PET calculation: Penman-Monteith (Monteith, 1965), Priestley-Taylor (Priestley and Taylor, 1972), and Hargreaves

(Hargreaves et al., 1985) methods. The methods have various data needs of climate variables. Penman- Monteith method requires solar radiation, air temperature, relative humidity and wind sped; Priestley-Taylor method requires solar radiation, air temperature and relative humidity; whereas Hargreaves method requires air temperature only. For this study Penman-Monteith Mothedd was selected in the SWAT Set up option. Because The Penman–Monteith model is probably the most suitable ET model for watershed studies, The Penman–Monteith approach includes all parameters that govern energy exchange and the corresponding latent heat flux (evapotranspiration) from uniform expansion of vegetation.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$ -------------------------Equation 3.4

ETo evapotranspiration [mm day^{-1}]

Rn net radiation at the crop surface [MJ m^{-2} day^{-1}]

G soil heat flux density [MJ m^{-2} day^{-1}]

T mean daily air temperature at 2 m height [°C]

U2 wind speed at 2 m height [m s^{-1}]

es saturation vapour pressure [kPa]

ea actual vapour pressure [kPa]

es - ea saturation vapour pressure deficit [kPa]

Δ slope vapour pressure curve [kPa $°C^{-1}$]

γ psychrometric constant [kPa $°C^{-1}$]

3.3.3 Ground Water Flow

To simulate the ground water, SWAT partitions groundwater into two aquifer systems: a shallow, unconfined aquifer which contributes return flow to streams within the watershed and a deep, confined aquifer which contributes return flow to streams outside the watershed (Arnold et al., 1993). In SWAT the water balance for a shallow aquifer is calculated with equation.

$aqsh, i = aqsh, i - 1 + Wrchrg - Wrevap - Wdeep - Wpump, sh$----------------Equation 3.5

Where, aq sh, i is the amount of water stored in the shallow aquifer on day i (mm), aq sh, i-1 is the amount of water stored in the shallow aquifer on day i-1 (mm),

Wrchrg is the amount of recharge entering the aquifer on day i (mm),

Qgw is the ground water flow, or base flow, or return flow, into the main channel on day i (mm), W revap is the amount of water moving in to the soil zone in response to water deficiencies on day i (mm), W deep is the amount of water percolating from the shallow aquifer in to the deep aquifer on day i (mm), and Wpump, sh is the amount of water removed from the shallow aquifer by pumping on day i (mm).

3.3.4 Flow Routing Phase

The second component of the simulation of the hydrology of a watershed is the routing phase of the hydrologic cycle. It consists of the movement of water, sediment and other constituents (e.g. nutrients, pesticides) in the stream network.

Two options are available to route the flow in the channel network: the variable storage and Muskingum methods. The variable storage method uses a simple continuity equation in routing the storage volume, whereas the Muskingum routing method models the storage volume in a channel length as a combination of wedge and prism storages. In the latter method, when a flood wave advances into a reach segment, inflow exceeds outflow and a wedge of storage is produced. As the flood wave recedes or retreat, outflow exceeds inflow in the reach segment and a negative wedge is produced. In addition to the wedge storage, the reach segment contains a prism of storage formed by a volume of constant cross-section along the reach length. Both of the methods are variations of the kinematic wave model. In this study due to its simplicity, the variable storage model was selected. SWAT assumes the main channels are a trapezoidal shape. Storage routing is based on the continuity equation for a given reach:

$V_{in}-V_{out}=\Delta V stored$---Equation 3.6

Where: Vin is the volume of inflow during the time step (m3H2O)

Vout is the volume of outflow during the time step (m3H2O)

ΔVstored is the change in the volume of storage during time step (m3H2O)

3.3.5 Evaluation of Data (Checking the Consistency of Data) quality

The most common method of checking for consistency of record is Double Mass Curve analysis (DMC). The curve is plot on arithmetic graph paper, of cumulative rainfall collected at a gauge where measurement condition may have changed significantly against the average of the cumulative rainfall for the same period of record collected at several gauge in the same region. The data is arranged in the reverse order that is the latest record ass the first entry and the oldest record as the last entry in the list.

The series data Stream flow of Geba catchment were checked the unrealistic data record or the outlier. An outlier is an observation that appears to deviate markedly from other observations in the sample. Identification of potential outliers is important for the following reasons.

1. An outlier may indicate bad data. For example, the data may have been coded incorrectly or an experiment may not have been run correctly. If it can be determined that an outlying point is in fact erroneous, then the outlying value should be deleted from the analysis (or corrected if possible).
2. In some cases, it may not be possible to determine if an outlying point is bad data. Outliers may be due to random variation or may indicate something scientifically interesting. In any event, we typically do not want to simply delete the outlying observation. However, if the data contains significant outliers, we may need to consider the use of robust statistical techniques.

The monthly flow data of the Geba River was checked by the Grubb's test and there is no outlier detected.

3.3.6 Approach in Arc Swat Model

The SWAT (Soil and Water Assessment Tool) watershed model is one of the most recent models developed at the USDA-ARS (Arnold et al., 1998) during the early 1970's. SWAT model is semi-distributed physically based simulation model and can predict the impacts of land use change and management practices on hydrological regimes in watersheds with varying soils, land use and management conditions over long periods and primarily as a strategic planning tool (Neitsch, et al, 2005). The interface of SWAT model is compatible with ArcGIS that can integrate numerous available geospatial data to accurately represent the characteristics of the watershed.

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

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 (Arnold et al., 1998). Stream flow is determined by its components (surface runoff and ground water flow from shallow aquifer).The basic model inputs are rainfall, maximum and minimum temperature, solar radiation, wind speed, relative humidity, land use, soil and topographic data.

3.3.7 Weather Generator Data Preparation

SWAT requires daily precipitation (mm), maximum/minimum air temperature (°C), solar radiation (MJ/m²/day), wind speed (m/s) and relative humidity (%). in the study area have data gaps. As SWAT has a built in weather generator called WGEN (Richardson et., 1998) that is used to fill the gaps. All the missing values are filled with No data identifier, -99.

For the sake of data generator, weather parameters were developed by using the weather parameter calculator PCPSTAT and dew point temperature calculator DEW02, which were downloaded from the SWAT web site (http://www.brc.tamus.edu/swat/soft_links.html) in this study weather generator parameters were calculated for Mekelle observation station. The weather generator parameters used and their values are in Appendix A.

3.3.8 Solar Radiation

Once water is introduced to the system as precipitation the available energy solar radiation exerts a major control on the movement of water in the land phase of the hydrologic cycle. Arc SWAT takes the daily solar radiation but the data acquired from the National Meteorological

Agency (NMA) is sunshine hour, hence a conversion of variable were made using Angstrom (1994) empirical equation.

$$R_s = (a_s + b_s \frac{n}{N})R_a$$ --Equation 3.7

Where Rs solar or shortwave radiation [$MJm^{-2}day^{-1}$]

n actual duration of sunshine [hour]

N maximum possible duration of sunshine or daylight hour [hour]

Ra extraterrestrial radiation [$MJm^{-2}day^{-1}$]

a_s regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days(n=0)

$a_s + b_s$ fraction of extraterretrial radiation reaching the earth on clear days (n=N).

3.4 SWAT model inputs

3.4.1 Digital Elevation Model (DEM)

The spatially distributed data (GIS input) needed for the Arc SWAT interface include the Digital Elevation Model (DEM), soil data, land use and stream network layers. Data of the weather and river discharge are also used for prediction of stream flow and calibration purposes; observed daily rainfall data and discharge data are obtained from the Meteorology and Hydrology Department, and the Ministry of Water Irrigation and Electricity.

Taking seven rainfall stations, such as Adigrat, Atsbi, Senkata, Wukro, Mekelle, Hykmeshal and Tsgereda and one gauged station discharge at Geba near Mekelle for using calibration. For this specific study a DEM with a resolution of 90m was used, which was sourced from ASTER GDEM official website (http://srtm.csi.cgiar.org/), and the observed daily discharge data period 1997-2014 used in this model is divided into two periods: model calibration (2000-2009) and validation (2010-2014). As the input data for the weather generator of SWAT, the daily temperature, humidity, wind speed and precipitation data are used.

The DEM forms the base to delineate the watershed boundary, stream network and create sub basins. This was performed by the pre-processing module of the SWAT. And sub-basin parameters such as slope, slope length, and defining of the stream network with its characteristics such as channel slope, length, and width were derived from the DEM.

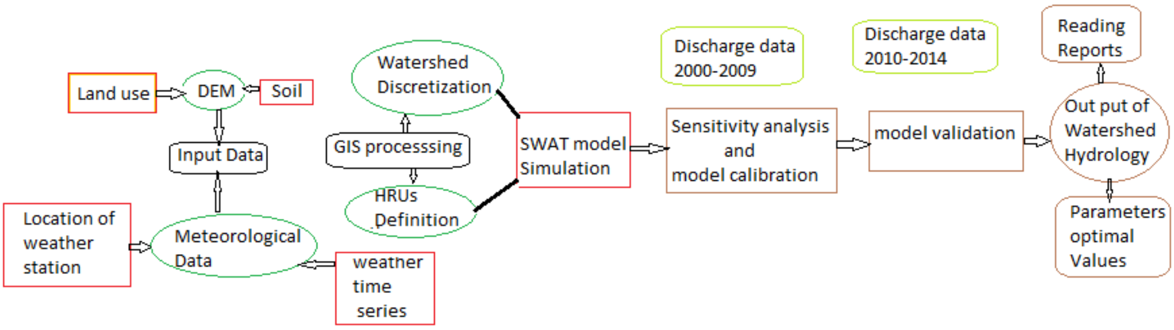


Figure 3.4. SWAT model component and methodology structure

3.4.2 Soil properties

A catchment rainfall-runoff response is related to the soil type in the catchment. The surface soil characteristics determine the infiltration rates and so the contributions from different flow components (surface runoff, through flow and base flow)

Soils in the study watershed are classified on the basis of the FAO/Globe soil (FAO/UNESCO,) classification system. The soil of suluh According to FAO six major soils types are identified for the study area (Figure 3.7). Humic cambisols (clay loam), Lithic Cambic Arenosols (sandy loam), Eutric Nitosols (clay), Orthic Acrisols (clay), Lithic Cambic Arenosols(sandy loam) and Lithic Eutric Nitosols (clay) are found in the

3.4.3 Land Use and Land Cover (LULC) data

Land use land cover in a catchment can often be correlated with the amount of interception storage/loss and actual evapotranspiration in a catchment.

The Land Use, Soil and Slope Definition option in the HRU Analysis menu allows to specify the land use, soil and slope themes that will be used for modeling using SWAT. These themes are then used to determine the hydrologic response unit (HRU) distribution in each sub watershed. SWAT require land use data to determine the area of each land category to be simulated within each sub basin. In addition to land use information, SWAT relies on soil data to determine the range of hydrologic characteristics found within each sub basin. Land Use, Soil and Slope Definition option guides the process of specifying the data to be used in the simulation and of ensuring that those data are in the appropriate format. In particular, the option allows the user to select land use or soil data that are in either shape or grid format. Shape files are automatically converted to grid, the format required by ArcGIS to calculate land use and soil distributions within the sub basins of interest. Select the Land Use / Soil / Slope Definition option from the HRU Analysis menu. The Land Use / Soil / Slope Definition dialog box will open.

The LULC map and all datasets were obtained from the Ministry Of Water Irrigation and Electric (MoWIE) as shape file format. The reclassification of the land use map was made to represent the land use according to the specific LULC types and the respective crop parameter for SWAT database. A lookup table that identifies the SWAT land use code for the different categories of LULC was prepared so as to relate the grid values to SWAT LULC classes.

Table 3.1 Land use/land cover types in the study area and redefine according to SWAT code

Original Land cover	Redefined Land cover according to the SWAT Database	SWAT_Code
INTENSIVELY CULTIVATED	Agricultural Land: Generic	AGRL
EXPOSED SAND SOIL SURFACE WITH SCAT.SCRUB & GRASS	Barren	BARR
DENSE SHRUBLAND	Range_Brush	RNGB
OPEN BUSHLAND	Hay	HAY

