SWAT MODEL EVALUATION USING GENERATED DATA AND ASSESSING THE IMPACT OF LAND USE CHANGES

by

NETHI NAGA HARI SAIRAM

(2016 - 18 - 014)

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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ABSTRACT OF THE THESIS
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2018

Dedication

This thesis is dedicated to my parents, teachers, almighty and for my country

DECLARATION

I, hereby declare that this thesis entitled **"SWAT MODEL EVALUATION USING GENERATED DATA AND ASSESSING THE IMPACT OF LAND USE CHANGES"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Tavanur, **NETHI NAGA HARI SAIRAM**
Date: (2016-18-014)

CERTIFICATE

Certified that this thesis entitled **“SWAT MODEL EVALUATION USING GENERATED DATA AND ASSESSING THE IMPACT OF LAND USE CHANGES”** is a record of research work done independently by **Er. NETHI NAGA HARI SAIRAM (2016-18-014)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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Assistant Professor (IDE)
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SYMBOLS AND ABBREVIATIONS

%	:	Percentage
&	:	and
95 PPU	:	95 Percentage Prediction Uncertainty
AET	:	Actual Evapotranspiration
Agric.	:	Agricultural
AGWA	:	Automated Geospatial Watershed Assessment
AI	:	Artificial Intelligence
ALOS	:	Advanced Land Observing Satellite
ALPHA_BF	:	Base flow alpha factor
Am.	:	American
AMC	:	Antecedent Moisture Condition
ANN	:	Artificial Neural Networks
Appl.	:	Applied
ARS	:	Agricultural Research Service
ASABE	:	American Society of Agricultural and Biological Engineers
ASCII	:	American Standard Code for Information Interchange
Assoc.	:	Association
Aquat.	:	Aquatic

ASTER	:	Advanced Spaceborne Thermal Emission and Reflection Radiometer
Bio.	:	Biology/Biological
CFSR	:	Climate Forecast System Reanalysis
CH_K2	:	Effective hydraulic conductivity in main channel alluvium
Chem.	:	Chemistry
CN2	:	Curve Number with AMC-II
Conserv.	:	Conservation
CREAMS	:	Chemicals, Runoff and Erosion from Agricultural Management System
Curr.	:	Current
CWC	:	Central Water Commission
DEM	:	Digital Elevation Model
Drain.	:	Drainage
EE	:	Earth Explorer
Eng.	:	Engineering
Environ.	:	Environment/Environmental
EPIC	:	Erosion Productivity Impact Calculator
Eq.	:	Equation
ESCO	:	Soil Evaporation Compensation Factor

ESRI	:	Environmental System Research Institute
ET	:	Evapotranspiration
Exp.	:	Experiment/Experimental
et al.	:	and others
etc	:	et cetera
FAO	:	Food and Agricultural Organization
Fig.	:	Figure
FL	:	Fuzzy Logic
GDEM	:	Global Digital Elevation Model
GIS	:	Geographical Information System
GLEAMS	:	Groundwater Loading Effects on Agricultural Management System
GLUE	:	Generalized Likelihood Uncertainty Estimation
GW_Delay	:	Ground water delay time
GW_Q	:	Ground water contribution to stream
GWQMN	:	Threshold depth of water in shallow aquifer
ha	:	Hectare
hr	:	Hour
HRU	:	Hydrologic Response Unit

Hydrol.	:	Hydrology
HYMO	:	Hydrologic Model
i.e	:	That is
IMD	:	India Meteorological Department
Int.	:	International
Irrig.	:	Irrigation
IRS	:	Indian Remote Sensing
IVF	:	Index of Volumetric Fit
J.	:	Journal
km^2	:	Square Kilometer
LH	:	Latin Hypercube sampling
LISS	:	Linear Imaging Self Scanning
LULC	:	Land use and Land Cover
Manag.	:	Management
MCM	:	Million Cubic Meter
MCMC	:	Marcov Chain Monte Carlo
METI	:	Ministry of Economy, Trade and Industry
Microbiol.	:	Microbiology
MLC	:	Maximum Likelihood Classifier
Mon.	:	Monthly
mm	:	Millimeter
m^3 ; m^3/s	:	Cubic meter; Cubic meter per second

NASA	:	National Aeronautics and Space Administration
NCEP	:	National Centers for Environmental Prediction
NDWI	:	Normalized Difference Water Index
NSE	:	Nash Sutcliffe Efficiency
NYSKIP	:	Number of Years to SKIP
OAT	:	One at a Time analysis
Parasol	:	Parameter solution
PBIAS	:	Percent bias
PERC	:	Water that Percolates below root Zone
PET	:	Potential Evapotranspiration
Phys.	:	Physics
PSO	:	Particle Swarm Optimization
R^2	:	Coefficient of Determination
RARS	:	Regional Agricultural Research Station
RCHRG_DP	:	Deep Aquifer Percolation fraction
Res.	:	Research
Resour.	:	Resource
Rev.	:	Review
RMSE	:	Root Mean Square Error

RPZ	:	Resource Potential Zones
RSR	:	RMSE-observations standard deviation ratio
s	:	second
SCS CN	:	Soil Conservation Service Curve Number
Sci.	:	Science/Sciences
S.D	:	Standard Deviation
Soc.	:	Society
SOL_AWC	:	Available Water holding capacity of soil
SOL_K	:	Soil hydraulic Conductivity
SOL_Z	:	Depth from soil surface to bottom of layer
SPAW	:	Soil Plant Atmosphere Water
Stud.	:	Studies
SUFI2	:	Sequential Uncertainty Fitting
SURLAG	:	Surface Runoff Lag coefficient
SURQ	:	Surface Runoff
SWAT	:	Soil and Water Assessment Tool
SWAT SC	:	SWAT Seasonal Calibration Scheme
SWATCUP	:	SWAT Calibration and Uncertainty Programs
SWRRB	:	Simulator for Water Resources in

		Rural Basins
Syst.	:	System
t	:	Tonnes
Technol.	:	Technology
TMDL	:	Total Maximum Daily Loads
Trans.	:	Transactions
USDA	:	United States Department of Agriculture
USGS	:	United States Geological Survey
UTM	:	Universal Transverse Mercator
Viz.	:	Namely
WGS	:	World Geodetic System
WWDR	:	World Water Development Report
WYLD	:	Water Yield

CHAPTER I

INTRODUCTION

Land and water are the two most vital and essential natural assets needed by mankind as well as by flora and fauna. These resources are gradually declining day by day because of unplanned and ineffective utilization. All over the World, water occupies about 75% of the earth's surface. Nevertheless, fresh water scarcity and security have been identified as the major global environmental problems of the 21st century. The increase in worldwide demand for water is seen to be at an annual rate of 1% which is dependent mainly on population growth, economic development and changing consumption patterns and this is predicted to increase significantly over 2020 to 2040 (WWDR, 2018). The land use changes also play a vital role in adjusting the hydrologic system and have potentially huge impacts on water resources because of the rapid socio-economic development. Hence, there is a need of effective planning for these resources with the use of latest scientific and technological interventions.

Modelling studies in watersheds is used as a means to better apprehend surface and sub surface water movement and also to study the interaction between the various hydrologic components. Watershed models are required for assessment and management of these water resources which are used to analyze the quantity and quality of surface and ground water resources. The models can simulate flow processes which are naturally occurring in the watershed, the sediment and other chemical movements in a watershed, and are also able to quantify the results of human interventions on such processes. Since 1960's, computerized watershed models have been used by scientists to simulate the hydrology of a watershed, removal of soil by way of erosion and re-depositing it in the watershed, and non point pollution loads from the watershed. The capability of models to estimate future conditions is very useful for projecting the outcomes of various possible management measures and strategies. It has become increasingly difficult to the water resource managers, engineers and researchers on conveying available water resources to the entire population and also reduce surface and ground water contamination as well as to predict the future events. In order to overcome these challenges, different techniques making use of watershed models and advanced systems in hydrologic modelling are made use of. The use of recent techniques like artificial intelligence in modelling processes is very useful in a variety of applications including evaluating and developing Total Maximum Daily Loads (TMDL). These models act as a screening tool to identify the best management strategy for allocating sufficient water for different purposes with reduced problems under the series of possibilities.

Watershed models are grouped into different categories based on the modelling approaches such as nature of input and uncertainty, nature of algorithms, nature of spatial representation and type of storm event. The primary features for distinguishing the watershed scale modelling approaches include nature of algorithms employed. A deterministic or stochastic approach is used in some cases for model parameter specification and in some cases the lumped or distributed model (spatial representation) is used. Generally, Soil and Water Assessment Tool (SWAT) model which is a physically based model can be employed which depends on the knowledge of physics related with hydrological processes. The model is able to control catchment response and also employ equations which are physically based which help in depicting these processes.