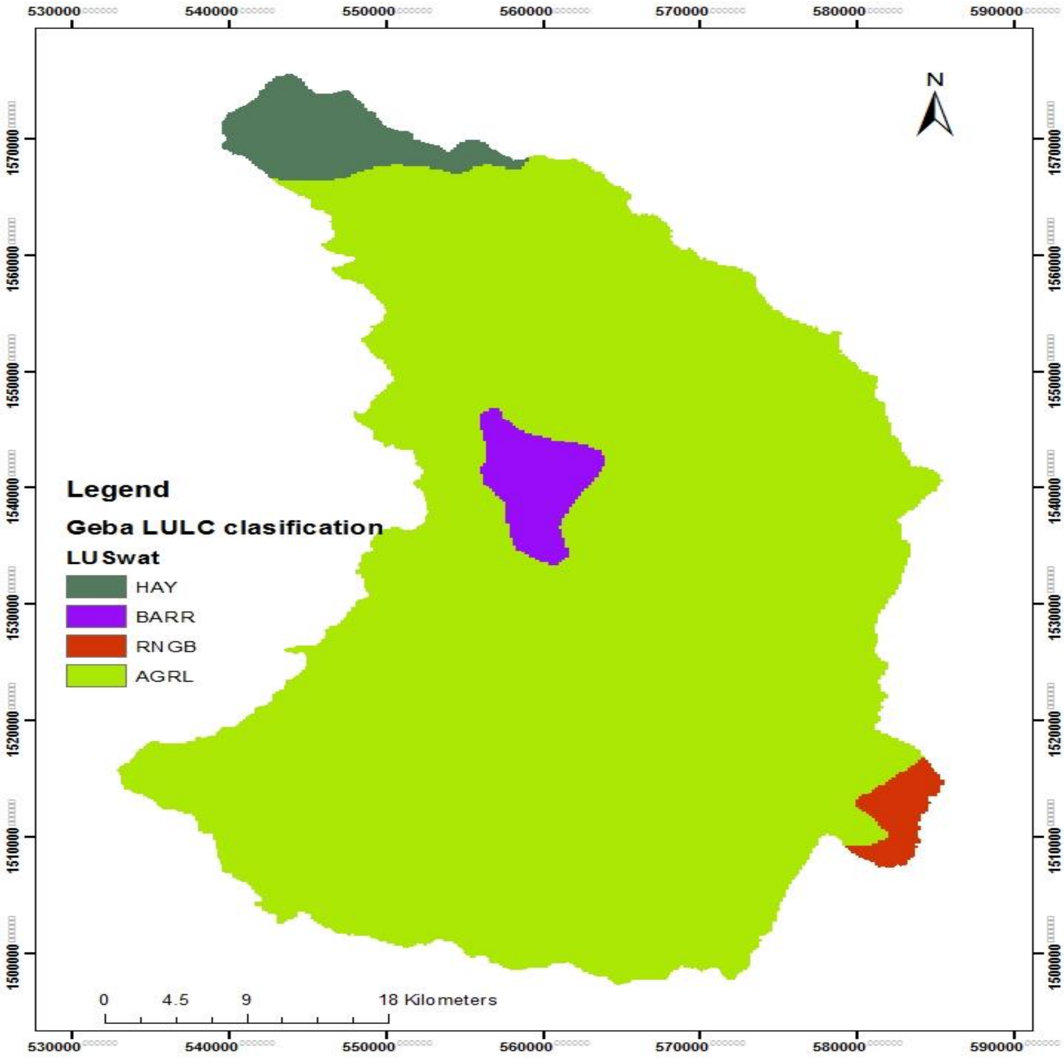


Figure.3.5 Geba LULC Classification

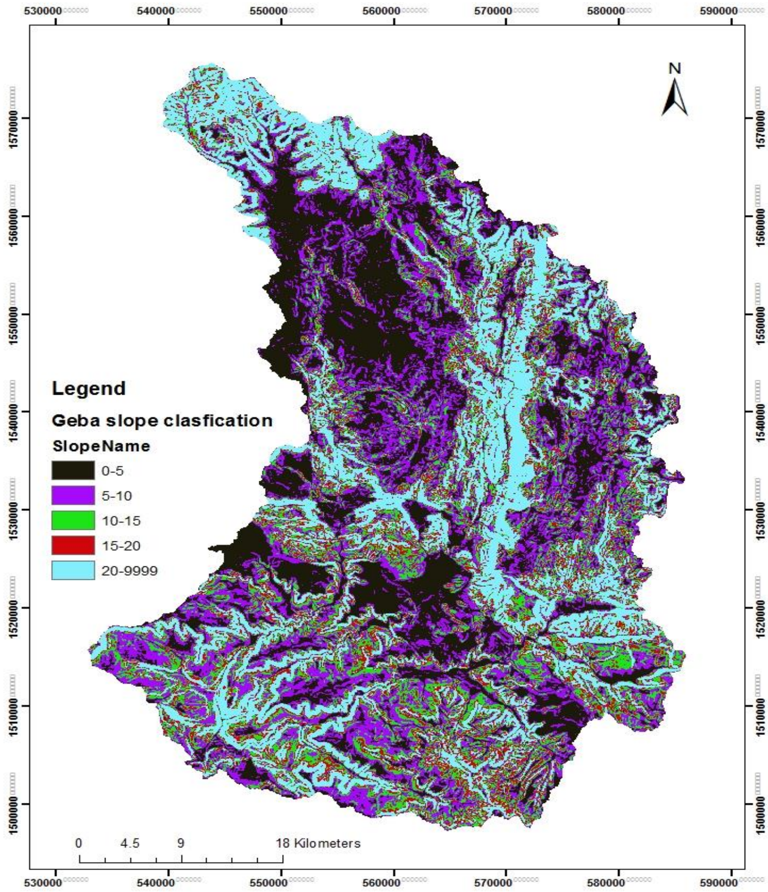


Figure.3.6 Geba Slope Classification

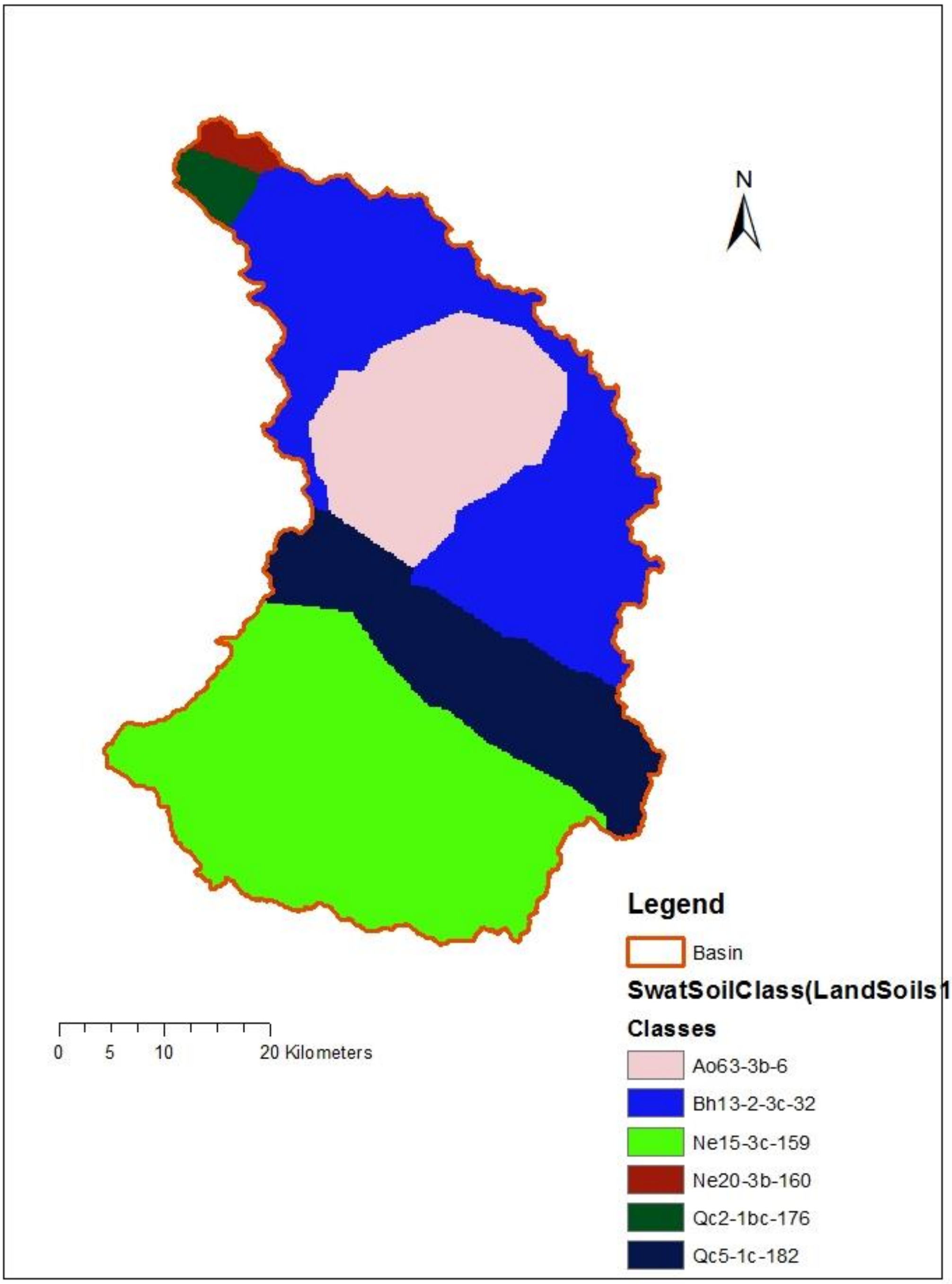


Figure.3.7 Geba Soil Classification

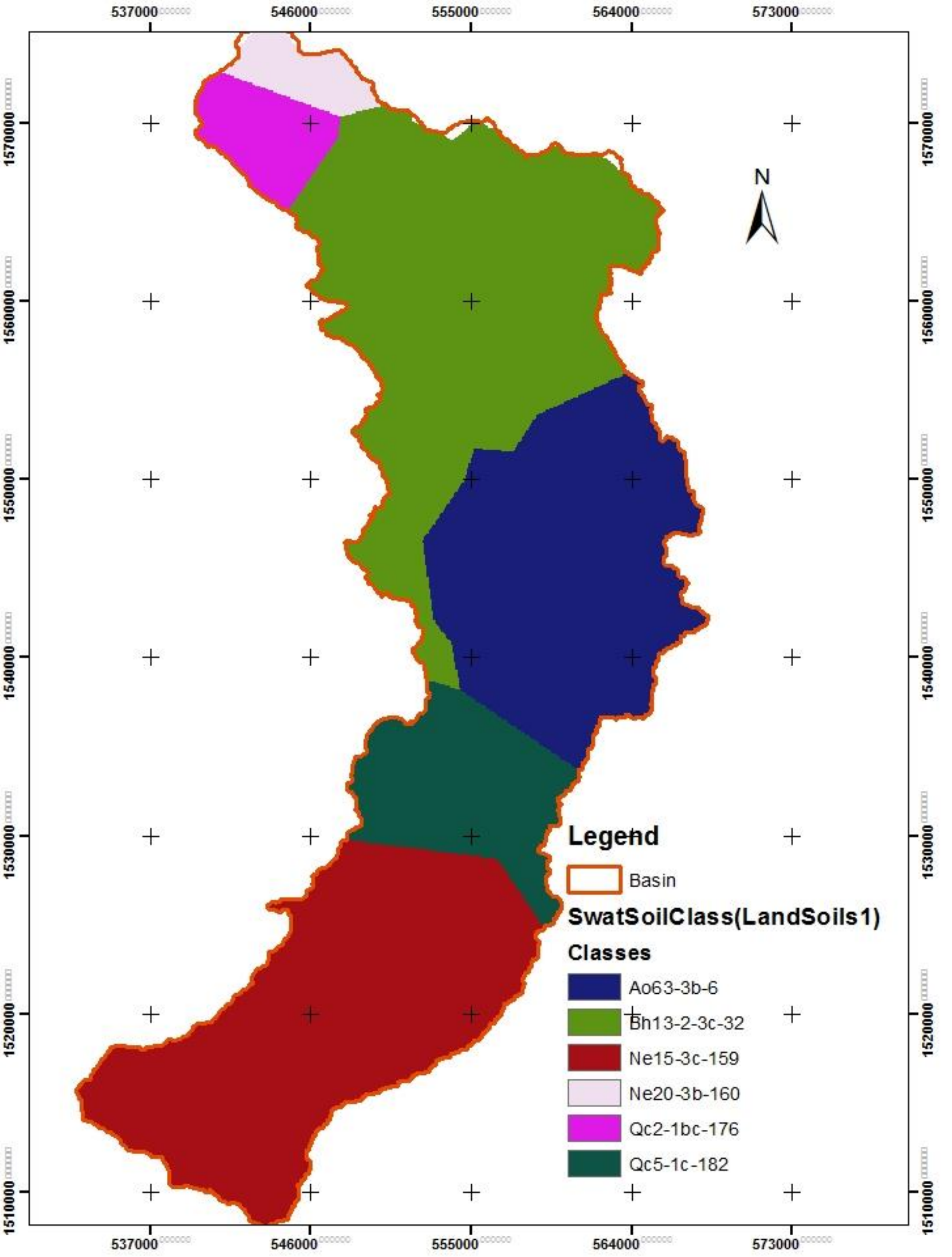


Figure.3.8 Suluh Soil Classification

3.4.4 Meteorological data

The SWAT model requires daily meteorological data that could either be read from a measured data set or be generated by a weather generator model which include precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity. Meteorological data collected from National Meteorological Service Agency of Ethiopia (NMSA) for Adigrat, Senkata, Hykmesshal, Atsbi, Wukro, Tsgereda and Mekelle stations are within the watershed and some are in the vicinity of watershed boundary. The SWAT weather generator model WXGEN was used to fill missing values in weather data. The Penman–Montheith method which utilizes the solar radiation, relative humidity and wind speed data records was employed for estimation of potential evapotranspiration (PET) for this specific study. Meteorological stations were geo referenced using latitude, longitude, and elevation data. The typical quality of rainfall data was checked by Double Mass Curve and cross correlation between the stations. The correlation coefficient among the stations on monthly rainfall amount implies a good agreement or consistency of data record on the monthly rainfall series of the gauging stations. The climate data were finally prepared in .dbf format and imported to the SWAT model database.

Table 3.2 correlation of monthly rainfall of Stations

Variables	ATSB	AG	HML	MEK	SEN	TSG	WU
ATSB	**1**	**0.7080**	**0.6830**	**0.7922**	**0.7888**	**0.6105**	**0.7596**
AG	**0.7080**	**1**	**0.6693**	**0.7351**	**0.7551**	**0.6619**	**0.7114**
HML	**0.6830**	**0.6693**	**1**	**0.7650**	**0.7652**	**0.7271**	**0.8743**
MEK	**0.7922**	**0.7351**	**0.7650**	**1**	**0.7725**	**0.7456**	**0.8117**
SEN	**0.7888**	**0.7551**	**0.7652**	**0.7725**	**1**	**0.6708**	**0.8027**
TSG	**0.6105**	**0.6619**	**0.7271**	**0.7456**	**0.6708**	**1**	**0.7116**
WU	**0.7596**	**0.7114**	**0.8743**	**0.8117**	**0.8027**	**0.7116**	**1**

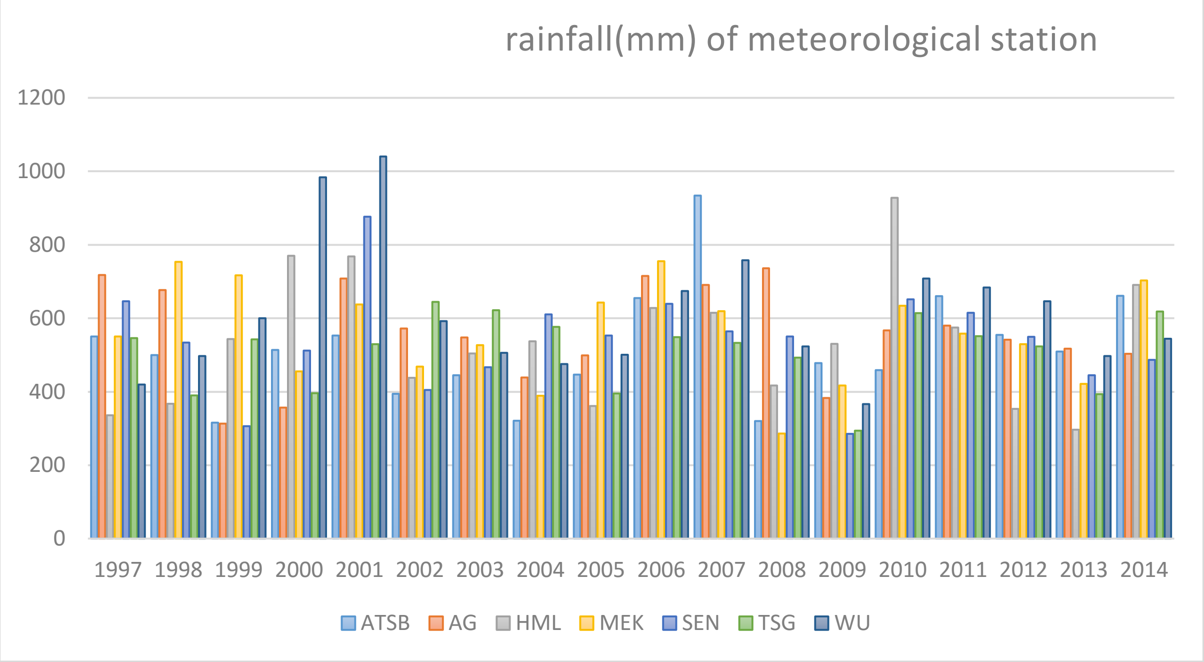


Figure3.9 yearly Rainfall of the Stations

Where, ATSB -Atsbi meteorological station, AG -Adigrat meteorological station

HML -Hykmeshal meteorological station, MEK- Mekelle meteorological station

SEN Senkata meteorological station, TSG- Tsgereda meteorological station

WU- Wukro meteorological station

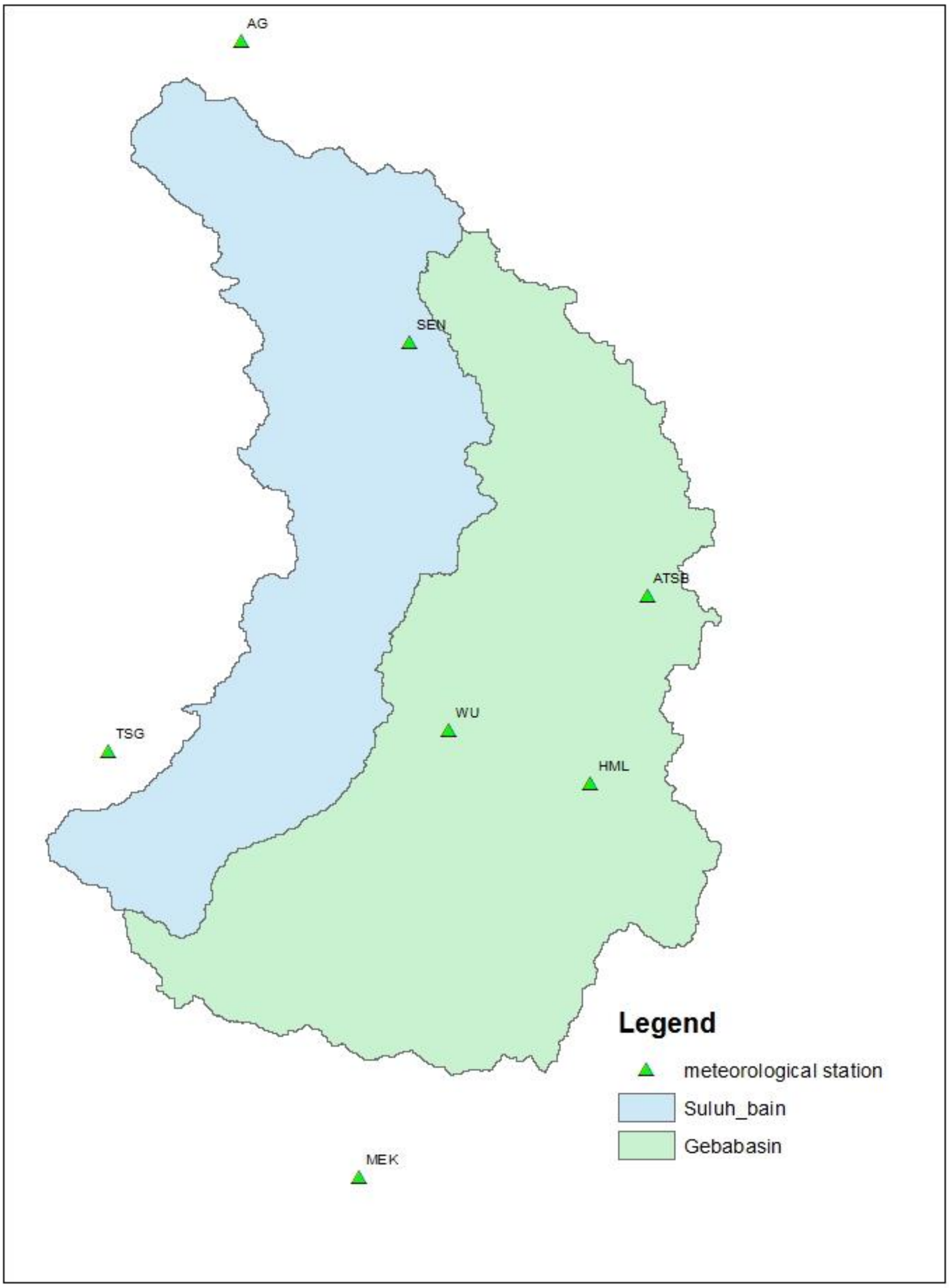


Figure3.10 Meteorological Station

Table 3.3Meteorological Station location

No.	Name Of Station	LAT	LONG	ELEVATION(m)	Data Series
1	Mekelle	13.47051	39.5312	2257	1997-2014
2	Adigrat	14.27814	39.44683	2497	1997-2014
3	Atsbi	13.8832	39.74142	2711	1997-2014
4	Senkata	14.06415	39.56873	2437	1997-2014
5	Hykmeshal	13.75	39.7	2121	1997-2014
6	Tsgereda	13.77379	39.34963	1977	1997-2014
7	Wukro	13.78749	39.59662	1987	1997-2014

3.4.5 Hydrological data

The hydrological data was required for performing sensitivity analysis, calibration and uncertainty analysis and validation of the model. Since the Suluh River is ungauged and have no hydrological data, then it is must to use neighbor gauged station that is Geba station. Daily river discharge data of the Geba River was obtained from the Hydrology Department of the ministry of water irrigation and electricity (MoWIE) for 1997-2014. It was used for performing sensitivity analysis, calibration and validation of the SWAT model. An automated baseflow separation technique (Arnold et al., 1999) was employed to separate the baseflow and surface runoff from the total daily stream flow records. This information was then used in order to get SWAT to correctly reflect basic observed water balance of the watershed.

3.5 Model set up

3.5.1 Watershed delineation

The first step in creating SWAT model input is delineation of the watershed from a DEM. Inputs entered into the SWAT model were organized to have spatial characteristics. Before going in hand with spatial input data i.e. the soil map, land use land cover (LULC) map and the Digital Elevation Model (DEM) 90m by 90m resolution were projected into the same projection called UTM Zone 37N, which is a projection parameters for Ethiopia.

A watershed was partitioned into a number of sub-basins, for modeling purposes. The watershed delineation process include five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-basin parameters. For the stream definition the threshold based stream definition option was used to define the minimum size of the sub-basins. Arc SWAT uses digital elevation model (DEM) data to automatically delineate the watershed into several hydrologically connected sub-watersheds. The watershed delineation operation uses and expands ArcGIS and Spatial Analyst extension functions to perform watershed delineation. The first step in the watershed delineation was loading the properly projected DEM. To reduce the processing time of the GIS functions, a mask was created over the DEM around the study area. Next, a polyline stream network dataset was burnt-in to force SWAT sub-basin reaches to follow known stream reaches. After the DEM grid was loaded and the stream networks superimposed, the DEM map grid was processed to remove the non-draining zones. The initial stream network and sub-basin outlets were defined based on drainage area threshold approach. The threshold area defines the minimum drainage area required to form the origin of a stream. The interface lists a minimum, maximum and suggested threshold area. The smaller the threshold area, the more detailed the drainage network delineated by the interface but the slower the processing time and the larger memory space required. In this study, defining of the threshold drainage area was done by successive re-run of the stream and outlet definition routine from the suggested to the minimum area until known smaller streams were created. Besides those sub-basin outlets created by the interface, outlets were also manually added. The watershed delineation activity was finalized by calculating the geomorphic sub-basin parameter.

3.5.2 Hydrological Response Units (HRUs)

Before executing SWAT, the distribution of hydrologic response units (HRUs) within the watershed must be determined based on the land use, soil and slope layers specified in the previous step. The interface allows to specify criteria to be used in determining the HRU distribution. One or more unique land use/soil/slope combination(s) (hydrologic response units or HRUs) can be created for each sub basin.

Subdividing the watershed into areas having unique land use, soil and slope combinations enables the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils. Hydrologic response units (HRUs) are lumped land areas within the sub-basin that are comprised of unique land cover, soil and management combinations. The runoff is estimated separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy in flow prediction and provides a much better physical description of the water balance. The land area in a sub-basin was divided into HRUs. The HRU analysis tool in Arc SWAT helped to load land use, soil layers and slope map to the project. The delineated watershed by Arc SWAT and the prepared land use and soil layers were overlapped 100%. HRU analysis in SWAT includes divisions of HRUs by slope classes in addition to land use and soils. The multiple slope option (an option which considers different slope classes for HRU definition) was selected. The LULC, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition. For this specific study a 10% threshold value for land use, 10% for soil and 10% for slope were used. The HRU distribution in this study was determined by assigning multiple HRU to each sub basin. 11 sub basin and 69 HRUs were created by integrating land use, soil and slope maps.

3.5.3 Importing Climate Data

The climate of a watershed provides the moisture and energy inputs that control the water balance and determine the relative importance of the different components of the water cycle.

The climatic variables required by SWAT consist of daily precipitation, maximum/minimum temperature, solar radiation, wind speed and relative humidity

3.5.4 Sensitivity analysis

Sensitivity analysis is a technique of identifying the responsiveness of different parameter involving in the simulation of hydrological process. Sensitivity analysis was performed to choose the most sensitive flow parameters that influence the catchment represented by SWAT to be used for calibration. This was achieved using the global sensitivity approach in semi-automated Sequential Uncertainty Fitting (SUFI2) algorithm. The global sensitivity analysis method takes into consideration, the sensitivity of one parameter relative to the other in order to give their statistical significances. The t-statistics and p-values of the parameters were used to rank to the different parameters considered to influence flow and the final selection done based on the significance of the ranked values. Table shows stream flow parameters that were tested for their sensitivity. These are useful in estimating the amount of flow from a catchment.

3.5.5 Calibration and Validation of model

An important part of any modeling exercise is the model calibration. Calibration is a process wherein certain parameters of the model are altered in a systematic fashion and the model is repeatedly run until the simulated results match field observed values within an acceptable level of accuracy. The process of model calibration is quite complex and limited by the model itself, input, and output data. Imperfect knowledge of watershed characteristics, mathematical structures of the hydrological processes and model limitations can cause error in calibration process. Before starting model calibration, field conditions at the site should be properly characterized. Lack of proper site characterization may lead to a wrong representation of the simulated system. Model calibration can be performed either by trial and error or by automated techniques. Automated calibration can be performed by means of specifying an objective or a set of objective functions (Schaake, 2003). Uncertainty in models and data leads to uncertainty in model parameters and model predictions. Automated parameter estimation techniques for model calibration are accurate and rapid. Validation of hydrologic models is a process of matching the simulated results with observed values without altering the calibrated parameters.