Soil and Water Assessment Tool (SWAT) model developed by Dr. Jeff Arnold is a continuous semi distributed, process based river basin or watershed scale model. This has been developed by the United States Department of Agriculture, Agricultural Research Service (USDA, ARS). It is used to predict the impact of land management practice on water, sediment and agricultural chemical yields on large watersheds with varying soils, land use and management practices over long periods of time. It is the successor of the "Simulator for Water Resources in Rural Basins" model (SWRRB) which is effective in executing long term simulations. The model divides the entire catchments into sub catchments which are further divided into Hydrologic Response Units (HRU) on the basis of land use, vegetation and soil characteristics. Daily precipitation data, maximum and minimum air temperature, solar radiation, relative humidity and wind speed are the inputs used and the model is thus able to describe water and sediment circulation.

Land based rain gauge data and stream flow data are indispensible records needed for planning and designing any project related to watersheds, especially for watershed modeling. In most of the areas, the number of stream gauge stations are limited when compared to the rain gauge stations. However, the rain gauge stations available may not always effectively represent the climate of a watershed since they are not equally distributed and are point measurements. The weather data obtained may not correctly represent the characteristics of watershed and can also have gaps when taken for a period of time. Further, to overcome the data deficiency problem, a possibility that arises is the use of global gridded data available for longer durations and are generally known as reanalysis datasets.

The best one from the various reanalysis datasets available, National Centers for Environmental Prediction’s Climate Forecast System Reanalysis (CFSR) which is freely available reanalysis dataset includes all the parameters required for the study, i.e. precipitation, temperature, solar radiation, humidity and wind speed. The spatial resolution of the dataset which is in the order of 30 km and available from 1979 onwards. In order to overcome the problems of data deficiency in the watersheds, CFSR data can be considered as an alternate option when the number of rain gauge stations is limited.

The natural landscapes are often converted for agricultural and other uses and further conversion of agricultural land to urban uses often impacts soil integrity and cause land degradation. The loss of natural landcover can have serious implications for water resources since the interception over the landcover decreases and the infiltration rates decreases. These changes will also affect the watershed hydrology by altering the different hydrologic processes. It also affects the ground water recharge, amount of surface and river runoff. So, rapid changes in the land use and land cover can alter the hydrologic response of a watershed. The effect of land use changes on the hydrological processes and river discharge using the simulation is used to analyze and predict water balance change in the catchment.

Watershed modelling plays an important role for effective planning of water resources. It can simulate natural processes of flow of water and sediment which is used to predict the future conditions. CFSR data is used in modelling these resources in places having data scarcity. Land use changes also play a major role in altering the hydrological response in watershed due to rapid urbanization. The impact of land use changes and lack of data in the watershed are the main problems in carrying out the hydrological modelling of watershed.

Keeping the above points in view, a small and independent sub catchment of Bharathapuzha river basin which is a west flowing river of Kerala state was selected for the study. Data scarcity in regard to rainfall and stream-flow is often encountered in the region. Changes in natural ecosystems to agricultural lands and built-up areas is causing imbalance in nature which is likely to affect the water resources. Therefore, this study has been initiated with the given below specific objectives.

1. Calibration and validation of hydrologic model SWAT adapted to the study area.
2. Comparison of SWAT outputs using CFSR data and observed meteorological data.
3. Study the impact of land use change on the hydrology of the watershed.

CHAPTER II

REVIEW OF LITERATURE

The chapter deals with the review of the previous research done on watershed modelling, climate forecast system reanalysis and impact of land use changes on water resources. In addition, a brief discussion on physically based distributed watershed models, sensitivity analysis, calibration and validation is also included. Reviews on SWAT model evaluation using generated data and assessing the impact of land use changes is also presented.

2.1 WATERSHED MODELS AND MODELLING

Models are simple representations of the complicated real life systems. Models which are used to study and understand the hydrological processes that are undergoing in the watershed are called watershed models. Some of the hydrological processes like precipitation, interception, runoff, infiltration, percolation and base flow can be modelled. Watershed modelling involves conceptualization of mathematical models to represent these hydrologic processes.

2.2 CLASSIFICATION OF HYDROLOGIC MODELS

Pechlivanidis *et al.* (2011) explained the classification of hydrological model types which mainly discusses about the significance of the different model types. These models are characterized dependent on their model structure, spatial distribution, stochasticity and spatial-temporal application (Wheater *et al*., 1993). In the model structure based classification, they are classified into metric models, conceptual models, physics based models and hybrid models.

The main characteristics of metric models is used to are mainly depends on observations which are used to describe the system response from the accessible data. Conceptual models broadly shows all segments of hydrological processes which are recognized to be of significance in catchment scale input-output relationships. Physically based models mainly illustrates about the hydrological process components such as evapotranspiration, infiltration, overflow, saturated and unsaturated zone flow employing the governing equations of motion based on continuum mechanics. The spatial distribution of these models is classified into lumped and distributed models. Lumped models consider the catchment area as single unit with state variables that corresponds averages over the catchment area. Distributed models make forecasts that are distributed in space, represent local averages by discretising the catchment into number of elements and solving the equations for the state variables associated with every element. Based on the stochasticity, models are classified into deterministic and stochastic. Deterministic models always generate a same output result from a simulation with single set of given input data and parameter values. Stochastic models use arbitrary values to illustrate process uncertainty and produce distinct outcomes from one set of input data and parameter values.

According to the time scale based classification, rainfall runoff models are categorised as continuous simulation models and event based models. Continuous simulation models chooses a time series of rainfall which may incorporate more than one rainfall storm event, while event based models incorporate only one rainfall storm event. According to the space scale based classification, models are grouped into small catchments (up to 100 km^2), medium scale catchments (100-1000 km^2) and large catchments (greater than 1000 km^2).

2.3 CURRENT TRENDS IN WATERSHED MODELLING

Edsel *et al.* (2011) described about ongoing trends in watershed modelling which includes stochastic based methods, distributed versus lumped parameter techniques, impact of data resolution and scalar problems and the utilisation of artificial intelligence (AI) as a component of data driven approach that help in watershed modelling. It will definitely advance in understanding of physical, chemical and biological processes affecting water quality, coupled with enhancements in the collection and analysis of hydrologic data contribute opportunities for significant innovations. The main findings from this work are

(i) use of AI techniques like artificial neural networks (ANN), fuzzy logic (FL) and genetic algorithms to substitute commonly used physically based techniques (ii) limitations in scale up of hydrological processes for watershed modelling (iii) impacts of data resolution on watershed modelling capabilities.

2.4 APPLICATION OF GIS AND REMOTE SENSING IN WATERSHED MANAGEMENT

Pachri *et al*. (2013) discussed about the enhancement of water management modelling by employing GIS in Chirchik river basin, Uzbekistan. In order to achieve the required results, different spatial data such as land use layers and hydrological layers are enhanced by handling the latest GIS technology. By extracting ASTER DEM and Advancing Land Observing Satellite (ALOS) data on autumn and spring, a series of land use classification is generated using the supervised classification method. The overview of hydrologic model using Geomorphology based hydrological model is used to analyze the river basin. As a result, enhancement of spatial modelling is achieved and GIS-based analysis is an effective method to study water management in the Chirchik river basin.

Narmada *et al*. (2015) studied about the resource potential of Nambiar watershed by the combination of GIS and remote sensing techniques to identify and evaluate the land quality and water resources. In order to evaluate the resource potential of watershed, diverse thematic maps have been set up with the utilization of visual interpretation keys using IRS P6, LISS IV data, topographical maps and relevant secondary data. Land and water resources are evaluated independently by combining data extracted from remote sensing satellite data. A composite map on the Resource Potential Zones (RPZ) was generated by integrating land resources with water resources using the GIS techniques. The integrated resource analysis supports in the effective management of water, agriculture, forest and other natural resources for sustainable development of Nambiar watershed.

2.5 SWAT MODEL AND ITS COMPONENTS

Soil and Water Assessment Tool (SWAT) is a continuous-time, semi distributed, process based river basin or watershed scale model developed by Dr. Jeff Arnold for United States Department of Agriculture, Agricultural Research Service (USDA, ARS) (Arnold *et al*., 2012; Arnold *et al*., 1998). In order to predict the impact of land management practice on water, sediment and agricultural chemical yields on large watersheds with varying soils, land use and management practices over long periods of time, SWAT is developed (Neitsch *et al*., 2009). In SWAT model, the watershed is divided into sub watersheds which are further divided into hydrological response units which represent homogenous land use, management and soil characteristics that provide a high level of spatial detailed simulation.

2.5.1 Estimation of Surface Runoff

The surface runoff is the flow of water that occurs by excess storm water after satisfying all the abstraction losses. The surface runoff is estimated based on the SCS curve number method and Green-Ampt infiltration method. SCS curve number method is an empirical model which provides consistent basis on direct runoff on different land use and soil types. The Green-Ampt is a time based model which can simulate impacts of rainfall intensity, duration and infiltration processes. The SCS curve number is the simple method adopted to predict runoff.