Following the sensitivity analysis result, model calibration will done to obtain optimum values for sensitive parameters. Calibration was accomplished by comparing the output of the SWAT model with the observed data at the same conditions. For calibration and validation, the Sequential Uncertainty Fitting (SUFI-2) calibration method within the SWAT Calibration and Uncertainty Procedures (SWAT-CUP) was used. The model was calibrated with observed Monthly discharge data for the period of 2000 to 2009and validated for the period of 2010 to 2014.

3.5.6 Evaluation of Model Performance

The performance and behavior evaluation of hydrological models is commonly made through comparison of different efficiency criteria. To achieve adequate reliability of the simulation models, it is important that they are rigorously calibrated and validated before any analysis and/or management scenario analysis are conducted. It is highly recommended to do the sensitivity analysis of model parameters before starting the calibration process. Model calibration and evaluation efforts are performed to achieve a reasonable correspondence between measured field data and the output of the model.

The model could be evaluated in order to determine the performance that how the model, simulated value fitted with the observed value. Statistics techniques like the coefficient of determination is one of the method to assess the model performance and also estimate that at which level simulate value fitted with the observed value. It shows the best fitness and efficiency of the model. R square describes the proportion of the total variance in the measured data that can be explained by the model. It ranges from 0.0 to 1.0. High values indicating better agreement. The goodness-of-fit measures used were the coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (ENS) value. The Nash and Sutcliffe simulation efficiency indicates the degree of fitness of the observed and simulated plots with the 1:1 line (Santhi et al.2002).

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}\left(q_{oi} - q_{si}\right)^2}{\sum_{i=1}^{n}\left(q_{oi} - \bar{q}_o\right)^2}$$

------------------------------------Equation 3.8

$$R^2 = \frac{\left[\sum_{i=1}^{n}\left(q_{si} - \bar{q}_s\right)\left(q_{oi} - \bar{q}_o\right)\right]^2}{\sum_{i=1}^{n}\left(q_{si} - \bar{q}_s\right)^2 \sum_{i=1}^{n}\left(q_{oi} - \bar{q}_o\right)^2}$$

----------------Equation 3.9

Where q_{oi} is observed flow at i and q_{si} is simulated flow at I days

ENS can have values ranging from -∞ to 1. If the Simulation I accurate, ENS is equal to 1. If the accuracy of the simulation result is smaller than the average value of the measured variables, then ENS will have a negative value. The sum is taken over the whole period of the data used for calibration. A value closer to unity, means the model explains the variance better. A negative modelling efficiency means the model prediction is worse than simply using the mean of the observed flow.

3.5.7 Selected Model Parameters transfer to the ungauged catchments

Transfer of model parameters to ungauged catchments generally needs a different study approach on the catchments. Runoff ungauged catchments is estimated by three procedures that are of different complexity. The first procedure applies a regionalization procedure where a regional model (Merz and Bl¨ oschl, 2004; Booij et al.2007) is established between catchment characteristics and model parameters that in turn are used for ungauged catchment modelling. A second procedure simply transfers model parameters from neighboring or nearby catchments to ungauged catchments to allow for runoff Simulation. In the third procedure parameter sets of gauged catchments are transferred to ungauged catchments by simple comparison of catchment size.

Parameter transfer by a regional model. The regional model developed for gauged catchments is used to estimate model parameters of ungauged catchments by respective Physical Catchment Characteristics (PCCs). Thus, prohibiting extrapolation using similarity of spatial. But it needs more than two gauged stream flow around the target station or ungauged station.

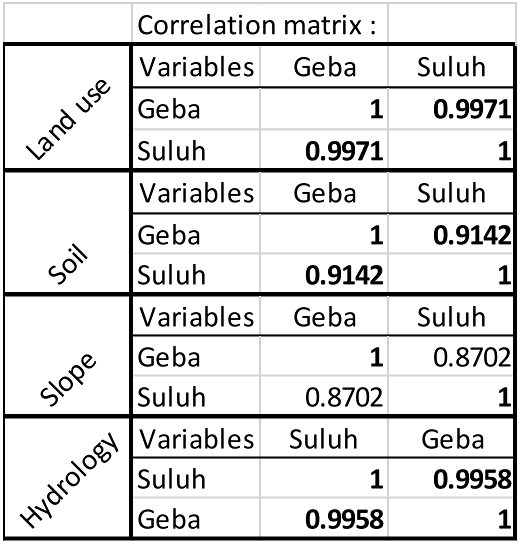
Parameter transfer by spatial proximity. The transfer of catchment information was based On some sort of PCCs similarity between ungauged and gauged catchments. The PCCs were Determined using Arc GIS integrated with Arc SWAT. Therefore, calibrated model parameter Values from gauged catchments were transferred to the ungauged catchments based on PCCs Similarities.

Parameters transfer by catchment size comparison (Area Ratio).

Model parameter sets of gauged catchments are transferred to ungauged catchments by catchment size comparison. It is assumed that catchment size is the dominant factor that affects the runoff hydrograph and that runoff may be rescaled by area ratio conversions. The method is a simple approximation, which works best when the gauging station is close to the respective outlet. This method does not consider the influences of vegetation, soil type, and geology on the flow in the investigated area.

For this study similarity of spatial proximity were selected. Based on the physical catchment characteristic similarity correlation of (Land use, soil classification, and slope) and hydrology the correlation of gauged Geba and ungauged Suluh catchment were checked. Then after the calibrated parameters in the gauged catchment of Geba were back to the original Arc SWAT project from SUFI-2 in SWAT-CUP and editing SWAT and run the program to simulate the runoff at Suluh watershed outlet. The correlation result of land cover, Soil, slope and hydrology of Geba and Suluh catchment is **99.42**%, **91.42%, 87.02**% and **99.58**% respectively. Which indicates that the two catchments are similar.

Table 3.3 correlation matrix of Geba and Suluh catchment



	Correlation matrix :		
Land use	Variables	Geba	Suluh
	Geba	1	**0.9971**
	Suluh	**0.9971**	1
Soil	Variables	Geba	Suluh
	Geba	1	**0.9142**
	Suluh	**0.9142**	1
Slope	Variables	Geba	Suluh
	Geba	1	0.8702
	Suluh	0.8702	1
Hydrology	Variables	Suluh	Geba
	Suluh	1	**0.9958**
	Geba	**0.9958**	1

Table3.5 Percentage of Catchment characteristic of Geba and Suluh Catchment

Physical catchment character similarity		**Geba (gauged) catchment**	**Suluh (ungauged) catchment**
Land Cover	Hay --> HAY	3.27%	9.06%
	Agricultural Land-Generic --> AGRL	93.26%	84.8%
	Barren --> BARR	2.27%	6.14%
	Range-Brush --> RNGB	1.2%	0%
Soil Classification	Ne20-3b-160	0.99%	2.46%
	Qc2-1bc-176	1.55%	3.83%
	Bh13-2-3c-32	30.47%	32.67%
	Ao63-3b-6	15.5%	23.33%
	Qc5-1c-182	15.6%	9.77%
	Ne15-3c-159	35.89%	27.95%
Slope	0-5	6.83%	35.83%

	5-10	23.59%	24.7%
	10-15	26.16%	11.98%
	15-20	28.86%	7.38%
	>20	14.56%	20.11%
	Hydrological Similarity		
Hydrology	PRECIP	547.3	562.4
	SURFACE RUNOFF Q	116.82	133.85
	LATERAL SOIL Q	12.29	19.53
	GROUNDWATER (SHAL AQ) Q	2.36	9.94
	GROUNDWATER (DEEP AQ) Q	1.08	1.58
	REVAP (SHAL AQ => SOIL/PLANTS)	24.79	25.9
	DEEP AQ RECHARGE	1.09	1.59
	TOTAL AQ RECHARGE	21.8	31.75
	TOTAL WATER YLD	132.55	164.9
	PERCOLATION OUT OF SOIL	21.81	31.76
	ET	397.8	377.5
	PET	1390.9	1744.2

4. Result and Discussion

4.1. Sensitivity Analysis of Stream Flow Parameters Results

A sensitivity analysis was implemented for fourteen years to identify sensitive parameters for model calibration. Twenty one hydrological parameters related to stream flow were tested. The sensitivity analysis method implemented in SWAT is a Latin hypercube one factor at a time (LH-OAT). The sensitivity analysis resulted in a list of parameters ranked from the most to the least sensitive. Based on this ranking, the eight most sensitive parameters for this area were chosen for calibration. The post calibration fitted values of these parameters by means of SUFI-2 are listed in Table 4.3 below.

Table 4.1 List of parameters and their initial ranges used for Sensitive analysis

Parameters	**Definition**	**Range Value**	
		Min	**Max**
CN2.mgt	SCS runoff curve number (dimensionless)	-0.2	0.2
ALPHA_BF.gw	Base-flow alpha factor (days)	0	1
GW_DELAY.gw	Groundwater delay (days)	30	450
GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0	2
GW_REVAP.gw	Groundwater “revap” coefficient (dimensionless)	0.02	0.2
REVAPMN.gw	Threshold depth of water in the shallow aquifer for “revap” to occur (mm)	0	500
RCHRG_DP.gw	Deep aquifer percolation fraction (dimensionless)	0	1
SOL_AWC().sol	Available water capacity of the soil layer (mm H2O/mm soil)	-0.25	0.25
SOL_K().sol	Saturated hydraulic conductivity (mm/h)	-0.25	0.25
SOL_ALB().sol	Moist soil albedo	-0.25	0.25
CH_N2.rte	Manning’s “n” value for the main channel	-0.01	0.3
CH_K2.rte	Effective hydraulic conductivity in main channel alluvium (mm/h)	-0.01	500
ALPHA_BNK.rte	Base-flow alpha factor for bank storage (dimensionless)	0	1
TLAPS.sub	Temperature laps rate (^{0}C/km)	-10	10
SLSUBBSN.hru	Average slope length (m)	10	150
HRU_SLP.hru	Average slope steepness	0	1
OV_N.hru	Manning’s n value for overland flow	0.91	31
CANMX.hru	Maximum canopy storage (mm)	0	100
ESCO.hru	Soil evaporation compensation factor (dimensionless)	0	1
EPCO.hru	Plant uptake compensation factor	0	1
SURLAG.bsn	Surface runoff lag time (days)	0.05	24

After a thorough preprocessing of the required input for SWAT model, flow simulation was performed for 18 years of recording periods starting from 1997 through 2014.The first three years of which was used as a warm up period and the simulation was then used for sensitivity analysis of hydrologic parameters and for calibration of the model. Out of the 21 parameter 8 of them are the most sensitive value. The sensitive parameters are identified based on the value of P-value and t-stat. the P- value having less than 0.05 is the more sensitive model parameter.

Table 4.2 Sensitivity rankings of stream flow parameters in the Geba catchment.

Parameter Name	t-Stat	P-Value	Rank
CN2.mgt	27.84	0	1
ALPHA_BNK.rte	16.89	0	2
SLSUBBSN.hru	-5.83	0	3
CANMX.hru	-5.57	0	4
SOL_AWC(..).sol	-4.68	0	5
CH_K2.rte	-3.1	0	6
HRU_SLP.hru	2.87	0	7
EPCO.hru	-2.59	0.01	8
ESCO.hru	-1.63	0.1	9
GW_DELAY.gw	1.59	0.11	10
OV_N.hru	-1.57	0.12	11
REVAPMN.gw	1.53	0.13	12
SOL_ALB(..).sol	-1.24	0.21	13
ALPHA_BF.gw	1.22	0.22	14
SOL_K(..).sol	-1.15	0.25	15
CH_N2.rte	-0.81	0.42	16
GW_REVAP.gw	0.79	0.43	17
RCHRG_DP.gw	-0.47	0.64	18
GWQMN.gw	-0.38	0.7	19
TLAPS.sub	-0.26	0.8	20
SURLAG.bsn	0.22	0.82	21

The global sensitivity analysis of twenty one flow parameters showed that, only eight were very sensitive to flow. The rankings of the flow parameters are presented in Table 5 while the fitted values for the most sensitive parameters are indicated in above Table 6. The most sensitive parameter was the SCS runoff curve number (CN2).The curve number estimates runoff based on the relationship between precipitation, hydrologic soil group and land uses. The other sensitive parameters included the Base-flow alpha factor for bank storage (ALPHA_BNK), Average slope length (SLSUBBSN), Maximum canopy storage (CANMX), Available water capacity of the soil layer (SOL_AWC), Average slope steepness (HRU), effective hydraulic conductivity (CH_K2) and Plant uptake compensation factor (EPCO). Although, the rest of the parameters were found not to be sensitive to flow in the catchment as their p-values were greater than 5%.

Table4.3 List of sensitive parameters, their calibrated and fitted values

Parameter Name	Fitted Value	Min_value	Max_value
R__CN2.mgt	0.1236	-0.2	0.2
R__SOL_AWC(..).sol	0.1655	-0.25	0.25
V__CH_K2.rte	445.498932	-0.01	500
V__ALPHA_BNK.rte	0.497919	0.274948	0.569494
V__SLSUBBSN.hru	36.18	10	150
V__HRU_SLP.hru	0.787	0	1
V__CANMX.hru	6.5	0	100
V__EPCO.hru	0.637365	0.0167	1

The extension (.mgt, .sol .rte, hru) refers to the SWAT input file where the parameter occurs. The qualifier (R__) refers to relative change in the parameter where the value from the SWAT database is multiplied by 1 plus a factor in the given range, while the qualifier (V__) refers to the substitution of a parameter by a value from the given range.

4.2. SWAT Model Calibration and Validation Result

4.2.1 Uncertainty Analysis Results for Geba River

SUFI-2 methods were used to calibrate the SWAT model. Table 4.4 summarizes the statistical performance measures for monthly hydrological process. Some previous studies (Moriasi et al. 2007; Santhi et al. 2001) suggested that model simulation should be judged as satisfactory if r2 is greater than 0.6 and Nash-Sutcliffe efficiency (NSE) is greater than 0.5. The comparison between the observed and simulated stream flow indicated that the SWAT model accurately captured the hydrologic characteristics of the study area and reproduced acceptable monthly discharge, which was verified by higher values of r2 and NSE (Fig. 4.1 and Fig. 4.2).

According the result of flow calibration shows **59%** of the observed data is bracketed by the 95PPU (P-factor) and r-factor had a value of **0.57**. For the validation **57%** of the measured data were bracketed by the 95%PPU while r-factor had value of **0.7**. The SUFI-2 results indicated that the coefficient of determination R^2 76% and Ns 75% for during the calibration period and R^2 68% and with Ns 66% in validation period.

The flow simulation during Calibration and validation is quite good having good result of R2 and ENs.

A review of published literature revealed performance ratings of very good (ENS>0.75), good (0.65<ENS<0.75, satisfactory (0.5<ENS<0.65), and unsatisfactory (ENS<0.5) for monthly simulations of stream flow (Moriasi et al., 2007; Santhi et al., 2001).

The graphical results of the model stream flow simulation performance during the Calibration and validation periods are shown in Figures 4.1 and 4.2 indicates adequate calibration and validation over the range of stream flow discharge. Likewise the model parameters were transferred as it is to the ungauged catchment of suluh since they have similar catchment character similarity. From the SWAT model output around 85% of the flow indicates surface runoff.

Table4.4. Uncertainty analysis result of SUFI-2 for Geba River

Geba River Calibration (2000-2009)				
Variable	p-factor	r-factor	R2	NS
FLOW_OUT_24	0.59	0.57	0.76	0.75
Validation period (2010-2014)				
FLOW_OUT_24	0.57	0.7	0.68	0.66

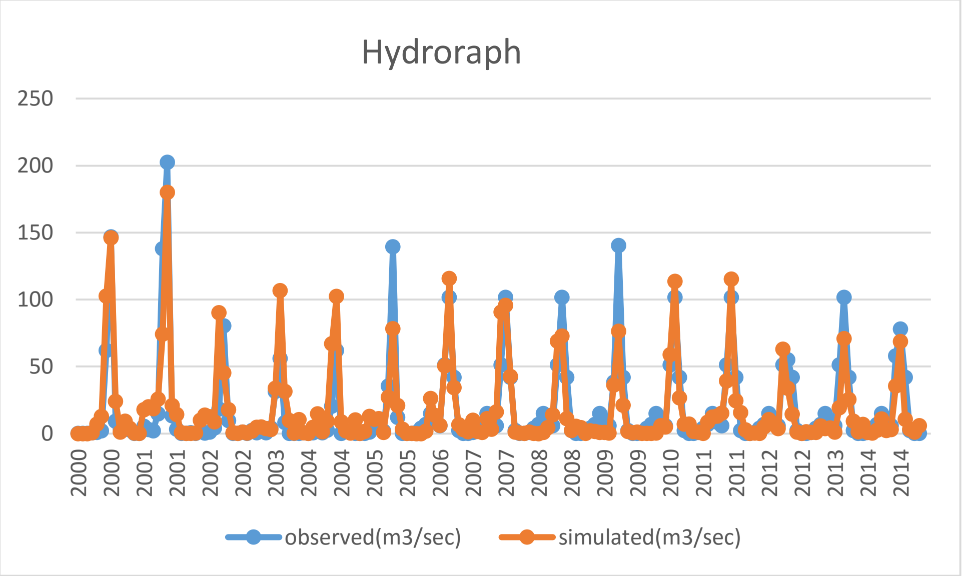


Figure 4.0 Hydrograph of Geba Observed versus Simulated

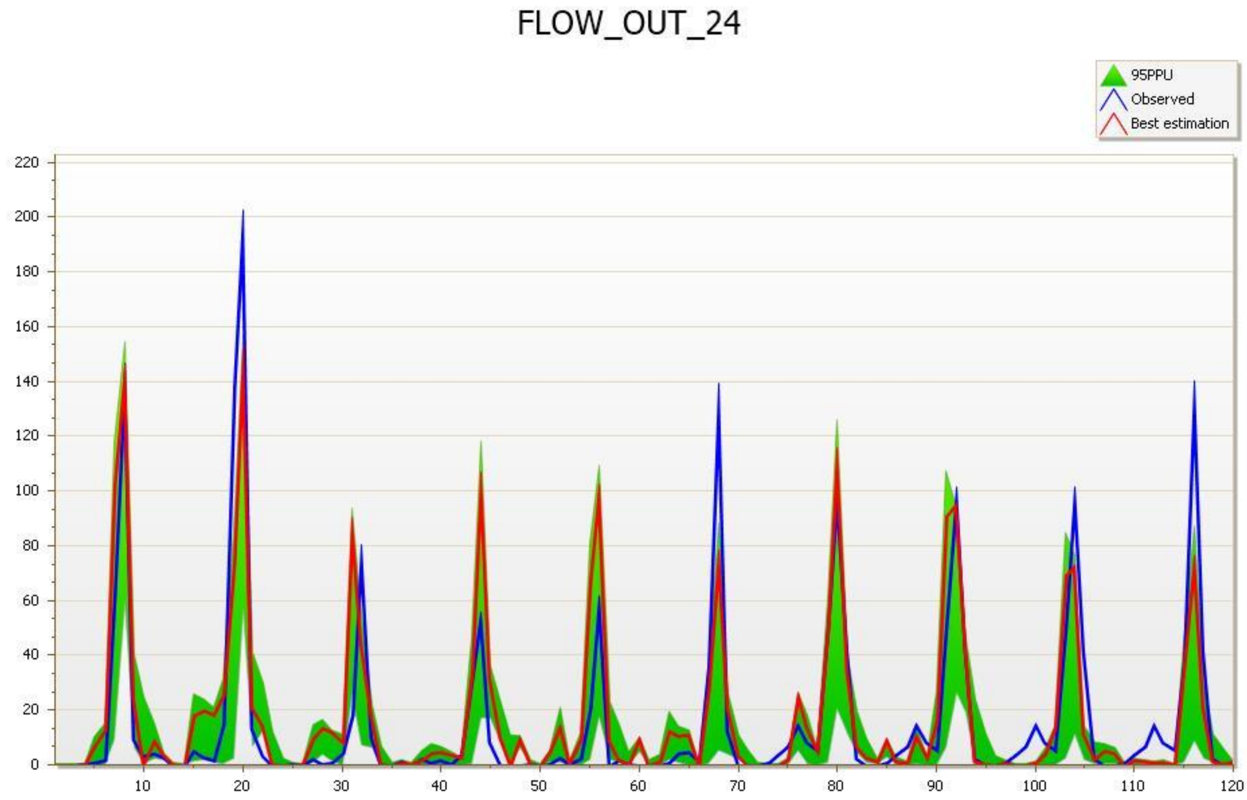


Figure.4.1 The 95% prediction Uncertain (95PPU) for Geba river flow Calibration (2000-2009)