Mohammad *et al*. (2016) studied on estimation of annual runoff and sediment of Duhok reservoir watershed using SWAT model for the period 1988-2011. This study is very useful since it directly influences the reservoir performance due to the reduction in storage capacity and also affects the dam efficiency and operation schedule. The estimated annual runoff volume and average annual sediment yield varied from 2.6 to 34.7 MCM and 50 to 1400 t/km^2/year. The average annual runoff volume values are influenced by rainfall depth, intensity and runoff coefficient causing an average runoff volume of 14.3 MCM. The average annual sediment load from the whole watershed was 124600 tonnes.

Swami and Kulkarni (2016) discussed on the simulation of stream flow and sediment yield for Kaneri watershed using SWAT model. This study mainly addresses the problems of sustainable rainwater management for enhancing livelihoods. SWAT model set up was done for the study area situated in the western Maharastra region. The coefficient of determination (R^2) for the monthly and annual runoff was 0.849 and 0.951 respectively for the calibration period (1979 to 2000) and 0.801 and 0.950 respectively for the validation period (2001 to 2013). The coefficient of determination (R^2) for the monthly and yearly sediment yield was obtained as 0.722 and 0.788 respectively for the calibration & 0.565 and 0.684 respectively for the validation. The above results can be considered satisfactory for assessing stream flow and sediment yield from a Kaneri watershed.

Tibebe *et al*. (2016) investigated on estimating runoff Holetta River using Geographical Information System (GIS) and SWAT model. The sensitivity analysis, calibration and validation of the model were performed at the sub basin which was used to assess runoff at the ungauged part of catchment. The SWAT model performance was evaluated by using statistical and graphical methods. The results showed that R^2 (coefficient of determination), NSE (Nash-Sutcliffe Efficiency) and IVF (Index of Volumetric Fit) were 0.85, 0.84 and 102.8 respectively for monthly calibration and 0.73, 0.67 and 108.9 respectively for monthly validation. These indicated that SWAT model performed well for simulation of the hydrological processes of the watershed.

Gull *et al*. (2018) discussed on the assessment of stream flow and sediment yield in Lolab watershed by employing SWAT model. In order to assess these areas, there is a need of model calibration and validation. Before calibration, some of the sensitive parameters are investigated. The results of the model calibration and validation represent the reliable estimates of monthly runoff (R^2=0.74 and E_{NS}=0.68) and annual runoff (R^2=0.90 and E_{NS}=0.68) throughout the calibration period & monthly runoff (R^2=0.85 and E_{NS}=0.83) and annual runoff (R^2=0.99 and E_{NS}=0.91) throughout the validation period. This study represents a tremendous model efficiency of monthly sediment yield (R^2=0.80 and E_{NS}=0.79) and annual sediment yield (R^2=0.86 and E_{NS}=0.78) throughout the calibration period and monthly sediment yield (R^2=0.88 and E_{NS}=0.86) and yearly sediment yield (R^2=0.83 and E_{NS}=0.58) throughout the validation period. From this study, SWAT model can be used as a best management strategy for water resources planning in the watershed.

2.5.2 Estimation of Evapotranspiration

Evapotranspiration is the process in which both evaporation as well as transpiration simultaneously occur from the soil and plant canopy. The three methods used for estimating the evapotranspiration are Penman-Monteith method (Monteith, 1965), Priestly-Taylor method (Priestly and Taylor, 1972) and Hargreaves method (Hargreaves *et al.*, 1985).

Earls and Dixon (2008) investigated to estimate Potential evapotranspiration (Hargreaves, Priestly-Taylor and Penman Monteith) based on different meteorological input data and PET calculation methods using SWAT. It mainly focuses on determining the prediction accuracy using simulated and observed weather data based on Potential evapotranspiration methods. The observed meteorological data was acquired from the local meteorological stations, whereas the simulated meteorological data was created by SWAT using one nearby meteorological site. The model predicted PET outcomes were validated based on the independent PET estimations from Florida Automated Weather Network Sites. The results showed that variation in the predicted PET between the simulated and observed meteorology for a chosen PET calculation method is not notable and is notable across the methods of PET calculation.

Izady *et al.* (2014) discussed on the assessment of actual evapotranspiration at regional- annual scale using SWAT. In order to achieve the objectives, calibration and validation of SWAT was performed depending on the stream discharge data from 5 gauging stations, rainfed and irrigated wheat yield data for the period October 2000 to September 2007 and October 2007 to

September 2010 respectively. These findings revealed that SWAT performed reasonable predictions on the hydrologic budget and crop yield. The calibration and validation periods were suitable for the watershed which was used to evaluate actual evapotranspiration. The mean ten-year actual evapotranspiration and precipitation was 230 and 270 mm respectively.

Wang *et al.* (2015) investigated three different potential evapotranspiration methods (Hargreaves, Priestly-Taylor and Penman Monteith) on SWAT hydrologic simulation in Wild Rice river watershed located in the north western Minnesota. These three models were individually calibrated and validated utilizing the observed stream flows at two USGS gauging stations. The SWAT model performance was evaluated using three statistical measures: Nash – Sutcliffe coefficient, coefficient of determination and performance virtue. The use of three PET methods resulted in different values for two calibration parameters namely the soil evaporation compensation factor and SCS curve number. After calibration, the results showed that the three models performed very similar hydrologic simulations within SWAT. The results showed that all the three models performed well when the monthly, seasonal and annual average discharges and satisfactory while predicting the daily stream flows. SWAT-Hargreaves seemed to be slightly superior when compared to the other models for the study area.

2.6 HYDROLOGIC MODELLING OF SWAT

The Soil and Water Assessment tool is able to simulate the hydrological components of the river basins using the water balance equation. This model is mainly capable of understanding and assessing the basin realistically in watersheds. It represents the reality of actual hydrological components in a simple way. Therefore, many findings suggested that SWAT is one of the most widely used hydrological models for simulating the hydrological components effectively in watershed.

Fukunaga *et al.* (2015) carried out the evaluation of the ability of the SWAT hydrologic model to simulate the continuous daily stream flows of the upper Itapemirim River basin (Brazil). The calibration and validation for the model parameters was done for the period from 1993 to 2000. The results showed that the model is highly sensitive to the base flow and statistical indexes of the validation (NS = 0.67; NSlog = 0.68; PBIAS = 22% and RSR = 0.57) showed that performance was satisfactory.

Shimaa (2015) carried out stream flow simulation, establish the water balance and evaluate monthly volume inflow in the study of Simly Dam watershed situated in the Saon river basin at the north-east of Islamabad using SWAT. The mentioned objectives are very useful for understanding the typical hydrological processes of watershed and also help the water resource managers to plan and handle the reservoir. The calibration and validation periods ranges between 1990-2001 and 2002-2011. Finally, the analysis represents a good performance for both calibration and validation periods based on the recommended statistical coefficients. The water balance components were accrately estimated and dam inflow was satisfactorily done with the coefficient of determination (R^2) of 0.75. From the above findings, he concluded that SWAT model can be used efficiently in semi arid regions to support water management policies.

George and Sathian (2016) investigated the hydrological behaviour of Kurumali sub basin of Karuvannur river basin by employing SWAT. The SWAT model set up was done for sub basin by inputing the digital thematic maps, physical properties of soil and climate parameters. The calibration and validation was done for the model which gives better performance in simulating the basin. The calibrated model predicted the hydrological processes which were found to be 64% base flow, 12% lateral flow and 9% surface runoff of the annual rainfall. Finally, the study reported that SWAT model can be effectively used in the stream flow simulation and also for estimating the water balance of river basin.

Surojit *et al.* (2016) carried out the study on the simulation of hydrological components in an agricultural dominated Chotki Berghi watershed in Eastern India using SWAT. It mainly focuses on estimating the stream flow and sediment yield. The model calibration was done for the period of 2004-2006 and validation for 2007-2008. In this process, base flow was identified as the most sensitive parameter from the nine sensitive parameters. The conclsions were satisfactory for the gauging station with R^2= 0.75 and NSE= 0.78 for calibration and R^2=0.62 and NSE=0.68 for validation period. So, SWAT model is used to predict these hydrological components effectively for water resources planning and management at large scale.

Faiza *et al.* (2017) investigated on modelling of runoff and sediment transport with the help of SWAT model in the Harraza which is situated in the Northwest of Algeria. The soil and water assessment tool model integrated with GIS were used to simulate discharge and sediment concentration for the period 2004 to 2009. Model calibration and validation were done for monthly periods employing SUFI-2 within SWATCUP which gives good performance for runoff. The average total annual sediment in the basin which is estimated as 54.24 t ha^{-1}.

2.7 IMPORTANCE OF CFSR DATA AND INFLUENCE IN WATERSHED MODELS

The National Centers for Environmental Prediction’s Climate Forecast System Reanalysis is a freely available reanalysis dataset which include parameters like precipitation, humidity, temperature, solar radiation, wind speed etc. The spatial resolution of CFSR dataset which is in the order of 30 km and available from 1979 onwards (Tomy and Sumam, 2016). The CFSR data is also used for solving the issues of data scarcity in the watersheds when the rain gauge stations are limited.

Fuka *et al.* (2013) investigated on the influence of CFSR data as weather input for the watershed models. This study presents a method for employing CFSR global meteorological dataset to obtain historical weather data in order to model five watersheds representing different hydro climate regimes. The requirement of CFSR mainly occurred because the land based weather stations won’t represent the weather occurring over the watershed and can have gaps in their data series. The results showed that employing the CFSR rainfall and temperature data to drive watershed models that generates stream flow simulations that are performed well when compared with traditional weather stations, especially when stations are greater than 10 km from the watershed. These ultimately define that considering CFSR data to the watershed modelling creates new opportunities or meeting the challenges of modelling ungauged watersheds.

Dile and Srinivasan (2014) studied the applicability of NCEP CFSR climate data in modelling the hydrology of the Blue Nile river basin. The SWAT model was set up to compare the CFSR weather with that of conventional weather in simulating observed stream flow at four river gauging stations in the Lake Tana basin. The results showed that the conventional weather simulation performed satisfactorily for three gauging stations, while the CFSR weather simulation performed satisfactorily for the above two gauging stations. From the above statement, we can conclude that CFSR can be a valuable option in the data scarce regions for the hydrological predictions.

2.8 COMPARISON OF CFSR AND OBSERVED METEREOLOGICAL DATA IN SWAT

Tomy and Sumam (2016) reported the adequacy of CFSR data for rainfall runoff modelling using SWAT in the Karuvannur watershed in Thrissur district. The main reasons behind adopting these satellite data products like CFSR are inadequate no of stream gauge stations when compared to rain gauge stations and that land based rain gauge stations are point measurements that can have gaps in their data series. In order to overcome these data deficiency problems, CFSR data is used to assess the data accuracy in the rainfall runoff modelling. Finally, they have reported that CFSR data produces more reliable results for ungauged stations and watersheds with less number of rain gauges.

2.9 PREDICTION ACCURACY OF MODEL PERFORMANCE

All models need to be calibrated properly so as to obtain a more realistic model performance. In order to use the model predictions for water management studies, the SWAT model also need to be properly calibrated (Arnold *et al*., 2012). In order to obtain more confidence on the model performance, it need to be further validated.

2.9.1 Sensitivity Analysis

Sensitivity analysis is the process of analyzing the parameters based on the hydrological characteristics of the basin. It is an essential process to recognize the key parameters and parameter precision needed for calibration (Ma *et al*., 2000). So, it plays a vital role in model parameterization, optimization, calibration and uncertainty quantification.

The sensitivity analyses are of two types: local sensitivity analysis and global sensitivity analysis. The local sensitivity analysis is the process of changing one parameter at a time. This type of analysis is also called as one at a time analysis. The major disadvantage of this method is that the sensitivity of one parameter depends on other parameters and the corrected values of those parameters are unknown. The global sensitivity analysis is the process of allowing all the parameter values to change simltaneously. The main disadvantage is that it requires more no of simulations.

Holvoet *et al*. (2005) investigated the sensitivity analysis for hydrology and pesticide supply towards the river using SWAT located in the Nil catchment in Belgium. In order to understand the different hydrological processes and to determine the pesticide fate component, sensitivity analysis is needed. The Latin Hypercube (LH) sampling of One at a Time Analysis (OAT) is used for the study. Curve number (CN2), surface runoff lag (SURLAG), recharge to deep aquifer (RCHRG_DP) and the threshold depth of water in the shallow aquifer (GWQMN) are the most sensitive hydrological parameters. Next, the chosen parameters were evaluated by manual calibration. The other parameter which affects pesticide concentrations in surface water is apfp_pest that handles direct losses to the river system. The results of the study showed that hydrologic parameters are prominent in controlling pesticide predictions.

Khalid *et al.* (2016) studied about the sensitivity analysis in watershed model using SUFI-2 method for Langat river basin. This analysis examines the input parameters for model development and also used as a guidance for future research. The SWAT model is employed in the study area for the daily simulation of stream flow and sensitivities of 21 parameters have been examined by employing the SUFI-2 method in SWAT_CUP. The results showed that CN2.mgt, GW_Delay.gw, SLOPE.hru, SOL_AWC.sol and SOL_K.sol are the most sensitive for both local and global sensitivity procedures.

2.9.2 Model Evaluation with Statistical Parameters

Moriasi *et al.* (2007) reported the model evaluation guidelines for systematic quantification of accuracy in watershed simulations since there is no detailed guidance available to facilitate model evaluation in terms of the precision of simulated data compared to observed flow. The objectives focus on simulation of stream flow and transport of sediment and nutrients. Three quantitative statistics Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), and ratio of the root mean square error to the standard deviation of measured data (RSR) in addition to the graphical techniques were used for model evaluation. Finally, model simulation can be considered as satisfactory if $NSE > 0.5$ and $RSR \leq 0.7$, and if PBIAS ± 25% for stream flow, PBIAS ± 55% for sediment, and PBIAS ± 70% for N and P. For PBIAS, constituent specific performance ratings were determined based on uncertainty of measured data.

2.10 CALIBRATION AND VALIDATION

Calibration is the process of determining the model parameters by comparing the model predictions with the observed data for the given set of assumed conditions. It is mainly used to help the model in achieving the realistic hydrological situations present in the watershed. Validation is the process of building confidence in the model whether the model is accurately simulated or not. It involves running the model input parameters obtained during the calibration process for the observed data which is not used in calibration.

A good calibration and validation should involve the following analysis

1. Observed data includes wet, average and dry years
2. Multiple evaluation techniques
3. Calibrating all constituents to be evaluated; and
4. Verification that other important model outputs are reasonable.

Arnold *et al*. (2012) investigated the model use, calibration and validation of SWAT model. SWAT requires large number of input parameters in which it leads to complexity of calibration and model parameterization. In order to reduce the complexity, several calibration techniques like manual calibration techniques and automated procedures employing the shuffled complex evolution and other general algorithms are introduced. In addition, SWAT-CUP incorporates a semi automated approach (SUFI-2) using both manual and automated calibration incorporating sensitivity and uncertainty analysis. The user component of SWAT-CUP helps user for the better understanding of the overall hydrologic process and parameter sensitivity. Parameter sensitivity analysis helps to focus on the calibration and uncertainty analysis which is used to apply statistics for goodness-of-fit. It also helps in future calibration enhancements to spatially account for hydrologic components; enhance model run time efficiency; include the impact of uncertainty in the conceptual model and measured variables used in calibration and helps the user in checking model errors.

Narsimlu *et al*. (2015) reported the use of SWAT model Calibration and Uncertainty analysis for runoff estimation in the Kunwari River Basin (KRB) for effective management of water resources. In order to meet the requirements, Soil and Water Assessment Tool (SWAT), a semi distributed physically based model and SWAT-CUP (SWAT-Calibration and Uncertainty Programs) was selected and set up in the KRB for hydrologic modelling for model calibration, sensitivity and uncertainty analysis, employing the SUFI-2 technique. The model calibration was done for the period ranges from 1987–1999 and the model validation was done for the period 2000–2005. The results of SWAT simulations denotes that during the calibration, the p-factor and r-factor were 0.82 and 0.76 respectively, while during validation p-factor and r-factor were obtained as 0.71 and 0.72. The goodness of fit was assessed for the coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE) between the observed and final simulated values. The results indicate that R^2 and NSE were 0.77 and 0.74 during calibration and 0.71 & 0.69 for validation.

Pereira *et al*. (2016) investigated on the hydrological simulation of typical tropical climate and soil using SWAT model located in Pomba river basin, southeast region of Brazil in the continent of South America. It mainly focussed to (a) model calibration and validation of SWAT for a sub-basin of Pomba River Basin, (b) validate it for use with upstream and downstream control sections and (c) validate it for sub-basins other than the one where calibration was performed. The model was calibrated by trial and error for the period 1996-1999 and validated for the period 2000-2004. The maximum, average and minimum annual daily stream flows were estimated based on the paired t- test and linear regression analysis. The estimation of maximum, average and minimum annual daily stream flows in upstream and downstream of the calibration section performed statistically satisfactory. The model can be applied for the hydrological simulation in the Novo river sub basin and it is not recommended in the Xopoto river sub basin. So, this model still requires development in its representatives of precipitation in order to simulate extreme stream flow values to obtain good results.

Abbaspour *et al*. (2017) investigated not only on the serious issues in calibration and uncertainty analysis for SWAT but also for a protocol of calibration to guide users in order to obtain better modelling results. The calibration of watershed models affected from a number of conceptual and technical problems. These include (i) inadequate definition of the base model (ii) parameterization (iii) objective function definition (iv) use of different optimization algorithms (v) non-uniqueness (vi) model conditionality (vii) time constraints and (viii) modeller's inexperience and lack of sufficient understanding of model parameters. Several issues were described in the study which are used to reduce and overcoming the related problems for users.