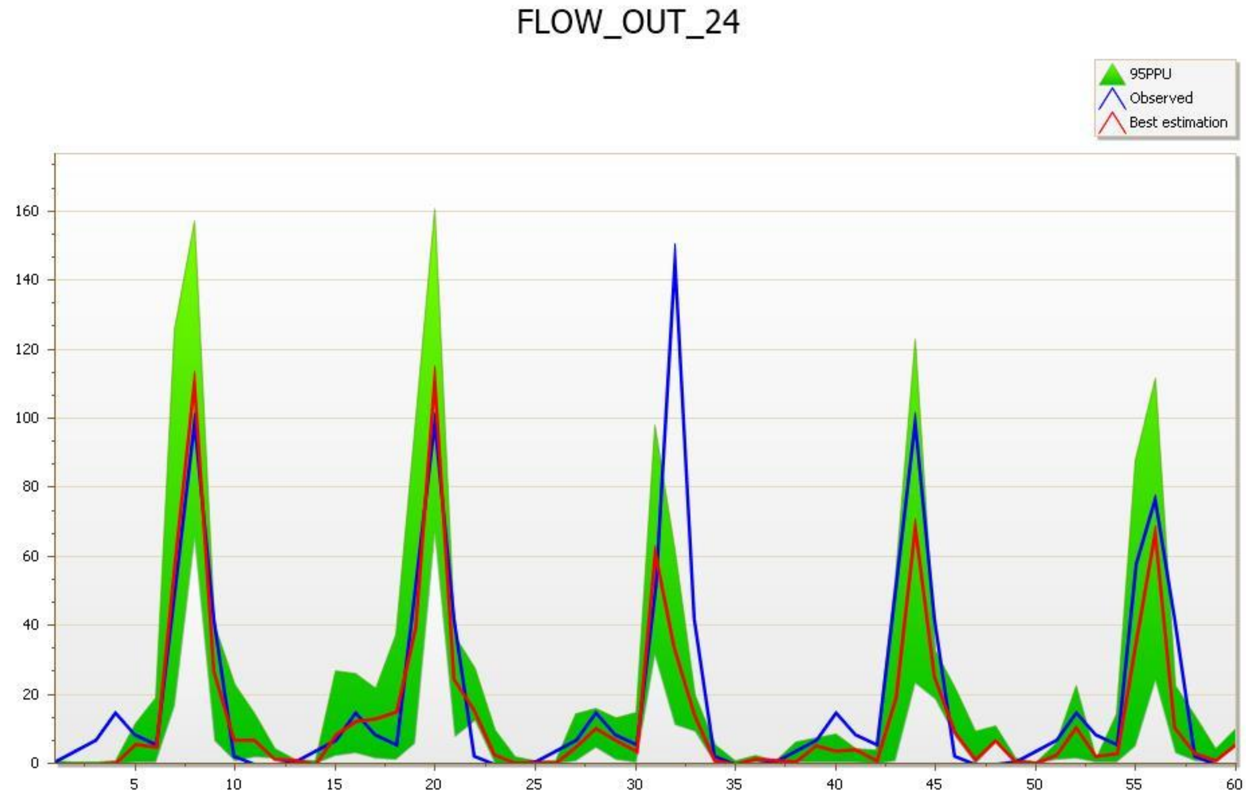


Figure4.2. The 95% prediction Uncertain (95PPU) for Geba river flow Validation (2010-2014)

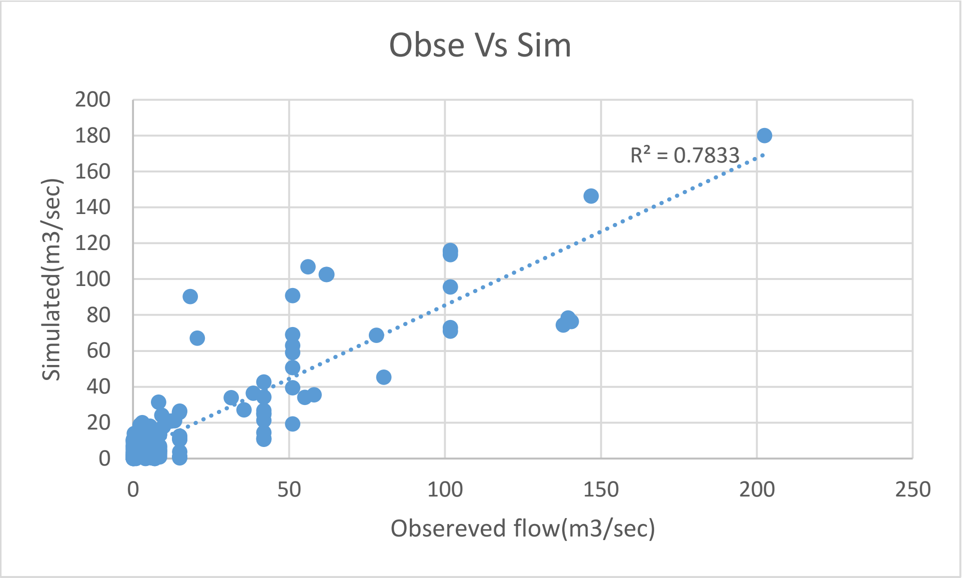


Figure4.3. Observed versus Simulated monthly stream flow at Geba water shed outlet

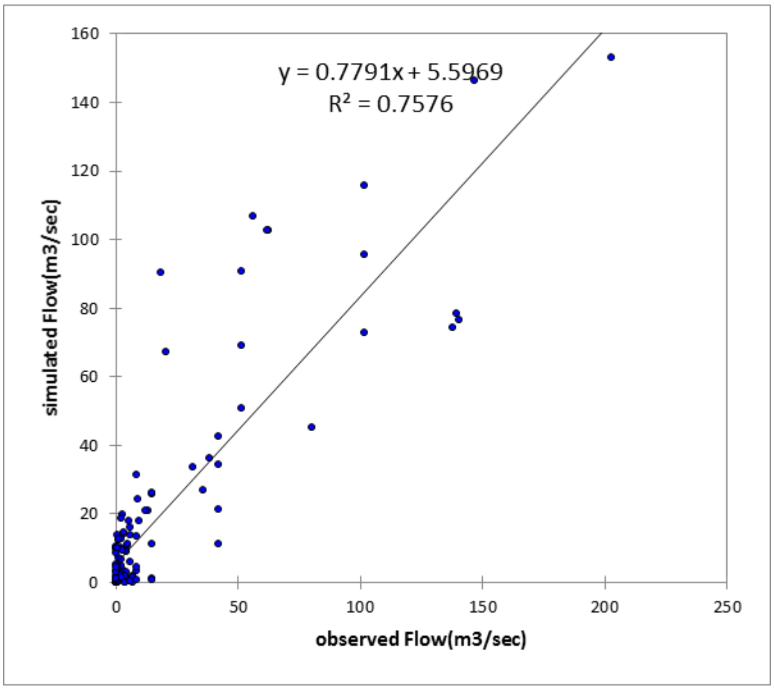


Figure 4.4. Scatter plot of calibrated (2000-2009)

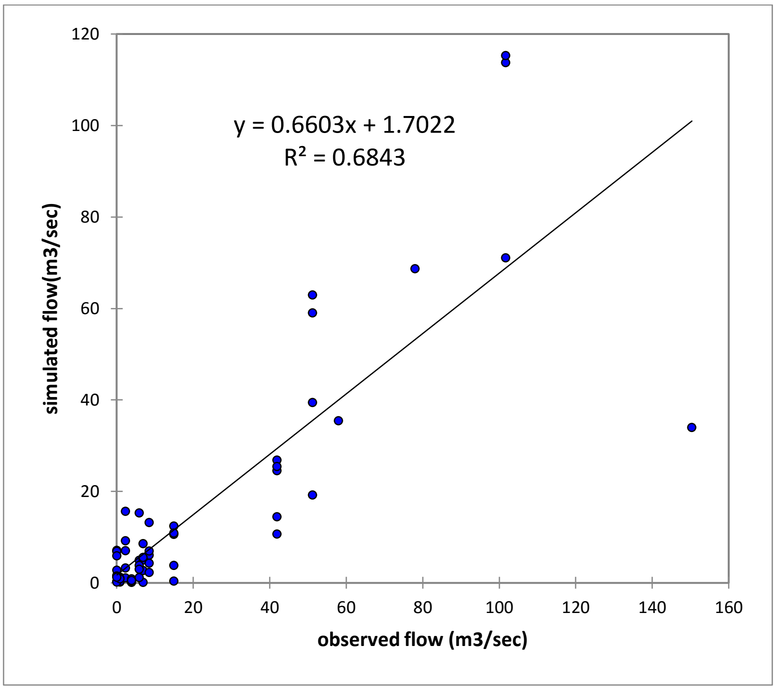


Figure4.5. Scatter plot of Validation (2010-2014)

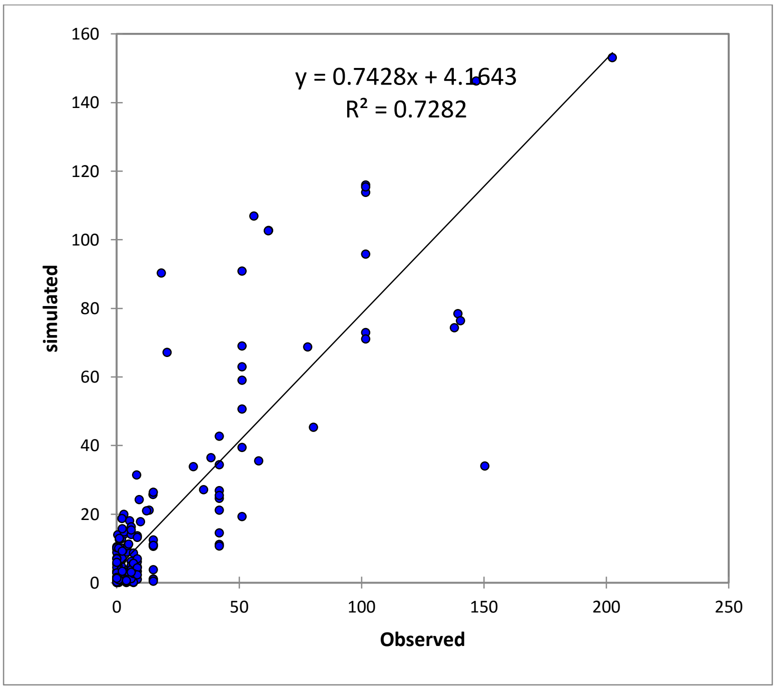


Figure 4.6 Scatter plot of calibration and validation period shows the correlation of the observed flow and simulated flow

From the figure 4.6 above the hydrological model of Geba is linearly correlated the observed flow and the simulated flow having with a coefficient of determination 73% and the model performance indicates that there is good correlation and agreement between observed and simulated flow. Then after the regional hydrologic model parameter were transferred from the Geba gauged catchment to the ungauged catchment of Suluh.

4.3 Model Result of Suluh catchment

4.3.1 Suitable model for hydrological process

A hydrologic model is a simplification of a real-world system (e.g., surface water, soil water, wetland, groundwater, and estuary) that aids in understanding, predicting, and managing water resources. Both the flow and quality of water are commonly studied using hydrologic models. In order to do this model representation of suluh catchment identification of hydrological process method have been accounting in this model. In the surface runoff model the daily rainfall method were preferred to generate the rainfall-runoff relationship. Potential Evapotranspiration of the suluh catchment is calculated based on the penman/Monteith because it considered all types of data needed for the model.

4.3.2 Evaluation of Meteorological and hydrological data

The meteorological and hydrological data of Suluh catchment were evaluated by the SWAT model and the result indicates that high rainfall exists in the rainy season mainly in June, July and August.

The maximum rainfall of the catchment is about 331mm during a month of August and similarly with surface runoff of 98.3mm as indicated in figure 4.7 and 4.8 below respectively. The detail value of figure 4.7, 4.8 and 4.9 of Suluh catchment is in appendix C.s

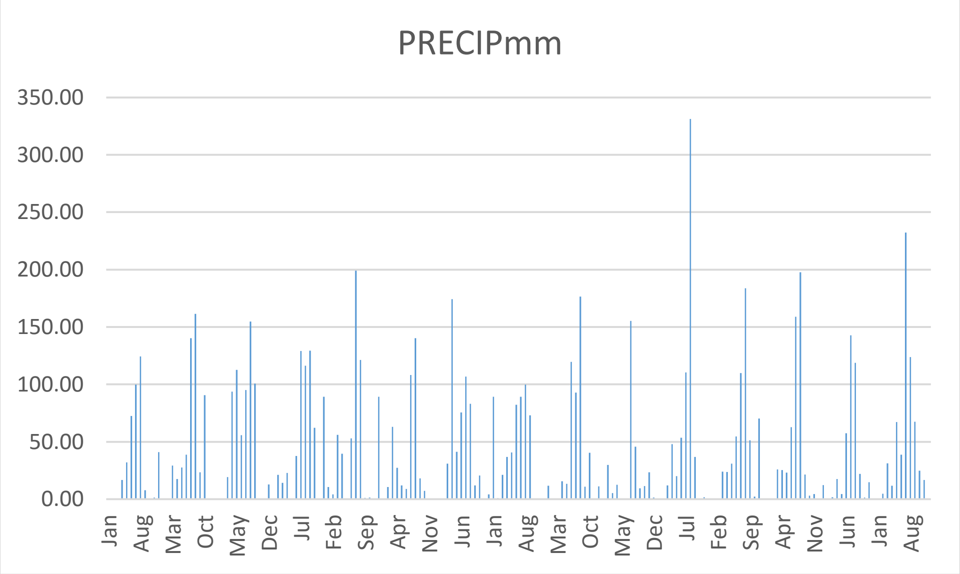


Figure4.7 monthly precipitation of Suluh

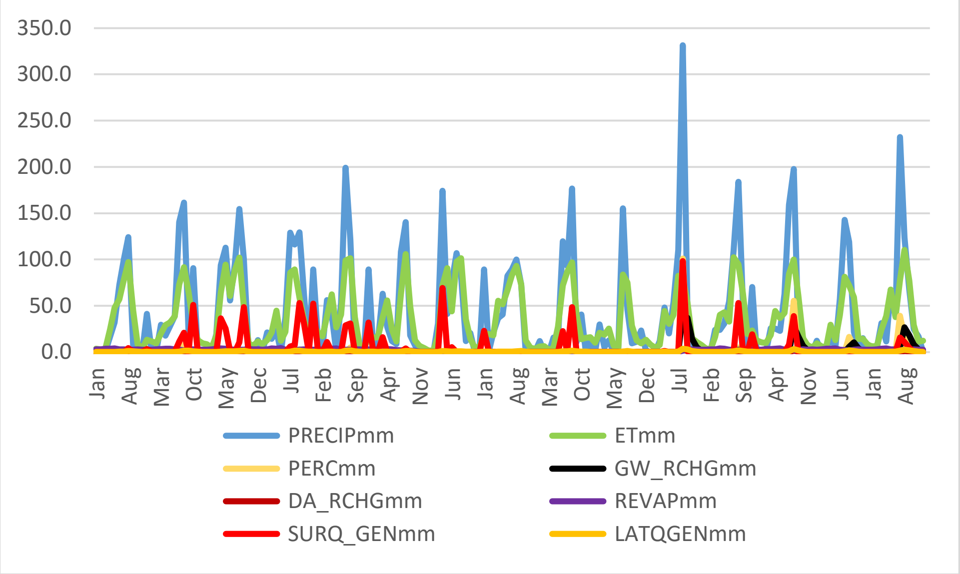


Figure 4.8 water balance of suluh catchment

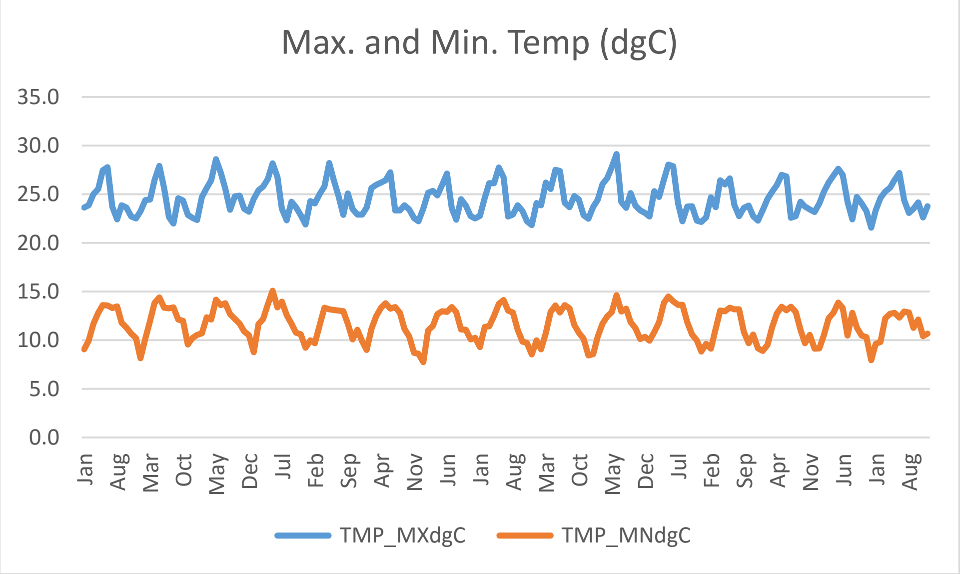


Figure 4.9 Maximum and Minimum Temperature of suluh

4.3.3 Regional model parameters

The regional parameters in one catchment have the influence on the general hydrological process of the watershed. Then after evaluation of regional model parameter of suluh were evaluated based on the identified suitable model of hydrological process.

The regional model parameters are identified by taking place the sensitivity analysis in the gauged catchment of Geba and transferred the regional parameters by the regionalization method of catchment characterization. The regional model parameters are listed in Table 4.3 and with the fitted value of model parameter in Table4.4 above.

4.3.4 Monthly runoff series of the Suluh catchment

Runoff series of the Suluh catchment was estimated based on the SCS method by SWAT model and the result is indicated below figure 4.10. Detail values are indicated in Appendix C.