2.10.1 Calibration and Validation with SUFI-2 Technique

Recent developments have entirely changed the scenario in determining the model calibration. SWAT-CUP is an interface which makes calibrations in a very easier way. For successful calibration and uncertainty analysis there are different algorithms such as Particle Swarm Optimization (PSO), Sequential Uncertainty Fitting (SUFI-2), Generalized Likelihood Uncertainty Estimation (GLUE), Parameter solution (Parasol) and MCMC. Among these, Sequential Uncertainty Fitting (SUFI-2) method is extensively used technique to perform the parameterization, sensitivity analysis, uncertainty analysis, calibration and validation. The SUFI-2 is a semi automated procedure that makes the calibration process simple within the reliable time bounds. Sequential Uncertainty Fitting Algorithm (SUFI-2) is very advantageous because it is able to handle large number of parameters.

Sushant *et al*. (2017) explained the possibility of the combined use of SUFI-2 and SWAT for enhancing the simulation of stream flow in Skunk Creek (SK) watershed in South Dakota for the period 1980-2000. Twenty four parameters were taken and model calibration and validation were done for both daily and monthly time periods. The results proved that the monthly performance is better than daily performance in model calibration (1987-1994) with NSE and R^2 values of 0.84 and 0.84. During validation period (1995-2000) the statistical values of monthly performance are better than daily performance with NSE and R^2 values of 0.76 and 0.77. SOL_AWC was identified to be the most sensitive parameter with absolute t-value of 17.50 and p-value of 0.00 to simulate the runoff of the SK watershed. It was concluded from the study that combination of the SWAT and SWAT-CUP made the calibration process quicker and reliable to simulate local hydrology within the watershed.

Tejaswini and Sathian (2018) in their research carried out the calibration and validation of SWAT model for Kunthipuzha Basin using SUFI-2 algorithm. In this study, both one at a time and global sensitivity analysis were done in which SUFI-2 was used for sensitivity analysis, calibration and validation of model. The calibration was done for the period of 2000 to 2006 where as validation was done for the period of 2007 to 2009. The results indicate that NSE and R^2 for calibration was 0.81 and 0.82 & validation was 0.73 and 0.88 which shows that very good performance of the model in simulating hydrology.

2.11 IMPACT OF LAND USE CHANGE ON WATER RESOURCES

The land use changes act as a crucial role in altering the hydrological changes of the watershed which have potentially large impacts on water resources (Stonestrom *et al.,* 2009). Rapid socio-economic development is the main driving force in land use changes, which include changes of land use classes. Due to this driving force, there is an increase of water scarcity which contributes to the degradation of liveihoods. There is a need to assess the impact of land use change on the hydrological changes in the watershed. From the several research works reported, it can be seen that while converting the forest land to agriculture the runoff increases.

Tracy and Scott (2013) conducted a study on impact of land cover and land use changes on the water resources in east African watershed. In order to assess these changes, three land use maps representing a 17 year period were chosen which serves as input for hydrological modelling using Automated Geospatial Watershed Assessment (AGWA) tool, a GIS-based hydrologic modelling system. This tool was used to parameterize the Soil and Water Assessment Tool (SWAT) for evaluating the relative effect of land cover change in hydrologic response. SWAT model was calibrated using observed data during 1990's and simulation results represented that land use changes have resulted in corresponding increase in surface runoff and decrease in ground water recharge.

Hydrologic changes were hugely variable both spatially and temporally, and the upper most reaches of the forested highlands were most significantly affected in the basin.

Wagner *et al.* (2013) evaluated the land use impacts on the hydrology of the Mula and Mutha rivers catchment upstream of Pune. This study focuses on estimating the past land use changes between 1989 and 2009 and their impacts on the water balance. In order to assess these land use changes, multi temporal land use classifications for the cropping years 1989/1990, 2000/2001 and 2009/2010 were selected for three rivers catchments. These land use changes caused due to rapid socio economic development which alternates the watershed hydrology that have large impact on the water resources. The two model runs were performed & compared using the land use classifications of 1989/1990 and 2009/2010 with the use of hydrologic model SWAT. The main land use changes were recognized as an increase in urban area from 5.1% to 10.1% and cropland from 9.7% to 13.5% of the catchment area during the 20 year period. Due to this urbanization there is an increase in water yield by up to 7.6%.

Welde and Gebremariam (2017) discussed on the potential impacts of land use land cover dynamics on hydrologic response in Tekeze Dam watershed, northern Ethiopia by uniting SWAT model with GIS. The impact of LULC dynamics on hydrologic response were assessed with three scenarios (climate of 2000s & 2008 LULC, climate of 2000s & 1986 LULC and climate of 1980s & 1986 LULC). Finally, land cover change had a beneficial impact on modelled watershed response due to the conversion from grass and shrub land to agricultural land. The mean annual stream flow has increased by 6.02% (129.20-137.74 m^3/s) and the impact of sediment yields amounts to an increase of 17.39% (12.54-15.18 t/ ha/year) due to LULC dynamics. The hydrologic response was more sensitive to LULC dynamics for the months of August to October than others in the year. These outcomes showed that the usefulness of integrated remote sensing and distributed hydrologic models through the use of GIS for evaluating watershed conditions.

Silva *et al.* (2018) investigated hydrological response of land cover changes in the Lower-Middle Sao River sub-basin (LMSFR), Brazil. In order to assess these changes, calibration and validation of the Soil and Water Assessment Tool (SWAT) model for different land uses was mainly studied. The SWAT model was calibrated for the year 1993-1994 and 1995-2004 period were used for validation. For analysing the land cover changes, three scenarios of land cover were compared to current landscape (pasture land): scenario I (pasture land is replaced by natural vegetation), scenario II (pasture land is replaced by maize crop cultivation), and scenario III (pasture land is replaced by bare soil). Finally, calibration and validation of SWAT model in the LMSFR obtained good results in their respective temporal basis. Scenario III has the greatest impact on sediment yield which corresponds to increase in 93.7% in comparison to current land cover. This study also identifies the regions where the reforestation should be quickly carried out in the north part and extreme south of sub-basin.

2.11.1 Improvement of Land use Classification

Amee *et al.* (2016) investigated on post classification errors in enhancing the classification of land use using RS and GIS. It mainly aims to extract reliable LU/LC data using the ancillary data and change detection between 2001 and 2011 for Arjuni watershed from highly arid state Gujarat. The Maximum Likelihood Classifier (MLC) was first applied to IRS LISS III imagery of 2001 and 2011 in which it is classified. Further, the study employed an innovative methodological data of ancillary data (texture imagery, Normalized Difference Water Index-NDWI and drainage network) for post classification corrections. Finally, it has significantly enhanced overall classification accuracies from 67.24% to 82.75% and 71.93% to 87.43% for 2001 and 2011, respectively.

2.12 LIMITATIONS AND IMPROVEMENTS MADE

The SWAT model has played a crucial role in assessing the different hydrological processes. In spite of carrying out many simulations in SWAT model, there is a need for improvements in the model.

The worldwide use and evaluation of SWAT reveals that the model can be used to combine the various environmental processes which assist more efficient watershed management. The necessary improvements to develop the model are:

1. It has to enable more accurate simulation of currently supported processes.
2. There is a need of incorporating the advancements in scientific knowledge.
3. It has to provide new functionality that will expand the SWAT simulation domain.

Zhang *et al*. (2015) investigated improved calibrated scheme of SWAT by splitting wet and dry seasons in south eastern china. This study was carried out in order to reduce the poor performance of SWAT in dry seasons which has hindered its applications to watersheds characterized largely by low-flows. So, a calibration scheme was proposed aiming at overcoming this shortage. The SWAT- SC (seasonal calibration scheme) was established and compared with original SWAT to simulate daily runoff in the Jinjiang watershed dominated by a typical subtropical monsoon climate. The genuine SWAT model denoted a satisfied model performance in the wet season or whole year but it may not give reasonable performance for the dry period. Finally, significant improvement was acquired using SWAT-SC for simulating runoff during dry period.

CHAPTER III

MATERIALS AND METHODS

This chapter discusses about the study area, watershed model used and the tools and techniques used for the study. The methodology adopted to set up the model and the procedures for sensitivity analysis, calibration and validation of the model are also detailed. SWAT- CUP is used for carrying out sensitivity analysis, calibration and validation of the SWAT model. This chapter also discusses the methodology used for assessing the impact of land use changes on the hydrology of the watershed. The SWAT model was also run with Climate Forecast System Re-analysis (CFSR) data to examine the feasibility of using this data for modelling studies.

3.1 DESCRIPTION OF STUDY AREA

The study area is situated in the south of Tapi basin where several west flowing rivers have originated. Among these rivers, Bharathapuzha river (longest river in Kerala) originates from the Anamalai hills in Western Ghats and has four main tributaries viz., Gayathripuzha, Chitturpuzha, Kalpathipuzha and Kunthipuzha. The sub catchment area of Bharathapuzha river basin which contributes flow to the Kunthipuzha river (main tributary of Bharathapuzha river basin) called Kunthipuzha watershed is selected for the study area. The boundaries of this watershed are Silent valley in the north, Nellipuzha watershed in the east, Ottappalam taluk in the south and Perinthalmanna taluk in the west. The location of the study area is shown in Fig 3.1 & Fig 3.2.

The watershed lies within $10^{o}48'47.36''$N latitude to $11^{o}13'01.08''$N latitude and $76^{o}05'00.70''$E longitude to $76^{o}38'02.89''$E longitude. The elevation of the watershed area ranges from 4 m near the outlet point of the watershed to 2367 m (which is situated near the silent valley) from mean sea level. The area receives rainfall from both south west (June to September) and north east monsoons (October to December). The maximum amount of rainfall is received from south west monsoon in which average annual rainfall of catchment is 2300 mm and the mean temperature of the area is 27.3^{o}C (Tejaswini, 2017).

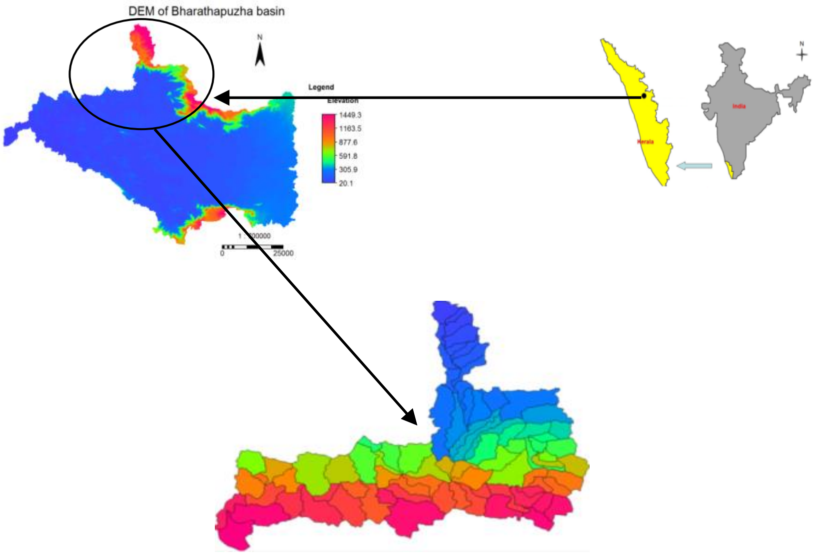

Fig. 3.1 Location of Kunthipuzha watershed

Fig. 3.2 Location of Kunthipuzha river basin

3.2 SOFTWARES AND TOOLS

The description of different softwares and tools used for solving the objectives are described below.

3.2.1 ArcGIS 10.3

ArcGIS is a proprietary geographic information system (GIS) software which is used for working with maps and geographic features. This platform comprises of ArcToolbox (which consists of functions or tools needed for the operations), ArcCatalog and ArcMap and is able to convert between data formats, manage map projections and perform analysis and queries. The ArcGIS is developed by Environmental System Research Institute (ESRI) and was initially released in 1999 at New York. ArcGIS 10.3, which was released in 2014, was used for this study.

ArcGIS desktop is consists of three integral applications such as ArcMap, ArcCatalog and ArcToolbox. Arc Map is the central mapping application which helps to create maps, analyze spatial relationships and layout projects. ArcCatalog is capable of organizing spatial data included in a computer and various other locations which allows to search, preview and add data to ArcMap as well as to organize metadata and set up address locator services. The tools for geoprocessing, data conversion, coordinate systems, projections etc. are available through ArcToolbox. ArcGIS 10.3 is not only useful for changing projection but also useful for analysing spatial information of swat inputs such as DEM, land use and soil maps.

3.2.2 Soil Plant Atmosphere Water (SPAW) Hydrologic Budget Model

SPAW model developed by Keith Saxton, United States Department of Agriculture (USDA)-Agricultural Research Service (ARS) performs daily hydrologic water budgeting using SCS Runoff curve number method. It is used for calculating the characteristics of soil. This program can simulate soil water tension, hydraulic conductivity and water holding capability based on the soil texture, organic matter, gravel content, salinity and compaction. The soil characteristics needed to prepare user soils database such as hydraulic conductivity, available water, electrical conductivity and bulk density were obtained using this model.

3.2.3 SWAT-CUP

SWAT Calibration and Uncertainity Program (SWAT-CUP) is a computer program used for performing sensitivity analysis, calibration and validation of SWAT models. It acts as a generic interface which was developed for SWAT and can be linked easily. It involves several methods such as SUFI-2, PSO, GLUE, ParaSol and MCMC which can be selected for calibration and uncertainty analysis. It accesses the SWAT input files and runs the SWAT simulations by modifying the chosen parameters.

Recent SWATCUP 2012 version 5.1.6 is used in the study for performing sensitivity analysis, calibration and validation. Among the different methods offered within the SWATCUP package, the SUFI-2 method was adopted in the study for the calibration purpose, since it is easy to handle and requires a minimum of runs and gives comparably good results. Moreover, it is able to describe all kinds of uncertainty sources.

3.3 SWAT MODEL OVERVIEW

Soil and Water Assessment Tool (SWAT) is developed by Dr. Jeff Arnold for the United States Development of Agriculture (USDA) is a physically based, watershed scale, continuous time model which can be used to analyse the effect of change of land management practices on water movement, sediment and chemical yields etc. in large watersheds with different soils, land use and management conditions over different periods of time. It is very useful for modelling the different physical processes related with water movement, sediment movement, crop growth, nutrient cycling etc. The hydrologic processes simulated by the model include precipitation, infiltration, surface runoff, evapotranspiration, lateral flow and percolation. In order to model these processes, there is a requirement of input data such as weather, soil properties, topography, vegetation and land management practices occurring in the watershed. It is also very helpful in simulation of very large basins without excessive investment of time or money.

The SWAT model is a direct outgrowth of the Simulator for Water Resources in Rural Basins (SWRRB) model which was developed to simulate non-point source loadings from watersheds. The SWRRB model is a combination of specific models used for Agricultural Management and Erosion Productivity. SWAT model was developed in early 1990’s and has undergone many improvements since its initial formulation. The command structure used in the model is similar to the structure of Hydrologic Model (HYMO) mainly for runoff routing as well as chemicals through a watershed. Later different interfaces have been developed for the model in Windows. Presently, ArcSWAT 2012 version is used for the study area which has already been validated for different areas across the globe.

SWAT model allows the simulation of a number of physical processes to by dividing the watershed into sub watersheds. Because of the partitioning of the watershed, the user is able to identify different areas of the watershed spatially. The use of sub basins in simulation is very beneficial when there is substantial difference in land use and soils which may impact the hydrology. Hydrologic response units are the lumped land areas within the sub basin that comprises of unique land cover, soil and management combinations. This model requires certain input data like Digital Elevation Model (DEM), Land use map, soil map and weather parameters which is useful for the simulation of the hydrological processes.

The simulation of the hydrology of watershed is divided into two major divisions. The first division is the land phase which controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub basin. The second phase is the routing phase (water phase) of the hydrologic cycle which can be defined as a movement of water, sediments etc through the channel network of the watershed through the outlet.

SWAT simulation is based on the water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \ldots \text{ Eq. (1)}$$

SW_t – final soil water content (mm)

SW_o – initial soil water content on day i (mm)

R_{day} – amount of precipitation on day i (mm)

Q_{surf} - amount of surface runoff on day i (mm)

E_a - amount of evapotranspiration on day i (mm)

W_{seep} - amount of water entering the vadose zone from the soil profile on day i (mm)

Q_{gw} - amount of return flow on day i (mm)

3.3.1 Surface Runoff

The flow of water that occurs when application rate of water on the earth’s surface exceeds the infiltration rate it contributes to surface runoff. The SWAT can simulate the runoff by making use of daily as well as sub daily rainfall. SWAT makes use of two procedures for estimating runoff: the SCS curve number method and Green & Ampt infiltration method. SCS curve number method, which is an empirical method is used for simulating runoff under diversed soil and land use types. The SCS curve number is a function of the soil’s permeability, land use and antecedent moisture conditions. Green & Ampt infiltration method is enhanced to estimate infiltration which is a function of wetting front metric potential and effective hydraulic conductivity assuming excess water at the surface at all times (Green and Ampt, 1911). A methodology was developed for determining the ponding time with infiltration using the Green & Ampt equation (Mein and Larson, 1973). In order to determine the surface runoff using this method, the rainfall interception by canopy should be calculated separately. This method is more suitable for predicting runoff because the infiltration parameters in this method can be directly related to watershed characteristics but its requirement of precipitation data at a sub-hourly time step limits its use.