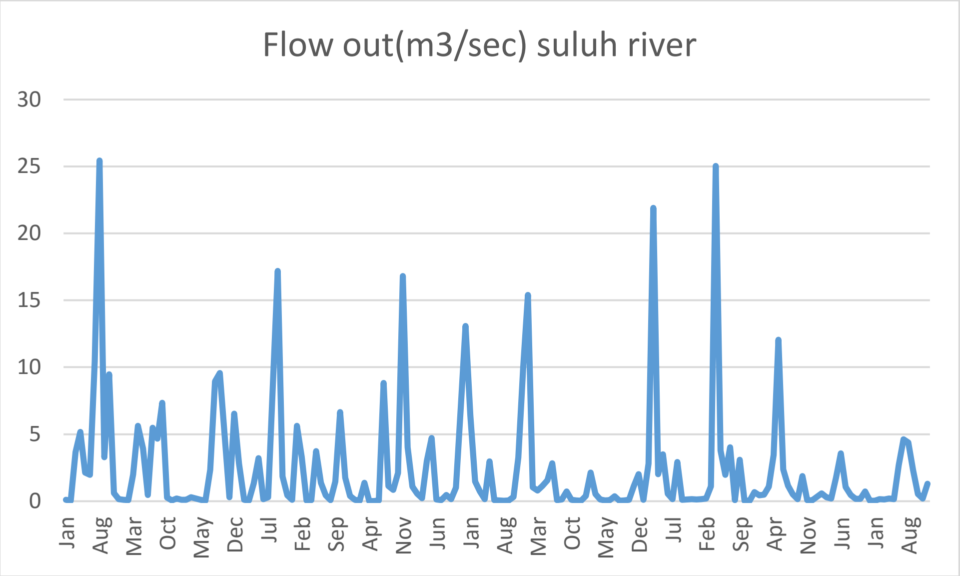
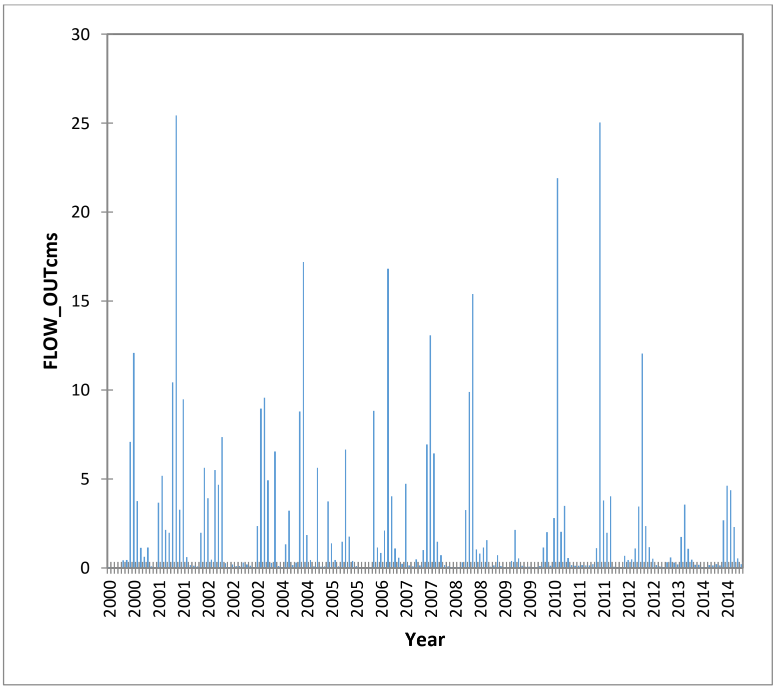


Figure4.10. a.Monthly flow of Suluh



b. out flow of suluh in a year

From the above figure 4.10 indicates that there is high runoff generation on the rainy season in August and July.

The result of this research finding on the SWAT version of 2012 hydrological modeling of on the ungauged Suluh catchment are the regional hydrological model parameters, the monthly runoff series , meteorological and hydrological data and the model of the hydrological process on the catchment.

Table.4.5 Annual water balance of Suluh watershed

YEAR	PREC	SURQ	LATQ	GWQ	PERCO	SW	ET	PET	WYLD
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
2000	481.97	56.96	5.61	10.54	15.31	77.71	360.1	1815.34	74
2001	739.82	151.08	8.71	10.11	58.41	53.27	546.21	1670.87	172.11
2002	526.76	70.74	6.44	4.43	7.86	47.64	447.24	1764.77	82.84
2003	536.53	81.21	7.01	3.05	16.64	60.63	418.73	1764.1	91.91
2004	566.39	99.03	6.29	2	12.88	58.03	450.77	1756.51	108.07
2005	485.3	37.1	6.06	0.91	6.47	38.02	455.78	1722.22	44.49
2006	618.81	84.62	7.95	4.18	29.87	61.03	473.33	1711.69	97.82
2007	582.66	76.69	8.33	10.16	38.88	57.95	461.85	1711	97.04
2008	551.69	81.41	7.64	2.54	16.12	75.8	428.56	1759.87	92.67
2009	306.85	7.97	3.74	0.09	1.68	29.55	339.8	1805.18	12.21
2010	630.96	80.81	8.52	4.16	50.87	68.55	451.78	1707.1	95.17
2011	592	88.86	6.66	4.51	13.55	59.76	491.71	1671.46	101.37
2012	545.47	45.89	7.5	7.05	36.19	37.76	477.89	1671.48	61.88
2013	439.2	14.7	6.1	2.14	16.45	32.54	407.16	1683.77	24.07
2014	540.73	30.84	7.31	2.65	38.03	38.27	458.82	1630.3	42.31

The annual monthly flow of Geba previously conducted by Tekeze master plan project from 1990-1990 were 184Mm^3 and recently from the Mekelle water supply project feasibility study Report from 1962 to 2005 analysis of average annual flow computing using the WATBALL software is 7.83m^3/sec as well as 98.6mm mean runoff depth. Then it is similar with the SWAT analysis for Suluh with a values of 115.6 Mm^3 of annual monthly flow from 2000-2014, 2.4m^3/sec average annual flow. The hydrograph shown below is the comparison of the Geba flow result of SWAT model and WATBALL model from Mekelle water supply project feasibility study of flow computation for the year of 2000-2005 for comparison the two models are most likely.

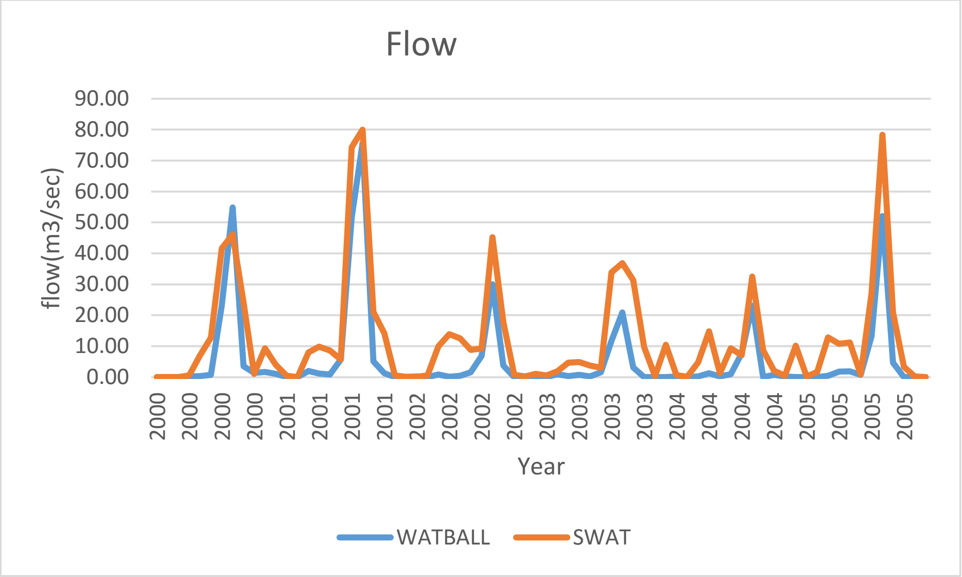


Figure 4.11 flow of Geba Model result of SWAT and result of WATBALL from Mekelle water supply study

5. Conclusion and Recommendation

In this study the SWAT model was used for the hydrological process on Suluh catchment in order to evaluate the meteorological and hydrological data of the catchment.

Transfer from gauged to ungauged catchments is the most critical factor for successful hydrological process predictions. To perform this first the sensitive parameter was identified from the donor catchment of Geba through the SWAT-CUP sensitive analysis and Transfer of selected model parameter was done based on the physical catchment characteristic similarity of the gauged and ungauged catchment in their Land use, soil and slope and it have high correlations between model parameters and catchment attributes. Two third (66.67%) and one third (33.33%) of the data was used for calibration and validation respectively. The calibrated SWAT model satisfactorily simulated stream flow with satisfactory statistical measures results. This is the first time the SWAT model has been used in the Suluh catchment. From this study all the regional hydrological model parameters, meteorological and hydrological data as well as hydrological process of the catchment was find. From the model result analysis indicates 85% of the flow from the total flow is contributed as surface runoff. The land cover of the catchment consists of Agricultural Land-Generic (AGRL) 86.27%, Barren (BARR) 5.6% and Hay (HAY) 8.13% with a soil type of Humic cambisols, Lithic cambic Arenosols, Eutric Nitosols, Orthic Arenosols and Lithic Eutric Nitosols.If all uncertainties are minimised, a well calibrated SWAT model can generate reasonable hydrologic simulation results in relation to land use, which is useful to water and environmental resources management policy, irrigation potential, and for Small scale hydropower development

5.1Recommendation

The hydrological finding of this study is calibrating a suitable model for the gauged catchment of Geba River and applying the same model for its ungauged catchment, in order to get runoff for the ungauged catchments of Suluh River. The importance of the study is in that the output data from the Model can be used in water resource planning and management for its irrigation potential and any water harvesting structures.

The following list shows recommendation of this study

- ✓ All available meteorological stations are around the vicinity and only one station is inside of the basin. In order to find better areal precipitation of the catchment additional weather station or meteorological station should be install inside of the watershed.
- ✓ As I mentioned above the model parameter transfer method regression technique is better but it needs more than two gauged stream flow data, therefore further study should be carried out.
- ✓ The uncertainty of discharge measurement should be minimized by improving data recording system, because in some of the year the whole year is filled only with one numerical value in case of Geba river. This value should lead to wrong hydrological model prediction.

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APPENDDIXS

APPENDIX A: Weather Generator Statistic and Probability Value

The statistical data desired to generate typical daily climate data for the sub basins for SWAT model is using the weather generator (WGN file). When the user specifies that simulated Weather will be used or when measured data is missing, climatic data will be generated. Following values were calculated for weather stations used in the research.

TMP_MX (mon): average daily maximum temperature in month [°C]

$$T_{\max,mon} = \frac{\sum_{d=1}^{N} T_{\max}}{N}$$

TMP_min = average daily maximum temperature in month [°C]

$$T_{\min,mon} = \frac{\sum_{d=1}^{N} T_{\min}}{N}$$

TMPSTDMX (mon): Standard deviation for daily maximum air temperature in month (ºC):

$$\sigma_{\max} = \sqrt{\frac{\sum_{d=1}^{N} (T\max - Tmn)^2}{N-1}}$$

Where: $\sigma_{\max}$ is the standard deviation for daily maximum temperature in month (ºC), Tmax, is the daily maximum temperature on record d in month (°C), Tmn is the average daily maximum temperature for the month (°C), and N is the total number of daily maximum temperature records for month.

TMPSTDMN (mon): Standard deviation for daily minimum air temperature in month (°C):

$$\sigma_{\min} = \sqrt{\frac{\sum_{d=1}^{N} (T\min - Tmn)^2}{N-1}}$$

Where $\sigma_{\min}$ is the standard deviation for daily minimum temperature in month (ºC), Tmin, is the daily minimum temperature on record d in month (°C), Tmn is the average daily minimum temperature for the month (°C), and N is the total number of Daily minimum temperature records for month.

DEWPT (mon): Average daily dew point temperature in month (ºC):

$$\mu_{dew} = \frac{\sum_{d=1}^{N} Tdew}{N}$$

Where μ_{dew} is the mean daily dew point temperature for the month (ºC), Tdew, is the dew point temperature for day d in month (ºC), and N is the total number of daily dew point records for month.

WNDAV (mon): Average daily wind speed in month (m/s).Calculated based on following formula:

$$\mu_{wnd} = \frac{\sum_{d=1}^{N} \mu wnd}{N}$$

Where μ_{wnd} is the mean daily wind speed for the month (m/s), μwnd is the average wind speed for day d in month (m/s), and N is the total number of daily wind speed records for the month.

PCP_MM=average monthly precipitation [mm] calculated based on the following formula

$$\bar{R}_{mon} = \frac{\sum_{d=1}^{N} R_{day}}{year}$$

Where: $\bar{R}_{mon}$ is the mean monthly precipitation (mm), Rday is the daily precipitation for record d in month (mm), N is the total number of records in month used to calculate the average.

PCPSTD=standard deviation

$$\sigma_{mon} = \sqrt{\frac{\sum_{d=1}^{N} (Rday - Rmn)^2}{N-1}}$$

Where σ_{mon} is the standard deviation for daily precipitation in month (mm), Rmn is the mean monthly precipitation (mm), Rday is the daily precipitation for record d in month (mm), N is the total number of records in month used to calculate.

PCPSKW = skew coefficient

$$g_{mon} = \frac{N\sum_{d=1}^{N}(R_{day} - Rmn)^3}{(N-1)(N-2)(N-3)}$$

Where g_{mon} the skew coefficient for precipitation in the month, N is the total number of daily precipitation records for month, Rday is the amount of precipitation for record d in month (mm H2O), Rmn is the average precipitation for the month (mm).

PR_W1 = probability of a wet day following a dry day

$$Pi(W/D) = \frac{daysW/Di}{daysdryi}$$

Where Pi(W/D) is the probability of a wet day following a dry day in month i, daysW/Di is the number of times a wet day followed a dry day in month i for the entire period of record, and daysdry,i is the number of dry days in month i during the entire period of record.

PR_W2 = probability of a wet day following a wet day

$$Pi(W/W) = \frac{daysW/Wi}{daysWeti}$$

Where Pi(W/W) is the probability of a wet day following a wet day in month i

PCPD = average number of days of precipitation in month

$$\bar{d}_{wet,i} = \frac{dayswet,i}{years}$$

Where $\bar{d}_{wet,i}$ is the average number of days of precipitation in month i, dayswet,i is the

Number of wet days in month i during the entire period of record.

RAINHHMX (mon): Maximum 0.5 hour rainfall in entire period of record for month. This value represents the most extreme 30-minute rainfall intensity recorded in the entire period of record.

SOLARAV (mon): Average daily solar radiation for month (MJ/m2/day).Calculated based on following formula:

$$\mu_{mon} = \frac{\sum_{d=1}^{N} Hdays}{N}$$

Where μ_{mon} is the mean daily solar radiation for the month (MJ/m2/day), Hdays, is the

Total solar radiation reaching the earth's surface for day d in month (MJ/m2/day), and N is the total number of daily solar radiation records for month.

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD	RAINHHMX	TMPMX	TMPMN	DEWPT	TMPSTDMX	TMPSTDMN	WNDAV	SOLARAV
Jan.	3.11	0.76	9.71	0.03	0.36	1.39	3.27	23.45	9.34	9.29	1.88	1.82	3.10	20.29
Feb.	3.14	0.83	11.09	0.03	0.33	1.17	3.97	24.74	10.4	8.53	1.71	1.72	3.79	22.34
Mar.	19.63	2.84	6.08	0.08	0.32	3.44	9.33	25.44	11.85	9.55	1.61	1.59	3.78	22.77
Apr.	27.76	4.42	11.20	0.12	0.33	4.83	24.97	26.19	13.16	9.97	1.42	1.75	3.65	23.75
May.	27.28	3.60	6.36	0.08	0.56	5.22	11.73	27.19	13.65	9.17	1.52	1.49	2.65	24.14
Jun.	33.15	3.58	5.36	0.18	0.43	7.22	11.20	27.21	13.53	10.28	1.88	1.50	1.98	20.11
Jul.	184.1	9.18	2.65	0.62	0.75	22.11	19.87	23.51	13.16	14.3	1.86	1.36	1.91	17.20
Aug.	212.14	9.36	1.96	0.65	0.74	22.72	17.63	22.57	13.07	14.96	1.60	1.12	1.65	17.27
Sep.	33.26	3.19	4.28	0.15	0.54	8.39	7.50	24.44	11.67	10.89	1.24	1.43	1.57	20.62
Oct.	14.19	2.51	10.67	0.05	0.54	3.72	13.70	23.9	10.89	9.26	1.07	1.75	2.67	22.17

Nov.	4.96	1.59	16.06	0.03	0.16	1.06	10.63	22.89	10.23	8.74	1.10	1.69	3.34	20.80
Dec.	3.22	0.40	4.05	0.02	0.68	2.44	1.17	22.71	9.49	8.49	1.71	1.71	3.46	20.06

APPENDIX B: Simulate output of the gauged catchment

Simulated monthly flow of Geba(m3/sec) catchment												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0.00	0.00	0.00	0.23	5.02	10.40	96.52	143.80	22.26	0.43	9.41	3.37
2001	0.31	0.00	16.82	18.23	16.97	23.60	71.42	155.80	20.50	12.81	0.15	0.00
2002	0.00	0.34	6.63	11.88	10.35	6.71	88.46	43.21	15.66	0.07	0.00	0.64
2003	0.19	1.23	3.93	3.33	2.81	1.74	29.22	98.80	28.33	9.02	0.18	10.63
2004	0.58	0.03	4.26	12.43	0.35	6.58	62.39	96.71	7.70	1.68	0.11	9.02
2005	0.31	0.95	10.57	8.13	9.81	0.22	24.06	72.99	18.52	2.58	0.00	0.00
2006	0.00	0.00	1.13	23.74	11.50	4.47	46.09	115.40	33.26	5.08	2.42	0.73
2007	8.74	1.52	0.42	8.66	1.97	14.48	84.97	98.51	41.12	0.59	0.07	0.02
2008	1.02	0.04	0.00	0.53	2.80	11.43	62.49	74.51	9.29	0.82	3.63	3.43
2009	0.02	1.41	1.19	0.31	0.43	0.06	30.14	69.88	19.02	1.17	0.30	0.93
2010	0.12	0.09	0.06	0.37	6.01	4.89	59.01	113.70	26.78	7.03	7.08	1.50
2011	1.18	0.19	8.55	12.39	13.12	15.27	39.40	115.30	24.51	15.63	2.75	0.25
2012	0.31	0.24	4.98	10.55	6.91	3.77	62.92	33.97	14.44	1.04	0.13	1.37
2013	1.00	0.83	5.55	3.75	4.25	1.15	19.18	71.00	25.39	9.15	1.48	6.85
2014	0.82	0.51	2.63	10.83	2.23	2.93	35.44	68.68	10.63	3.24	1.18	5.87
mean	0.97	0.49	4.45	8.36	6.30	7.18	54.11	91.48	21.16	4.69	1.93	2.97
max	8.74	1.52	16.82	23.74	16.97	23.60	96.52	155.80	41.12	15.63	9.41	10.63
min	0.00	0.00	0.00	0.23	0.35	0.06	19.18	33.97	7.70	0.07	0.00	0.00