Based on the availability of the precipitation data, different methods are chosen for calculating the runoff. In the present study, SCS curve number method is adopted for runoff simulation in SWAT since it requires minimum data that can be obtained from government agencies. The surface runoff can be determined based on the hydrologic group of soil, land use and AMC for each HRU. The equation for SCS-CN method is

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \qquad \text{……… Eq. (2)}$$

Where,

Q_{surf} – rainfall excess(mm)

R_{day} – daily rainfall (mm)

I_a – initial abstraction (mm)

S – retention parameter (mm)

$$S = 25.4(\frac{100}{CN} - 10)$$

Where,

CN – curve number for the day

Initial abstractions are commonly assumed as 0.2 S, then the above equation becomes

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

3.3.2 Peak Runoff Rate

The peak runoff rate is the maximum runoff flow rate for a given storm event. It is an indicator of the erosive power of a storm which is used to estimate sediment loss. In SWAT the peak runoff rate is calculated using the modified rational method.

$$Q_{peak} = \frac{\alpha_{tc} . Q_{surf} . Area}{3.6 \ . t_{conc}} \qquad \text{………. Eq. (3)}$$

Where,

Q_{peak} – peak runoff rate ($m^3 s^{-1}$)

α_{tc} – fraction of daily rainfall that occurs during the time of concentration

Q_{surf} - surface runoff (mm H_2O)

Area – subbasin area (km^2)

t_{conc} – time of concentration for the sub basin (hr)

3.3.3 Time of Concentration

The time of concentration is the amount of time taken from the beginning of a rainfall event till the entire area (sub basin) is contributing flow at the outlet. It is calculated by summing the overland flow time and channel flow time.

$$t_{conc} = t_{ov} + t_{ch} \qquad \text{……….. Eq. (4)}$$

t_{conc} – time of concentration for a sub basin (hr)

t_{ov} – time of concentration for overland flow (hr)

t_{ch} – time of concentration for channel flow (hr)

3.3.4 Evapotranspiration

Evapotranspiration is one of the processes by which water removal from a watershed takes place. It is the process which consists of evaporation from plant canopy, transpiration, sublimation and evaporation from the soil. The model computes evaporation from soils and plants separately (Ritchie, 1972). The actual evapotranspiration (AET) is very difficult to determine as it is related with number of parameters that can vary spatially and temporally. Generally AET can be calculated based on the PET using appropriate methods.

The model uses three methods for determining potential evapotranspiration: Hargreaves (Hargreaves *et al*, 1985), Priestly-Taylor (Priestly and Taylor, 1972) and Penman-Monteith (Monteith, 1965). The amount of required inputs will vary for different PET methods in SWAT. The Penman-Monteith method requires solar radiation, air temperature, relative humidity and wind speed. The Priestly-Taylor method requires solar radiation, air temperature and relative humidity. Lastly, Hargreaves method requires air temperature only. The AET in SWAT represents the water removed from the HRU through evaporation from soil and plant canopy, transpiration and sublimation if snow is present. The soil water evaporation is estimated by using exponential functions of soil depth and water content based on PET and soil cover index whereas plant transpiration is simulated as a linear function of depth of root, soil water content, potential evapotranspiration and leaf area index. In this study, Penman-Monteith method is used for calculating the required PET.

3.3.5 Lateral Flow

It is the stream flow contribution which originates below the surface but above the zone where rocks are saturated with water. This flow is called as lateral sub surface flow or interflow. In order to predict the lateral flow in each soil layer, SWAT incorporates a kinematic storage model which accounts for variation in conductivity, slope and soil water content. The equation which is used to determine the lateral flow is

$$Q_{lat} = 0.024\frac{2S\ SC\ sin\alpha}{\theta_d L} \quad \text{……….. Eq. (5)}$$

Where,

Q_{lat} – lateral flow (mm/day)

S – Drainable volume of soil water per unit area of saturated thickness (mm/day)

SC – saturated hydraulic conductivity (mm/h)

L – Flow length (m)

α – slope of the land

θ_d – drainable porosity

3.3.6 Base Flow

The flow in which the shallow aquifer contributes some amount of water to the main channel or reaches within the sub basin is called base flow. It is allowed to enter the reach only if the amount of water stored in the shallow aquifer exceeds a threshold value. SWAT can be able to simulate the base flow based on the equation

$$Q_{gw,i} = Q_{gw,i-1} . \exp[-\alpha_{gw} . \Delta t] + W_{rchrg,sh} . (1 - \exp[-\alpha_{gw} . \Delta t]) \ldots\ldots \text{ Eq. (6)}$$

If $aq_{sh} > aq_{shtr,q}$

$Q_{gw,i} = 0$ $aq_{sh} \leq aq_{shtr,q}$

$Q_{gw,i}$ – groundwater flow into the main channel on day i (mm)

$Q_{gw,i-1}$ – groundwater flow into the main channel on day i-1 (mm)

α_{gw} – base flow recession constant

Δt – time step (1 day)

$W_{rchrg,sh}$ – amount of recharge entering the shallow aquifer on day i (mm)

aq_{sh} – amount of water stored in the shallow aquifer at the beginning of day i (mm)

$aq_{shtr,q}$ – threshold water level in the shallow aquifer for the ground water contribution to the main channel to occur (mm)

3.4 INPUT DATASETS

The input datasets required by the SWAT model are DEM, land use map, soil map and weather data for the assessment of the water resource availability in the study area. The details of the required input datasets and pre-processing operations done before adding input to the model are described briefly.

3.4.1 Digital Elevation Model

Digital elevation model (DEM) is one of the essential requirements for a hydrologic model which represents a relief of a surface between the points of known elevation. Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) is produced by the Ministry of Economy, Trade and Industry (METI) of Japan jointly with the United States National Aeronautics and Space Administration (NASA). This ASTER GDEM is used for the study area. The sensor used for capturing the image is ASTER and the resolution of this DEM is 1 ARC-SECOND which is approximately 30 m spatial resolution. This DEM was downloaded for use from the website earthexplorer.usgs.gov. The U.S. Geological Survey (USGS) Earth Explorer (EE) tool helps users to search, and request for the required satellite images, cartographic products or aerial photographs from different sources. The DEM in the WGS_1984_UTM_Zone_43N coordinate system was used in ArcSWAT for watershed delineation.

3.4.2 Land Use Map

The Land use map of the study area of 2008 collected from Kerala State Remote Sensing and Environment Centre using LISS III imagery of IRS P6. For studying the impact of land use changes, the imagery of the area for the years 2000 and 2017 was downloaded from the USGS EARTH EXPLORER website and supervised classification was done in ARCGIS platform. The supervised classification was done based on the visual analysis and ground truthing which is strictly controlled by the user. The classification process was done by identifying the pixels representing the specific land use with the help of changing bands. Aerial imageries, google imageries and ground truth data was also utilized for confirming the areas while preparing the training data set needed for preparation of the land use map.

3.4.3 Soil Map

The soil map was collected from the Directorate of Soil Survey and Soil Conservation of Kerala state for the study area. Different morphological characteristics of the soils were also collected along with the map. Other soil properties needed for the study were computed using SPAW software. This map is very essential in SWAT model for computing HRU analysis. With the help of ArcGIS10.3, the soil map was converted to a grid file for use in SWAT model.

3.4.4 Climatic Data

Two types of weather data *viz.*, (i) Meteorological data and (ii) CFSR data were used for the study. The meteorological data represents the actual climatic conditions for the particular place. The CFSR data represents the high resolution satellite based rainfall products for the study area.

3.4.4.1 Meteorological Data

The SWAT model requires various climatic parameters like precipitation, relative humidity, temperature, solar radiation as well as wind speed data for running the model. The data was collected from Regional Agricultural Research Station, Pattambi, Kerala Agricultural University, IMD and Water Resources Department, Government of Kerala for the period of 1989 to 2016. The daily rainfall data from Pattambi rain gauge station was used for model simulation. The model also requires the Stream flow data. The data of Pulamanthole gauging station operating under Central Water Commission (CWC) was collected from their official website and was used in the study.

3.4.4.2 CFSR Data

The Climate Forecast System Reanalysis (CFSR) over the 36-year period spanning from 1979 through 2014 was collected and used for the study. It was designed and executed as a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system to provide the best estimate of the state of these coupled domains over a period. The daily CFSR weather data acquired from the globalweather.tamu.edu in SWAT file format was used. The CFSR data for the areas was collected for the period 1979 to 2013.

3.4.5 SWAT Text Files and Tables

The SWAT model requires different text files and tables for the land use map, soil map and weather data. The look up tables were prepared manually for the land use and soil maps in order to specify the SWAT codes to be modelled for each category in these different maps and then entered into the model. While adding the soil look up tables manually into the model, the data regarding soil characteristics of the study area should be entered into the user soil found in SWAT database.