APPENDIX C: Soil and water assessment tool model output for different sub basin of Suluh

a. Water Balance of Suluh catchment

Year	MON	PRECIP mm	PET mm	ET mm	SW_INIT mm	SW_END mm	PERC mm	GW_RCHG mm
2000	Jan	0.00	136.96	2.21	33.57	32.44	0.00	0.33
	Feb	0.00	152.38	2.35	31.30	30.09	0.00	0.12
	Mar	0.00	187.20	2.82	28.76	27.28	0.00	0.05
	Apr	16.60	171.60	28.02	20.56	15.82	0.00	0.02
	May	32.00	190.77	42.70	13.47	4.32	0.00	0.01
	Jun	72.60	139.03	54.89	13.54	14.77	0.00	0.00
	Jul	99.80	136.46	67.42	20.24	41.07	0.00	0.00
	Aug	124.30	120.50	85.88	53.54	52.31	0.00	0.00
	Sep	7.80	135.58	47.16	32.55	12.36	0.00	0.00
	Oct	0.00	147.31	2.66	10.43	9.70	0.00	0.00
	Nov	1.50	127.91	2.26	9.44	8.94	0.00	0.00
	Dec	41.10	133.09	15.02	21.89	25.67	0.00	0.00
2001	Jan	0.00	125.71	8.73	20.99	16.94	0.00	0.00
	Feb	0.00	147.52	3.19	14.70	13.75	0.00	0.00
	Mar	29.40	156.31	21.00	19.71	21.46	0.00	0.00
	Apr	17.70	181.45	28.55	14.62	10.57	0.00	0.00
	May	27.70	182.86	33.11	8.38	5.10	0.00	0.00
	Jun	38.70	138.25	37.85	7.02	5.88	0.00	0.00
	Jul	140.40	126.52	73.08	12.20	46.61	0.00	0.00
	Aug	161.40	100.08	80.25	56.45	75.99	7.08	0.63
	Sep	23.40	134.88	57.22	53.05	40.71	0.00	4.00
	Oct	90.70	136.94	22.04	50.18	44.72	0.00	1.55
	Nov	0.00	134.84	7.36	40.89	37.36	0.00	0.56
	Dec	0.00	135.55	3.47	35.19	33.90	0.00	0.22
2002	Jan	0.00	131.64	1.99	32.95	31.90	0.00	0.08
	Feb	0.00	149.90	2.20	30.86	29.70	0.00	0.03
	Mar	19.20	177.22	20.89	34.24	27.16	0.00	0.01
	Apr	93.60	191.32	56.54	29.78	9.50	0.00	0.00
	May	112.70	177.96	66.79	19.17	10.34	0.00	0.00
	Jun	55.90	148.80	48.25	13.00	10.59	0.00	0.00
	Jul	95.00	130.19	83.26	20.03	21.75	0.00	0.00
	Aug	154.70	120.93	88.77	52.59	52.73	0.00	0.00
	Sep	100.80	129.88	40.22	55.71	44.28	0.00	0.00
	Oct	0.00	157.02	5.27	41.26	39.01	0.00	0.00
	Nov	0.00	140.59	2.31	37.82	36.70	0.00	0.00

	Dec	12.80	136.78	9.13	40.06	39.76	0.00	0.00
2003	Jan	0.00	134.71	7.20	35.93	32.56	0.00	0.00
	Feb	21.30	141.13	10.48	34.26	42.54	0.00	0.00
	Mar	14.30	189.34	24.10	35.71	32.61	0.00	0.00
	Apr	22.90	179.84	44.90	19.82	10.56	0.00	0.00
	May	0.00	208.33	7.67	5.38	2.90	0.00	0.00
	Jun	37.60	133.32	20.54	4.64	19.88	0.00	0.00
	Jul	129.10	134.89	82.97	23.29	42.81	0.00	0.00
	Aug	116.30	105.00	72.78	64.20	62.07	0.00	0.00
	Sep	129.40	124.42	45.61	65.27	62.06	6.04	3.66
	Oct	62.20	142.84	25.31	63.56	58.18	0.00	1.50
	Nov	0.00	134.26	10.73	52.48	47.45	0.00	0.54
	Dec	89.10	128.82	19.89	54.51	49.98	0.00	0.21
2004	Jan	10.70	131.82	14.82	48.58	44.54	0.00	0.08
	Feb	4.30	152.52	11.12	40.29	37.72	0.00	0.03
	Mar	56.00	173.61	30.06	43.56	42.74	0.00	0.01
	Apr	39.60	175.80	61.56	38.89	18.43	0.00	0.00
	May	0.50	196.32	15.40	7.21	3.52	0.00	0.00
	Jun	53.10	123.29	41.05	8.74	14.92	0.00	0.00
	Jul	199.10	128.94	88.24	47.22	57.87	0.00	0.00
	Aug	121.40	134.95	85.43	61.24	39.35	0.00	0.00
	Sep	1.10	136.42	32.07	18.14	8.38	0.00	0.00
	Oct	1.50	144.21	2.43	7.90	7.45	0.00	0.00
	Nov	0.00	130.79	0.54	7.18	6.91	0.00	0.00
	Dec	89.10	139.89	15.87	26.82	39.67	0.00	0.00
2005	Jan	0.00	120.58	9.35	34.63	30.32	0.00	0.00
	Feb	10.70	149.50	11.09	30.90	29.56	0.00	0.00
	Mar	62.90	167.21	27.38	34.17	34.32	0.00	0.00
	Apr	27.30	175.65	48.80	21.25	12.73	0.00	0.00
	May	11.90	182.52	19.83	7.40	4.78	0.00	0.00
	Jun	8.80	146.54	10.38	3.87	3.18	0.00	0.00
	Jul	108.10	126.56	63.34	16.09	39.65	0.00	0.00
	Aug	140.30	124.44	91.14	54.07	62.27	0.00	0.00
	Sep	18.10	130.65	44.47	44.86	34.92	0.00	0.00
	Oct	7.30	141.28	11.66	34.90	30.46	0.00	0.00
	Nov	0.00	133.14	4.02	27.98	26.44	0.00	0.00
	Dec	0.00	130.07	1.98	25.36	24.46	0.00	0.00
2006	Jan	0.00	125.82	1.24	23.87	23.22	0.00	0.00
	Feb	0.00	153.89	1.53	22.48	21.69	0.00	0.00
	Mar	31.00	158.31	21.00	26.56	31.41	0.00	0.00

	Apr	174.20	154.87	61.90	49.61	43.94	0.00	0.00
	May	41.20	166.15	74.00	24.24	10.43	0.00	0.00
	Jun	75.50	150.73	36.58	14.11	30.57	0.00	0.00
	Jul	106.80	115.24	85.55	27.54	44.62	0.00	0.00
	Aug	83.10	122.31	90.04	36.29	30.46	0.00	0.00
	Sep	12.00	130.38	36.33	15.65	5.94	0.00	0.00
	Oct	20.60	147.20	14.54	10.96	11.90	0.00	0.00
	Nov	0.00	130.41	4.81	9.29	7.09	0.00	0.00
	Dec	4.10	136.85	4.87	7.55	6.31	0.00	0.00
2007	Jan	89.10	128.11	16.18	24.41	42.19	0.00	0.00
	Feb	0.80	152.56	12.68	35.79	30.30	0.00	0.00
	Mar	21.20	174.61	9.52	29.66	38.12	0.00	0.00
	Apr	36.80	163.44	56.68	32.94	15.25	0.00	0.00
	May	40.60	190.73	50.10	12.04	4.61	0.00	0.00
	Jun	82.40	133.11	62.70	13.69	22.05	0.00	0.00
	Jul	89.10	119.21	81.99	16.33	28.69	0.00	0.00
	Aug	99.80	112.49	86.59	37.87	36.39	0.00	0.00
	Sep	73.00	117.81	62.76	50.61	32.97	0.00	0.00
	Oct	0.00	149.39	11.11	25.28	21.85	0.00	0.00
	Nov	0.00	134.47	2.40	20.69	19.46	0.00	0.00
	Dec	0.00	125.51	2.25	18.33	17.21	0.00	0.00
2008	Jan	11.80	124.58	6.70	21.32	22.14	0.00	0.00
	Feb	0.00	148.49	6.68	18.52	15.46	0.00	0.00
	Mar	0.00	192.10	1.47	14.83	14.00	0.00	0.00
	Apr	15.70	183.63	8.95	10.53	20.64	0.00	0.00
	May	13.50	199.58	30.16	9.36	3.63	0.00	0.00
	Jun	119.50	143.73	69.80	20.40	14.15	0.00	0.00
	Jul	92.90	122.71	78.13	21.93	27.17	0.00	0.00
	Aug	176.60	136.57	88.66	36.58	40.16	0.00	0.00
	Sep	11.00	132.78	38.31	27.70	12.37	0.00	0.00
	Oct	40.50	145.55	11.12	15.99	39.50	0.00	0.00
	Nov	0.00	129.77	14.64	31.02	24.86	0.00	0.00
	Dec	11.20	133.98	13.67	27.48	21.97	0.00	0.00
2009	Jan	0.00	130.84	6.04	18.51	15.92	0.00	0.00
	Feb	29.80	142.41	20.62	26.75	22.67	0.00	0.00
	Mar	5.40	174.44	11.08	18.37	16.98	0.00	0.00
	Apr	12.50	181.25	22.15	13.12	7.30	0.00	0.00
	May	0.00	189.01	4.01	4.95	3.29	0.00	0.00
	Jun	0.00	170.14	1.71	2.40	1.58	0.00	0.00
	Jul	155.30	120.82	76.22	30.15	64.40	0.00	0.00
	Aug	45.60	132.71	62.61	45.40	45.54	0.00	0.00

	Sep	9.60	137.22	31.06	34.17	23.16	0.00	0.00
	Oct	11.30	148.70	11.51	24.68	22.93	0.00	0.00
	Nov	23.40	127.60	8.82	21.17	36.67	0.00	0.00
	Dec	1.50	137.12	17.09	26.84	21.08	0.00	0.00
2010	Jan	0.00	133.20	5.41	17.76	15.67	0.00	0.00
	Feb	0.00	155.22	1.23	15.07	14.44	0.00	0.00
	Mar	12.00	173.15	9.83	16.10	16.58	0.00	0.00
	Apr	48.10	165.09	46.41	20.35	10.63	0.00	0.00
	May	20.20	198.16	27.31	8.27	3.48	0.00	0.00
	Jun	53.60	142.82	41.01	7.08	15.97	0.00	0.00
	Jul	110.50	125.95	81.34	22.41	42.12	0.00	0.00
	Aug	331.30	90.20	72.84	71.86	65.00	78.35	32.32
	Sep	36.90	114.83	41.16	63.68	55.94	0.00	28.54
	Oct	0.00	145.57	9.91	50.86	46.03	0.00	11.05
	Nov	1.80	128.72	5.80	44.08	42.03	0.00	3.99
	Dec	0.00	131.25	2.65	40.70	39.38	0.00	1.55
2011	Jan	0.00	133.68	2.62	38.10	36.76	0.00	0.57
	Feb	0.00	147.20	2.71	35.43	34.06	0.00	0.20
	Mar	23.90	152.17	19.39	37.84	36.42	0.00	0.09
	Apr	23.80	188.67	43.62	31.28	15.38	0.00	0.03
	May	30.90	180.71	38.26	9.92	7.06	0.00	0.01
	Jun	54.70	122.48	30.56	10.15	30.86	0.00	0.00
	Jul	110.00	117.84	93.82	30.00	37.19	0.00	0.00
	Aug	183.90	109.37	84.56	64.42	45.49	0.44	0.19
	Sep	51.40	104.24	55.63	52.74	35.04	0.00	0.15
	Oct	2.10	148.69	20.79	23.76	16.34	0.00	0.06
	Nov	70.30	122.50	18.86	39.81	41.22	0.00	0.02
	Dec	0.00	129.19	8.38	36.76	32.85	0.00	0.01
2012	Jan	0.00	132.96	5.94	29.67	26.91	0.00	0.00
	Feb	0.00	158.83	1.73	26.10	25.18	0.00	0.00
	Mar	25.80	156.31	18.54	29.89	32.30	0.00	0.00
	Apr	25.50	173.91	43.68	22.79	14.07	0.00	0.00
	May	23.10	188.95	32.86	9.70	3.97	0.00	0.00
	Jun	62.80	134.88	35.75	12.00	29.84	0.00	0.00
	Jul	158.90	119.75	82.85	28.65	72.83	0.00	0.00
	Aug	197.60	108.12	88.27	72.45	66.12	39.87	20.27
	Sep	21.60	118.89	54.78	52.43	31.17	0.00	12.16
	Oct	3.20	143.67	14.38	22.04	19.98	0.00	4.71
	Nov	4.60	131.69	6.36	20.44	18.21	0.00	1.70
	Dec	0.00	140.75	2.74	16.40	15.47	0.00	0.66

2013	Jan	12.30	130.86	7.83	18.50	19.91	0.00	0.24
	Feb	0.00	150.40	6.32	16.22	13.59	0.00	0.08
	Mar	1.60	183.70	3.38	13.01	11.80	0.00	0.04
	Apr	17.60	177.26	21.84	11.70	7.53	0.00	0.01
	May	4.50	197.62	8.93	5.48	3.10	0.00	0.01
	Jun	57.50	130.92	41.51	10.54	16.72	0.00	0.00
	Jul	142.80	107.74	73.31	36.93	73.73	0.00	0.00
	Aug	118.90	75.55	65.47	76.50	79.15	31.64	14.54
	Sep	21.90	129.07	47.09	60.00	46.52	5.00	13.70
	Oct	1.40	149.70	9.92	41.13	37.99	0.00	5.31
	Nov	14.90	126.08	11.47	40.33	41.10	0.00	1.92
	Dec	0.00	127.78	7.71	37.15	33.39	0.00	0.74
2014	Jan	0.00	130.63	2.23	32.28	31.17	0.00	0.27
	Feb	4.80	138.27	5.76	30.82	30.20	0.00	0.10
	Mar	31.20	175.59	29.39	35.85	28.98	0.00	0.04
	Apr	11.60	190.96	30.73	18.47	9.82	0.00	0.02
	May	67.20	152.02	64.46	18.34	9.28	0.00	0.01
	Jun	38.90	142.96	36.24	11.39	11.75	0.00	0.00
	Jul	232.30	95.13	75.14	50.42	77.72	35.11	5.22
	Aug	123.90	122.03	93.76	69.55	66.20	7.43	21.60
	Sep	67.40	117.07	64.03	63.89	50.32	3.68	11.55
	Oct	24.80	142.86	24.36	54.21	48.62	0.00	4.96
	Nov	16.60	124.08	8.83	47.48	54.16	0.00	1.79
	Dec	0.00	134.82	10.69	48.56	43.47	0.00	0.69

Cont'…

Year	MON	DA_ RCHG mm	REVAP mm	SURQ_ GENmm	LATQ GEN mm	WYLD mm	CN	TMP_ MX dgC	TMP_ MN dgC	SOLAR MJ/m2
2000	Jan	0.02	2.74	0.00	0.03	0.16	89.69	23.64	9.08	20.95
	Feb	0.01	3.05	0.00	0.02	0.11	89.21	23.88	9.98	22.86
	Mar	0.00	3.74	0.00	0.01	0.09	88.61	25.03	11.70	24.35
	Apr	0.00	3.43	0.00	0.01	0.06	86.04	25.56	12.82	23.38
	May	0.00	3.82	0.74	0.04	0.82	82.39	27.45	13.62	23.95
	Jun	0.00	2.78	7.09	0.06	7.18	81.89	27.77	13.56	19.29
	Jul	0.00	2.73	5.84	0.12	5.98	85.13	23.70	13.30	21.16
	Aug	0.00	2.41	26.92	0.21	27.14	92.60	22.43	13.47	21.02
	Sep	0.00	2.71	0.58	0.16	0.76	88.71	23.88	11.81	23.11
	Oct	0.00	2.95	0.00	0.09	0.10	81.67	23.66	11.30	23.01
	Nov	0.00	2.56	0.00	0.05	0.06	81.08	22.72	10.70	20.84
	Dec	0.00	2.66	9.26	0.06	9.32	85.60	22.53	10.24	20.19
2001	Jan	0.00	2.51	0.00	0.04	0.05	86.32	23.25	8.15	20.87
	Feb	0.00	2.95	0.00	0.02	0.03	83.87	24.41	10.16	22.83
	Mar	0.00	3.13	0.64	0.03	0.67	85.57	24.46	12.02	21.20
	Apr	0.00	3.63	0.00	0.03	0.04	83.68	26.46	13.85	24.24
	May	0.00	3.66	0.00	0.04	0.04	80.31	27.92	14.40	24.70
	Jun	0.00	2.77	0.00	0.05	0.05	79.24	25.62	13.33	19.83
	Jul	0.00	2.53	26.31	0.09	26.38	81.73	22.65	13.29	19.98
	Aug	0.03	2.00	44.33	0.21	44.55	92.85	21.98	13.37	18.14
	Sep	0.20	2.70	1.43	0.21	1.68	92.54	24.58	12.14	22.58
	Oct	0.08	2.74	64.59	0.16	64.81	92.29	24.36	11.99	22.25
	Nov	0.03	2.70	0.00	0.09	0.15	91.02	22.87	9.57	21.40
	Dec	0.01	2.71	0.00	0.05	0.10	90.02	22.59	10.22	20.68
2002	Jan	0.00	2.63	0.00	0.03	0.07	89.56	22.35	10.56	20.58
	Feb	0.00	3.00	0.00	0.02	0.04	89.11	24.73	10.73	23.46

	Mar	0.00	3.54	0.81	0.02	0.86	89.75	25.66	12.37	23.61
	Apr	0.00	3.83	54.62	0.05	54.69	88.20	26.43	12.13	24.79
	May	0.00	3.56	44.87	0.09	44.97	84.28	28.61	14.18	23.30
	Jun	0.00	2.98	7.28	0.11	7.41	82.36	27.21	13.62	21.44
	Jul	0.00	2.60	0.37	0.15	0.53	85.56	25.59	13.81	20.53
	Aug	0.00	2.42	34.61	0.23	34.84	92.26	23.39	12.68	21.34
	Sep	0.00	2.60	68.95	0.20	69.15	92.87	24.78	12.20	22.50
	Oct	0.00	3.14	0.00	0.12	0.12	91.09	24.87	11.71	23.28
	Nov	0.00	2.81	0.00	0.06	0.07	90.51	23.50	10.92	20.96
	Dec	0.00	2.74	0.59	0.04	0.64	90.87	23.23	10.52	20.14
2003	Jan	0.00	2.69	0.00	0.03	0.03	90.15	24.53	8.79	21.06
	Feb	0.00	2.82	0.81	0.02	0.83	89.76	25.43	11.68	21.69
	Mar	0.00	3.79	0.10	0.03	0.13	90.09	25.76	12.18	23.19
	Apr	0.00	3.60	0.00	0.03	0.04	85.57	26.57	13.67	24.37
	May	0.00	4.17	0.00	0.03	0.03	78.11	28.18	15.10	26.35
	Jun	0.00	2.67	0.00	0.02	0.02	77.27	26.78	13.39	20.17
	Jul	0.00	2.70	22.91	0.10	23.01	85.32	23.52	13.97	21.56
	Aug	0.00	2.10	24.01	0.21	24.22	93.66	22.32	12.59	18.60
	Sep	0.18	2.49	77.61	0.20	77.83	93.86	24.25	11.71	21.66
	Oct	0.08	2.86	40.73	0.14	40.92	93.72	23.66	10.77	22.31
	Nov	0.03	2.69	0.00	0.08	0.13	92.61	22.85	10.61	21.36
	Dec	0.01	2.58	66.63	0.07	66.74	92.80	21.91	9.25	20.61
2004	Jan	0.00	2.64	1.31	0.05	1.39	92.13	24.28	10.01	20.72
	Feb	0.00	3.05	0.00	0.03	0.05	90.92	24.05	9.69	22.82
	Mar	0.00	3.47	20.84	0.04	20.90	91.38	25.02	11.55	22.27
	Apr	0.00	3.52	2.28	0.06	2.35	90.50	25.82	13.36	23.46
	May	0.00	3.93	0.00	0.04	0.05	79.32	28.22	13.20	25.79
	Jun	0.00	2.47	0.53	0.04	0.58	79.81	26.48	13.11	18.80
	Jul	0.00	2.58	67.52	0.17	67.70	90.69	24.84	13.06	20.65
	Aug	0.00	2.70	54.33	0.21	54.54	93.44	22.88	12.98	23.27
	Sep	0.00	2.73	0.00	0.13	0.13	84.46	25.08	11.70	23.45
	Oct	0.00	2.88	0.00	0.08	0.08	80.08	23.46	10.10	22.87

	Nov	0.00	2.62	0.00	0.04	0.04	79.58	22.91	11.07	21.43
	Dec	0.00	2.80	40.31	0.07	40.38	85.71	22.92	9.88	20.71
2005	Jan	0.00	2.41	0.00	0.07	0.07	89.88	23.66	9.00	20.62
	Feb	0.00	2.99	0.35	0.04	0.39	89.08	25.65	11.19	21.89
	Mar	0.00	3.34	30.69	0.05	30.74	89.61	25.97	12.51	23.10
	Apr	0.00	3.51	0.04	0.05	0.09	86.12	26.21	13.34	22.62
	May	0.00	3.65	0.00	0.05	0.05	79.60	26.43	13.82	25.10
	Jun	0.00	2.93	0.00	0.03	0.03	76.90	27.27	13.26	20.50
	Jul	0.00	2.04	8.01	0.07	8.09	82.19	23.34	13.43	20.15
	Aug	0.00	0.00	26.25	0.19	26.44	92.65	23.33	12.81	21.69
	Sep	0.00	0.00	0.95	0.17	1.11	91.54	23.88	11.18	22.76
	Oct	0.00	0.00	0.09	0.11	0.20	89.94	23.43	10.40	22.93
	Nov	0.00	0.00	0.00	0.06	0.06	88.41	22.55	8.71	21.08
	Dec	0.00	0.00	0.00	0.04	0.04	87.71	22.22	8.61	20.50
2006	Jan	0.00	0.00	0.00	0.02	0.02	87.28	23.55	7.75	20.79
	Feb	0.00	0.00	0.00	0.01	0.01	86.85	25.16	11.03	22.41
	Mar	0.00	0.00	0.22	0.02	0.24	87.89	25.36	11.48	22.25
	Apr	0.00	0.00	99.55	0.09	99.65	91.93	24.90	12.71	21.80
	May	0.00	0.00	0.63	0.10	0.73	86.06	25.98	13.00	23.25
	Jun	0.00	0.00	18.60	0.10	18.70	81.82	27.13	12.92	21.56
	Jul	0.00	0.00	6.94	0.16	7.10	87.52	23.59	13.42	19.47
	Aug	0.00	0.00	7.06	0.19	7.25	90.10	22.40	12.89	21.58
	Sep	0.00	0.00	0.17	0.15	0.32	83.30	24.48	11.10	22.62
	Oct	0.00	0.00	0.06	0.10	0.15	81.69	23.85	11.07	22.29
	Nov	0.00	0.00	0.00	0.06	0.06	80.95	22.75	10.08	21.37
	Dec	0.00	0.00	0.00	0.04	0.04	79.82	22.52	10.26	20.31
2007	Jan	0.00	0.00	36.86	0.07	36.93	84.35	22.79	9.30	20.35
	Feb	0.00	0.00	0.00	0.07	0.07	90.10	24.61	11.39	22.70
	Mar	0.00	0.00	3.83	0.05	3.88	88.75	26.15	11.46	23.18
	Apr	0.00	0.00	2.93	0.06	2.99	89.22	26.13	12.49	22.81
	May	0.00	0.00	1.06	0.07	1.13	82.12	27.74	13.74	24.61
	Jun	0.00	0.00	2.08	0.09	2.17	82.72	26.74	14.13	18.83

	Jul	0.00	0.00	0.27	0.13	0.40	84.20	22.70	13.05	19.74
	Aug	0.00	0.00	5.25	0.19	5.44	90.32	22.92	12.84	20.41
	Sep	0.00	0.00	13.51	0.20	13.71	92.24	23.86	11.09	21.04
	Oct	0.00	0.00	0.00	0.13	0.13	87.64	23.29	9.87	23.48
	Nov	0.00	0.00	0.00	0.07	0.07	86.26	22.23	9.74	21.18
	Dec	0.00	0.00	0.00	0.04	0.04	85.40	21.83	8.54	20.80
2008	Jan	0.00	0.00	0.15	0.03	0.18	86.35	24.11	9.98	20.07
	Feb	0.00	0.00	0.00	0.02	0.02	85.44	23.88	9.07	22.91
	Mar	0.00	0.00	0.00	0.01	0.01	83.94	26.22	10.74	24.02
	Apr	0.00	0.00	0.08	0.01	0.08	81.66	25.55	12.92	25.01
	May	0.00	0.00	0.32	0.03	0.35	80.38	27.53	13.57	26.18
	Jun	0.00	0.00	38.94	0.08	39.02	84.01	27.38	12.87	21.28
	Jul	0.00	0.00	1.57	0.14	1.68	86.32	24.13	13.61	19.76
	Aug	0.00	0.00	74.67	0.19	74.88	89.73	23.68	13.28	23.08
	Sep	0.00	0.00	0.46	0.15	0.62	87.80	24.83	11.58	22.61
	Oct	0.00	0.00	2.15	0.10	2.25	83.85	24.46	10.80	21.95
	Nov	0.00	0.00	0.00	0.09	0.09	89.07	22.86	10.16	21.20
	Dec	0.00	0.00	0.40	0.06	0.46	88.22	22.48	8.45	20.35
2009	Jan	0.00	0.00	0.00	0.03	0.03	85.44	23.72	8.57	20.94
	Feb	0.00	0.00	2.37	0.04	2.41	87.80	24.43	10.37	22.09
	Mar	0.00	0.00	0.00	0.03	0.03	85.38	26.04	11.72	23.07
	Apr	0.00	0.00	0.00	0.03	0.03	83.00	26.67	12.47	23.99
	May	0.00	0.00	0.00	0.02	0.02	77.84	27.79	12.90	26.48
	Jun	0.00	0.00	0.00	0.01	0.01	75.56	29.12	14.62	22.95
	Jul	0.00	0.00	15.86	0.09	15.95	86.96	24.21	12.96	19.94
	Aug	0.00	0.00	1.77	0.15	1.92	91.57	23.61	13.25	22.44
	Sep	0.00	0.00	0.90	0.11	1.02	89.57	25.11	11.86	23.07
	Oct	0.00	0.00	0.00	0.07	0.07	87.50	23.85	11.24	22.82
	Nov	0.00	0.00	0.80	0.05	0.84	86.31	23.35	10.13	20.19
	Dec	0.00	0.00	0.00	0.05	0.05	88.03	23.08	10.37	20.12
2010	Jan	0.00	0.00	0.00	0.03	0.03	85.16	22.71	9.97	20.92
	Feb	0.00	0.00	0.00	0.01	0.01	84.05	25.32	10.86	23.34

	Mar	0.00	0.00	0.01	0.01	0.02	84.41	24.74	11.88	23.11
	Apr	0.00	0.00	7.54	0.04	7.58	85.74	26.50	13.83	22.14
	May	0.00	0.00	0.00	0.05	0.05	80.08	28.05	14.49	25.47
	Jun	0.00	0.00	0.00	0.05	0.05	79.29	27.88	14.00	19.96
	Jul	0.00	0.00	2.73	0.11	2.84	85.34	24.10	13.65	20.41
	Aug	1.62	1.46	156.29	0.41	156.86	94.30	22.23	13.65	16.48
	Sep	1.43	2.30	4.74	0.38	5.73	93.73	23.74	11.87	20.17
	Oct	0.55	2.91	0.00	0.23	0.93	92.42	23.77	10.57	23.08
	Nov	0.20	2.57	0.00	0.12	0.71	91.52	22.29	10.00	20.81
	Dec	0.08	2.63	0.00	0.07	0.55	91.00	22.16	8.83	20.55
2011	Jan	0.03	2.67	0.00	0.04	0.40	90.56	22.63	9.64	21.04
	Feb	0.01	2.94	0.00	0.02	0.27	90.06	24.69	9.14	22.56
	Mar	0.00	3.04	2.10	0.02	2.33	90.45	23.67	11.21	21.08
	Apr	0.00	3.77	1.17	0.03	1.35	89.07	26.43	13.07	24.40
	May	0.00	3.61	0.90	0.04	1.05	81.06	26.01	12.98	25.39
	Jun	0.00	2.45	0.21	0.06	0.35	80.64	26.64	13.34	17.63
	Jul	0.00	2.36	9.62	0.13	9.81	88.60	23.93	13.19	19.09
	Aug	0.01	2.19	90.33	0.22	90.60	93.67	22.75	13.18	20.04
	Sep	0.01	2.09	6.13	0.18	6.34	92.52	23.62	10.84	18.72
	Oct	0.00	2.97	0.00	0.11	0.14	87.01	23.82	9.70	23.29
	Nov	0.00	2.45	26.44	0.11	26.56	90.33	22.75	10.60	20.17
	Dec	0.00	2.58	0.00	0.07	0.09	90.30	22.31	9.16	20.68
2012	Jan	0.00	2.66	0.00	0.04	0.05	88.81	23.39	8.93	20.93
	Feb	0.00	3.18	0.00	0.02	0.03	87.92	24.53	9.55	23.04
	Mar	0.00	3.13	0.09	0.02	0.12	88.80	25.24	11.32	21.55
	Apr	0.00	3.48	0.00	0.03	0.04	86.68	25.94	12.75	23.83
	May	0.00	3.78	0.29	0.05	0.35	80.80	26.99	13.44	24.65
	Jun	0.00	2.70	1.03	0.05	1.08	80.68	26.84	13.10	19.38
	Jul	0.00	2.40	32.68	0.13	32.64	87.99	22.59	13.46	19.68
	Aug	1.01	2.16	75.66	0.35	76.31	94.43	22.75	12.93	19.36
	Sep	0.61	2.38	1.74	0.27	2.33	92.42	24.23	11.07	21.12
	Oct	0.24	2.87	0.00	0.16	0.51	86.62	23.73	9.71	22.56

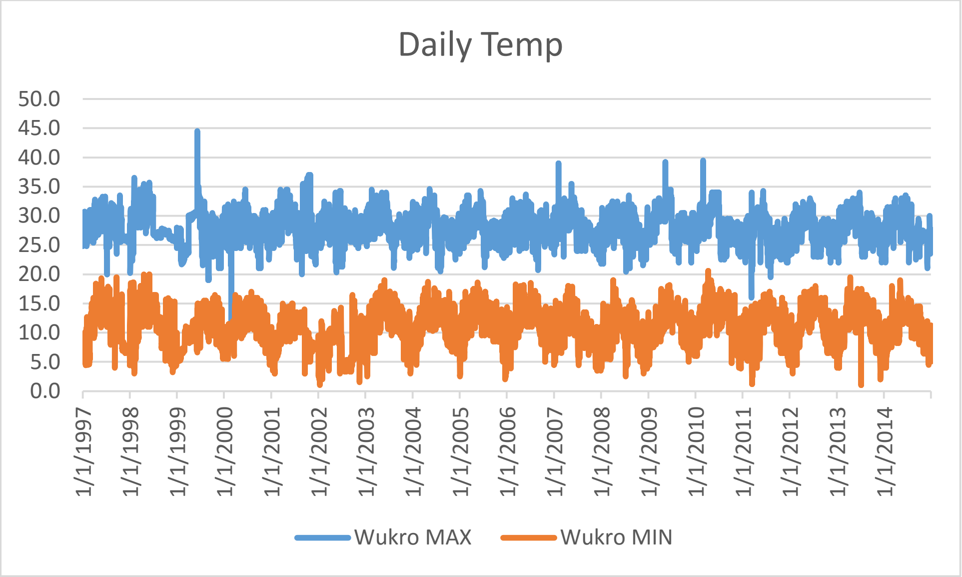
	Nov	0.09	2.63	0.00	0.09	0.38	86.16	23.45	10.56	20.70
	Dec	0.03	2.82	0.00	0.05	0.29	84.62	23.19	9.15	20.82
2013	Jan	0.01	2.62	0.00	0.04	0.21	85.36	24.08	9.18	19.81
	Feb	0.00	3.01	0.00	0.02	0.14	84.51	25.24	10.52	22.61
	Mar	0.00	3.67	0.00	0.01	0.11	83.07	26.20	12.26	23.70
	Apr	0.00	3.55	0.00	0.02	0.09	82.27	26.92	12.83	23.98
	May	0.00	3.95	0.00	0.02	0.07	78.25	27.63	13.89	25.51
	Jun	0.00	2.62	2.25	0.04	2.32	80.46	26.99	13.33	19.52
	Jul	0.00	2.16	12.10	0.13	12.24	88.95	24.23	10.50	18.87
	Aug	0.73	1.51	15.95	0.29	16.38	94.73	22.42	12.82	14.37
	Sep	0.69	2.58	2.37	0.24	2.90	93.32	24.73	11.30	22.20
	Oct	0.27	2.99	0.00	0.15	0.48	91.06	24.08	10.48	22.96
	Nov	0.10	2.52	0.30	0.09	0.66	90.92	23.28	10.32	19.95
	Dec	0.04	2.56	0.00	0.05	0.28	90.38	21.56	7.97	20.51
2014	Jan	0.01	2.61	0.00	0.03	0.20	89.42	23.35	9.64	20.59
	Feb	0.01	2.77	0.00	0.02	0.14	89.10	24.61	9.84	21.78
	Mar	0.00	3.51	2.96	0.03	3.10	90.06	25.30	12.25	23.14
	Apr	0.00	3.82	0.01	0.03	0.11	84.84	25.67	12.72	25.29
	May	0.00	3.04	3.14	0.06	3.26	84.77	26.48	12.83	21.18
	Jun	0.00	2.86	0.11	0.07	0.21	81.29	27.20	12.31	20.89
	Jul	0.26	1.90	55.36	0.21	55.56	90.86	24.40	12.96	16.77
	Aug	1.08	2.44	33.98	0.35	34.64	94.21	23.08	12.85	21.33
	Sep	0.58	2.34	15.43	0.28	16.10	93.70	23.52	11.27	20.26
	Oct	0.25	2.86	2.09	0.20	2.69	92.80	24.15	12.13	21.64
	Nov	0.09	2.48	2.20	0.11	2.59	91.99	22.62	10.41	20.29
	Dec	0.04	2.70	0.00	0.08	0.39	92.13	23.78	10.69	20.70

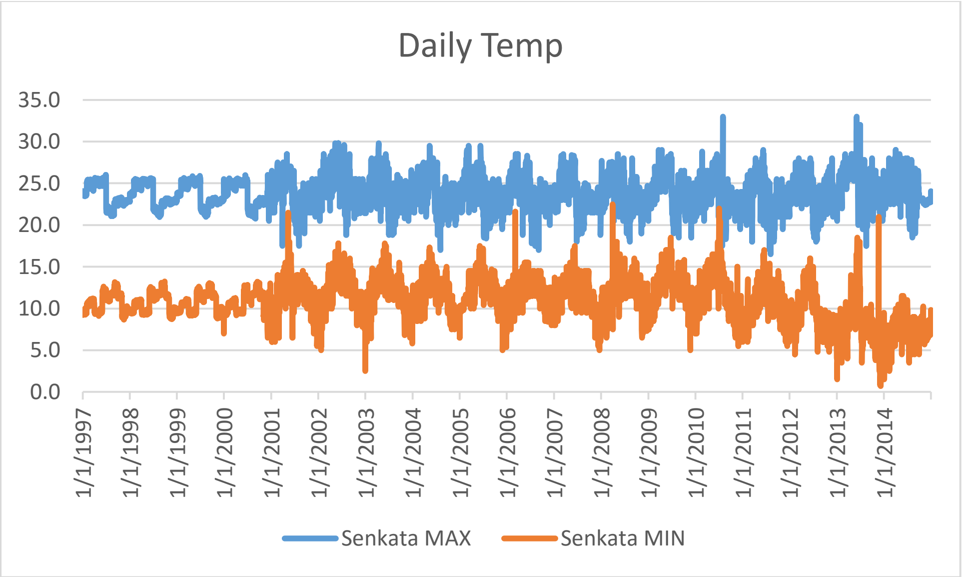
b. Routing Result of Suluh River

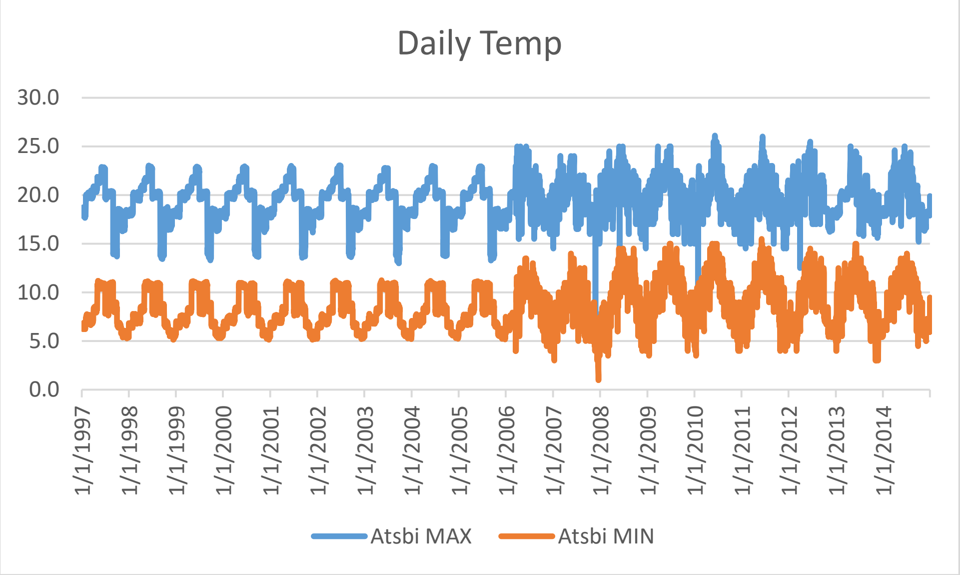
FLOW_In (m^3/sec)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0.04	0.03	0.02	0.02	0.42	0.50	7.87	11.65	3.41	1.09	0.58	1.14
2001	0.08	0.03	3.95	5.33	1.73	2.06	11.66	24.72	2.71	9.43	0.56	0.15
2002	0.11	0.08	2.01	5.60	3.93	0.48	5.54	4.78	7.17	0.24	0.05	0.20
2003	0.08	0.14	0.27	0.20	0.10	0.03	2.49	8.92	9.51	4.89	0.26	6.54
2004	0.09	0.05	1.32	3.21	0.15	0.33	9.09	16.97	1.75	0.42	0.08	5.63
2005	0.05	0.08	4.05	1.09	0.39	0.07	1.55	7.08	1.25	0.38	0.09	0.02
2006	0.01	0.01	0.06	8.89	1.09	0.90	2.19	17.38	3.32	1.08	0.53	0.22
2007	4.73	0.11	0.08	0.48	0.13	1.16	7.77	12.34	6.26	1.41	0.67	0.13
2008	0.08	0.05	0.04	0.05	0.33	3.24	11.21	14.14	0.96	0.86	1.05	1.55
2009	0.07	0.13	0.71	0.10	0.05	0.02	0.46	2.21	0.39	0.12	0.06	0.07
2010	0.03	0.04	0.12	1.18	1.98	0.11	3.20	21.82	1.75	3.47	0.52	0.15
2011	0.11	0.11	0.15	0.13	0.15	0.20	1.63	24.91	3.41	1.94	3.99	0.07
2012	0.03	0.02	0.79	0.33	0.48	1.23	4.01	11.70	2.05	1.12	0.48	0.14
2013	0.07	0.05	0.36	0.60	0.25	0.24	1.84	3.53	0.98	0.45	0.17	0.15
2014	0.04	0.03	0.16	0.13	0.21	0.13	2.94	4.62	4.14	2.28	0.51	0.18
FLOW_OUT (m^3/sec)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0.04	0.03	0.02	0.01	0.42	0.44	7.08	12.09	3.75	1.13	0.62	1.14
2001	0.09	0.03	3.67	5.17	2.14	1.96	10.42	25.44	3.27	9.47	0.60	0.16
2002	0.11	0.08	1.98	5.63	3.92	0.46	5.49	4.67	7.34	0.26	0.05	0.19
2003	0.10	0.10	0.30	0.19	0.11	0.02	2.34	8.95	9.57	4.92	0.29	6.54
2004	0.09	0.05	1.32	3.20	0.16	0.29	8.79	17.20	1.84	0.43	0.09	5.62
2005	0.06	0.07	3.73	1.37	0.43	0.08	1.47	6.66	1.75	0.39	0.10	0.02
2006	0.01	0.01	0.05	8.83	1.14	0.83	2.10	16.81	4.03	1.09	0.56	0.23
2007	4.72	0.13	0.08	0.47	0.14	1.00	6.93	13.07	6.42	1.46	0.71	0.15
2008	0.08	0.05	0.03	0.05	0.31	3.25	9.89	15.39	1.03	0.80	1.13	1.55
2009	0.07	0.13	0.71	0.11	0.05	0.02	0.39	2.14	0.54	0.12	0.06	0.07
2010	0.03	0.05	0.11	1.14	2.02	0.11	2.80	21.90	2.02	3.49	0.55	0.16

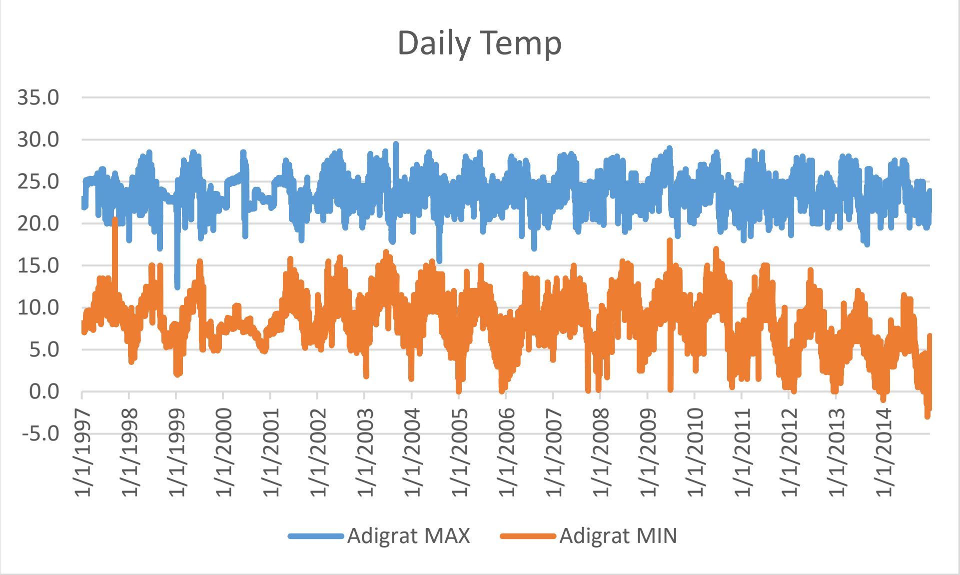
2011	0.11	0.12	0.14	0.13	0.14	0.20	1.10	25.03	3.78	1.97	4.01	0.07
2012	0.03	0.02	0.67	0.44	0.48	1.09	3.45	12.04	2.36	1.16	0.51	0.15
2013	0.08	0.05	0.32	0.59	0.30	0.20	1.74	3.56	1.06	0.46	0.17	0.17
2014	0.04	0.03	0.16	0.13	0.20	0.14	2.67	4.62	4.37	2.29	0.52	0.20

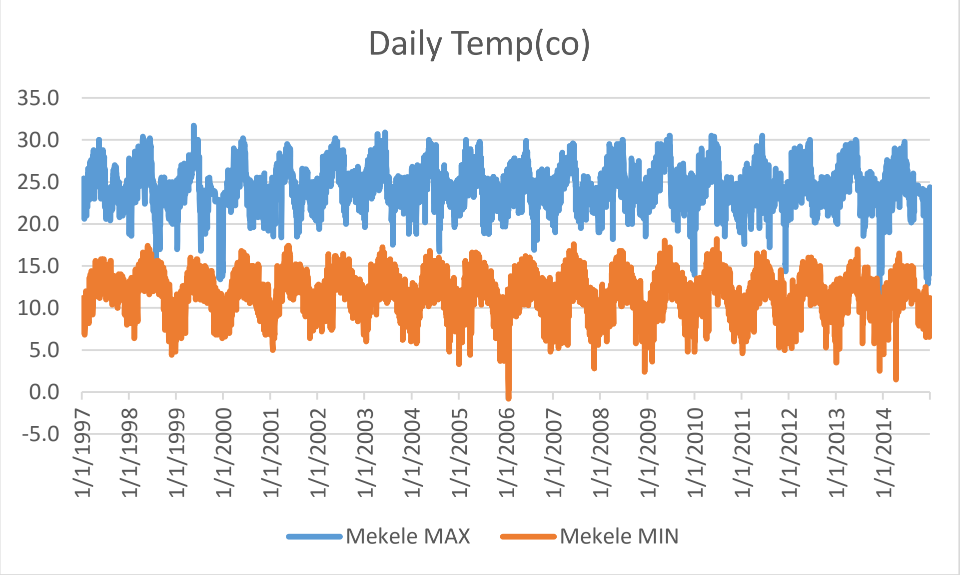
APPENDIX D: Daily Max. And min Temperature (from NMA)



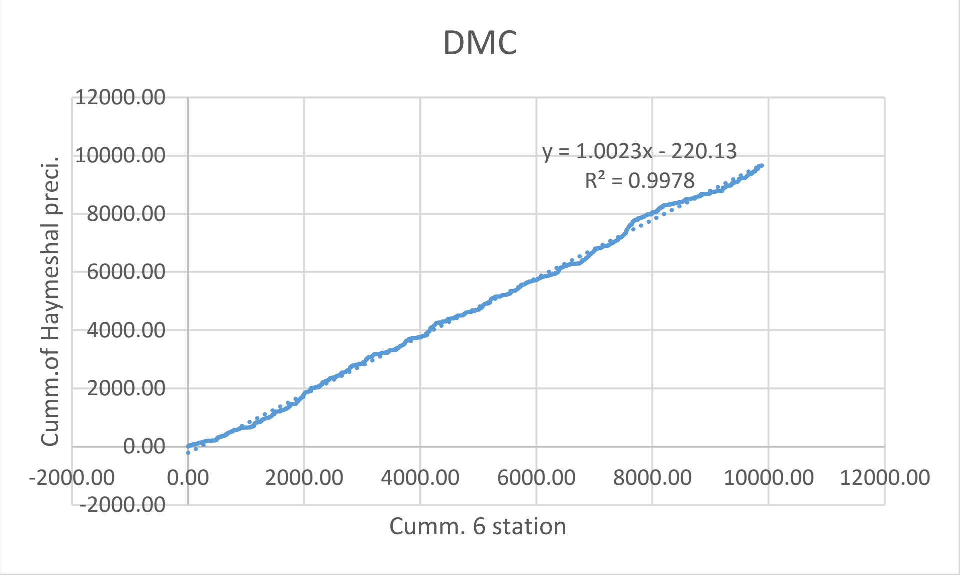


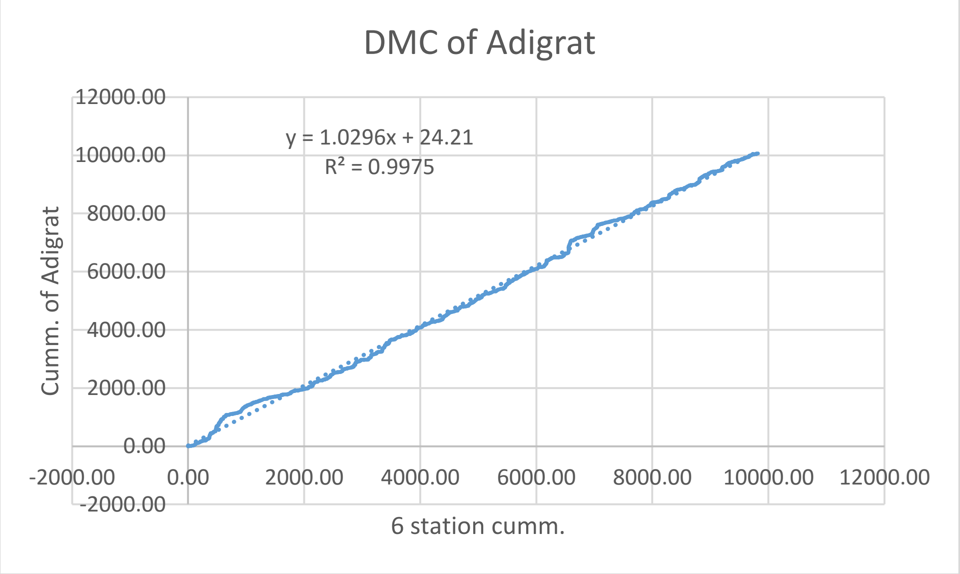

Daily Temp
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1/1/1997
1/1/1998
1/1/1999
1/1/2000
1/1/2001
1/1/2002
1/1/2003
1/1/2004
1/1/2005
1/1/2006
1/1/2007
1/1/2008
1/1/2009
1/1/2010
1/1/2011
1/1/2012
1/1/2013
1/1/2014
Atsbi MAX
Atsbi MIN

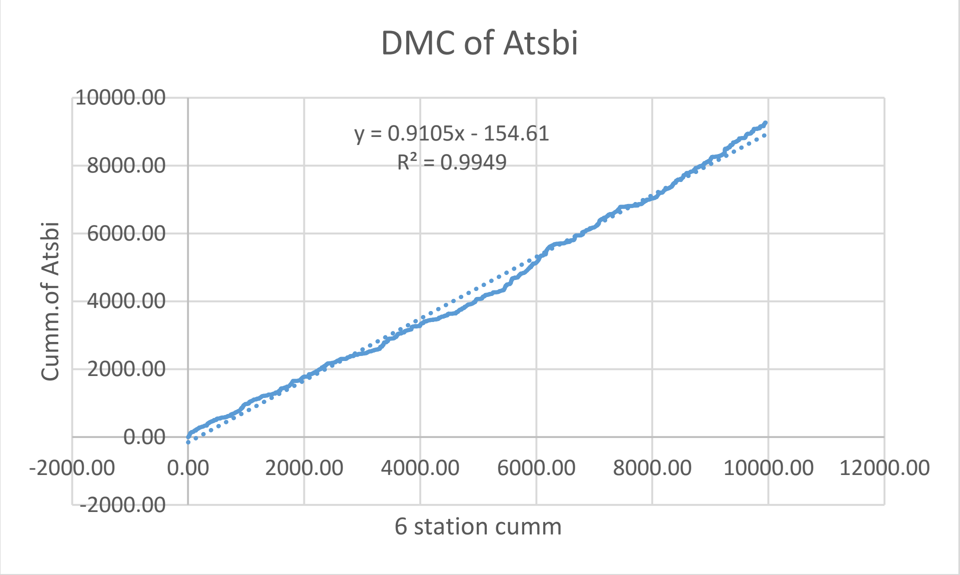

Daily Temp
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
1/1/1997
1/1/1998
1/1/1999
1/1/2000
1/1/2001
1/1/2002
1/1/2003
1/1/2004
1/1/2005
1/1/2006
1/1/2007
1/1/2008
1/1/2009
1/1/2010
1/1/2011
1/1/2012
1/1/2013
1/1/2014
Adigrat MAX
Adigrat MIN

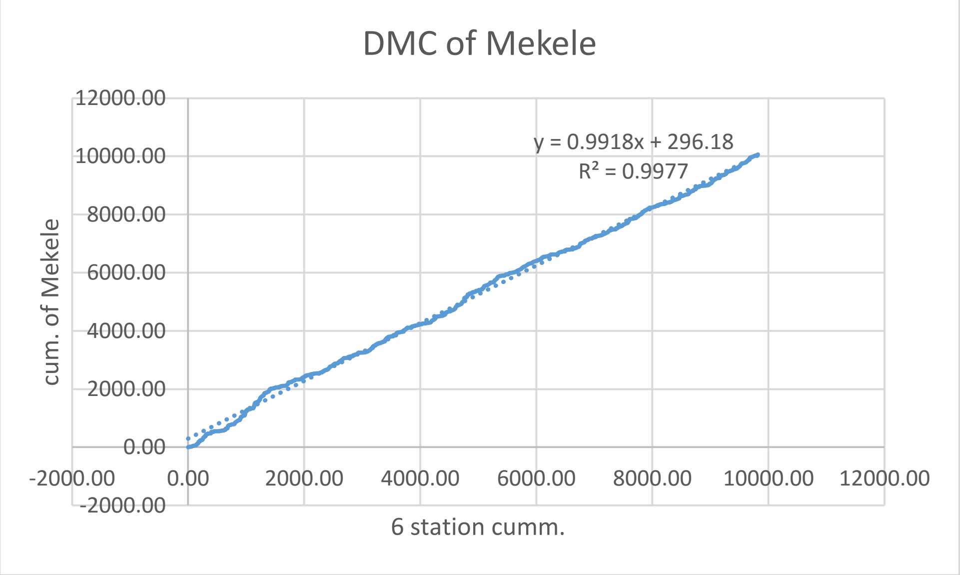

Daily Temp(co)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
1/1/1997
1/1/1998
1/1/1999
1/1/2000
1/1/2001
1/1/2002
1/1/2003
1/1/2004
1/1/2005
1/1/2006
1/1/2007
1/1/2008
1/1/2009
1/1/2010
1/1/2011
1/1/2012
1/1/2013
1/1/2014
Mekele MAX
Mekele MIN

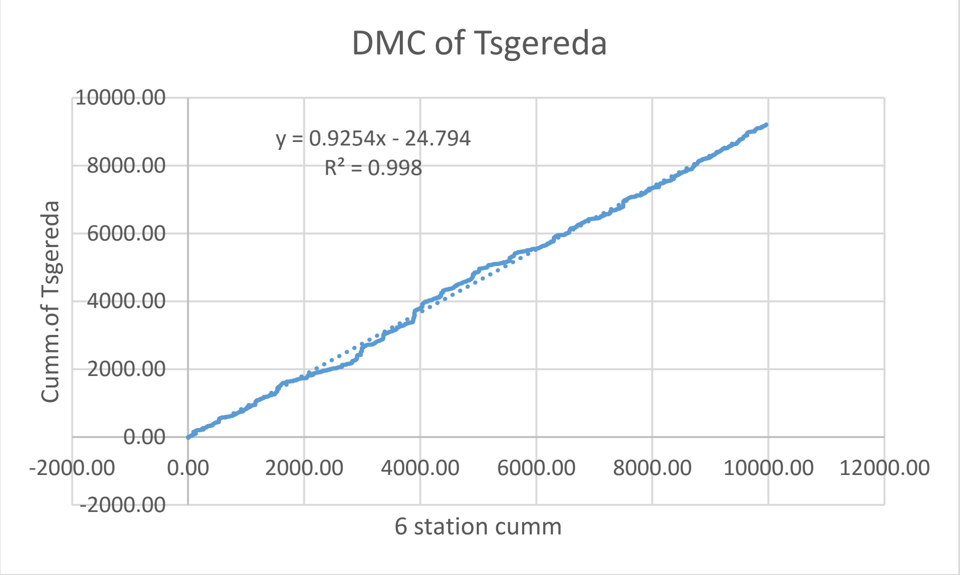
APPENDIX E: Figure of data consistency checking (DMC) for each meteorological station

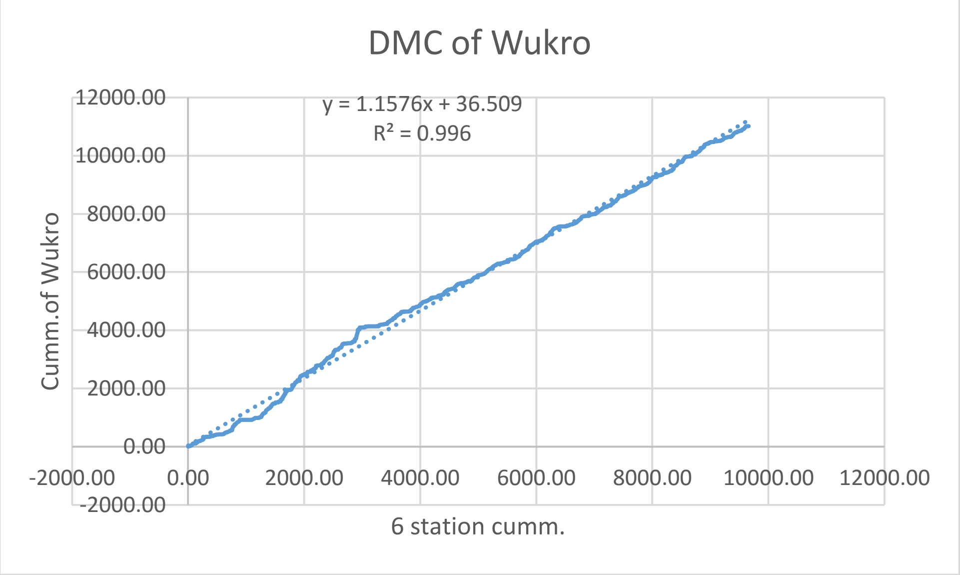


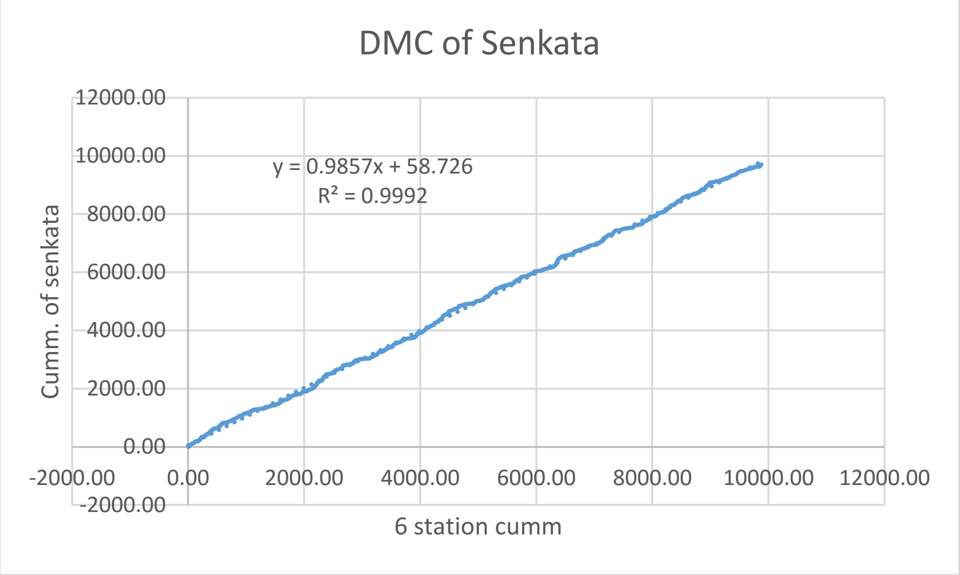



DMC of Atsbi
y = 0.9105x - 154.61
R² = 0.9949
Cumm.of Atsbi
10000.00
8000.00
6000.00
4000.00
2000.00
0.00
-2000.00
-2000.00
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00
6 station cumm


DMC of Mekele
y = 0.9918x + 296.18
R² = 0.9977
cum. of Mekele
12000.00
10000.00
8000.00
6000.00
4000.00
2000.00
0.00
-2000.00
-2000.00
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00
6 station cumm.


DMC of Tsgereda
y = 0.9254x - 24.794
R² = 0.998
Cumm.of Tsgereda
6 station cumm
10000.00
8000.00
6000.00
4000.00
2000.00
0.00
-2000.00
-2000.00
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00


DMC of Wukro
y = 1.1576x + 36.509
R² = 0.996
Cumm.of Wukro
6 station cumm.
12000.00
10000.00
8000.00
6000.00
4000.00
2000.00
0.00
-2000.00
-2000.00
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00


DMC of Senkata
y = 0.9857x + 58.726
R² = 0.9992
Cumm. of senkata
6 station cumm
12000.00
10000.00
8000.00
6000.00
4000.00
2000.00
0.00
-2000.00
-2000.00
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00