The precipitation data requires two text files such as precipitation gauge location file and daily precipitation data file. The precipitation gauge location file is used to represent location of rain gauges and daily precipitation location file is used to write the daily precipitation for an individual rain gauge. The precipitation gauge location file possess “.txt” file i.e., “.text” extension. The daily precipitation table should be in the ASCII text format. The daily precipitation location files should be located in the same folder where the precipitation gauge location table is located. The other climatic parameters like daily maximum and minimum temperature, wind speed, relative humidity and solar radiation should also be prepared in the same format as the precipitation files. Some of the text files are shown in the Fig 3.3 & Fig 3.4

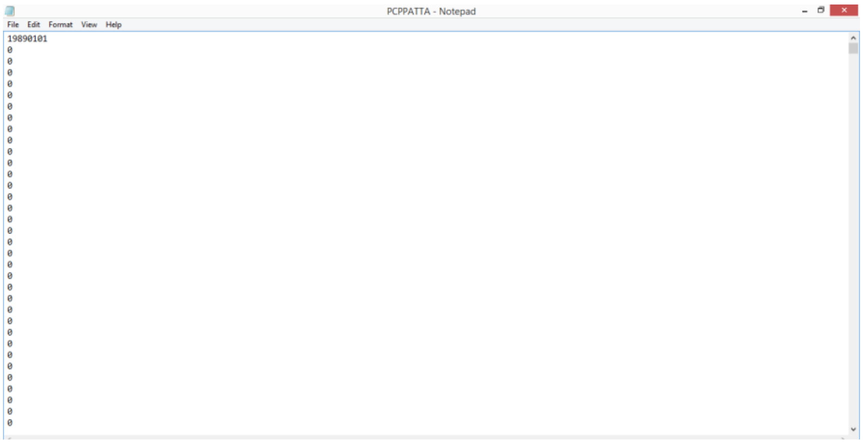

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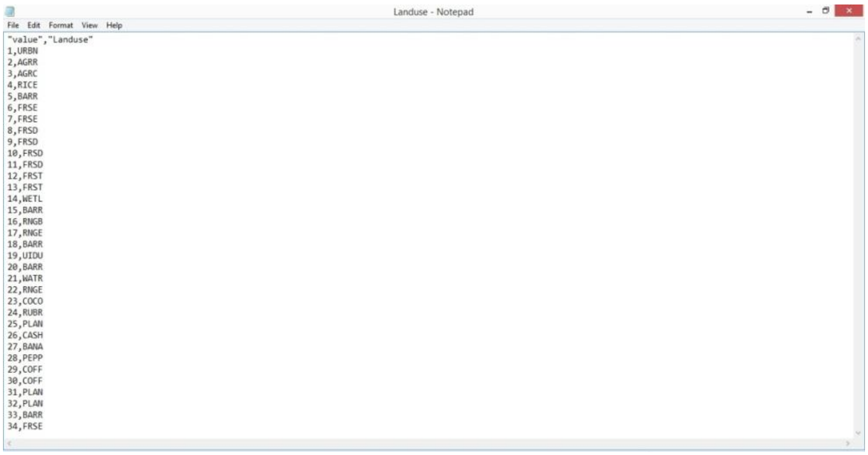
Fig. 3.3 Input file for precipitation



```
"value","Landuse"
1,URBN
2,AGRR
3,AGRC
4,RICE
5,BARR
6,FRSE
7,FRSE
8,FRSD
9,FRSD
10,FRSD
11,FRSD
12,FRST
13,FRST
14,WETL
15,BARR
16,RNGB
17,RNGE
18,BARR
19,UIDU
20,BARR
21,WATR
22,RNGE
23,COCO
24,RUBR
25,PLAN
26,CASH
27,BANA
28,PEPP
29,COFF
30,COFF
31,PLAN
32,PLAN
33,BARR
34,FRSE
```

Fig. 3.4 Input file for land use

3.5 METHODOLOGY OF SWAT MODEL RUN

In order to run the SWAT model, there is a requirement of spatial datasets, look up tables with their respective SWAT codes and weather data files which can be easily taken by the model at different steps. This model set up is mainly done in four steps: watershed delineation followed by HRU analysis, writing input tables and editing of SWAT input. The description of this detailed model run is described below.

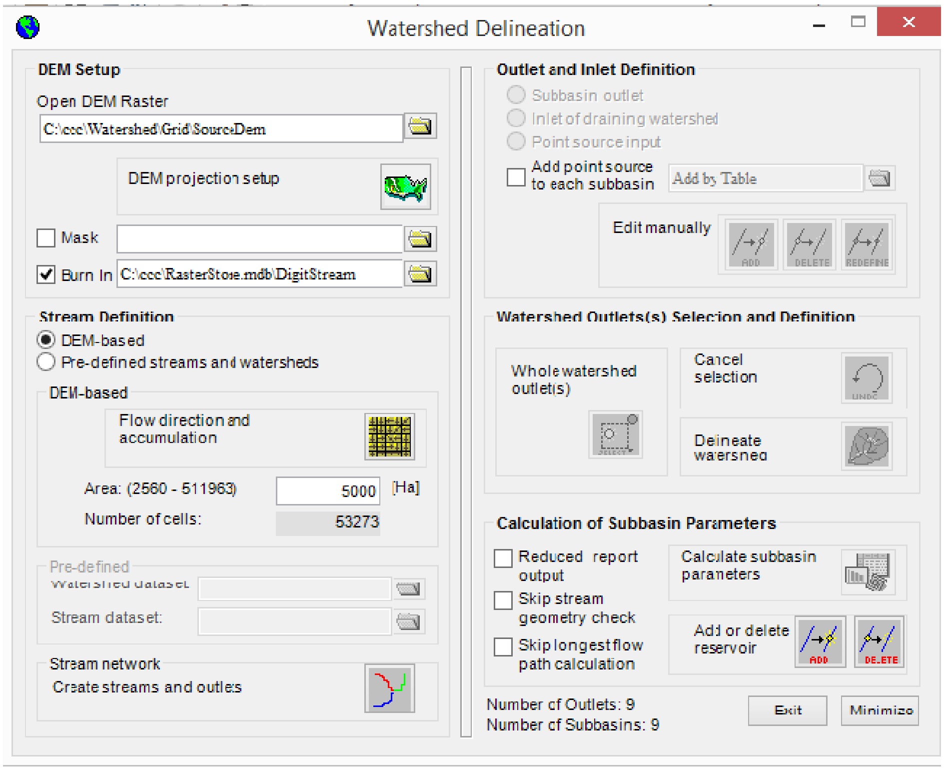
3.5.1 Create a new Arc SWAT project

The SWAT project set up menu contains certain features that can control set up and management of the SWAT projects. In order to create a separate SWAT project, the New SWAT Project command in the SWAT project setup menu generates a new structure for the SWAT project Directory. In this project directory, the SWAT geodatabase will be stored and press ok which will complete project set up.

3.5.2 Watershed delineation

Advanced GIS functions are needed in watershed delineation while segmenting watersheds into separate and hydrologically connected sub watersheds in modelling with SWAT. It requires Digital Elevation Model (DEM) in ESRI grid format. Once the delineation is completed, a detailed topographic report is got which can be linked to the current project. The SWAT interface for watershed delineation is shown in Fig. 3.5. A number of additional layers will be added to the current map including Basin, Watershed, Reach, Outlet and Monitoring point. The key procedure for running the watershed delineation is

1. Enter the DEM
2. Load the stream network for delineation
3. Pre-process the DEM
4. Enter the minimum sub-watershed area
5. Edit the stream network points
6. Run the calculation of the sub basin parameters



Open DEM Raster: C:\ccc\Watershed\Grid\SourceDem

☐ Mask

☑ Burn In C:\ccc\RasterStore.mdb\DigitStream

● DEM-based

○ Pre-defined streams and watersheds

Area: (2560 - 511963) 5000 [Ha]

Number of cells: 53273

☐ Add point source to each subbasin

☐ Reduced report output

☐ Skip stream geometry check

☐ Skip longest flow path calculation

Number of Outlets: 9

Number of Subbasins: 9

Fig. 3.5 SWAT interface for watershed delineation

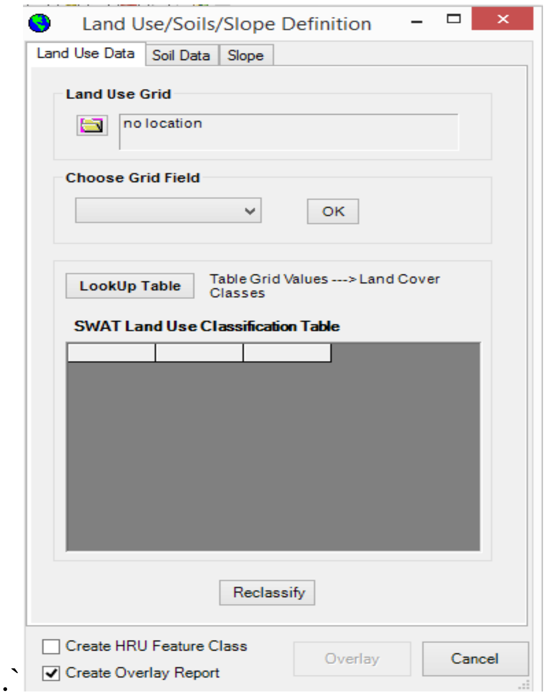
3.5.3 HRU analysis

HRU analysis plays a major role in performing land use, slope and soil characterization in a watershed using certain commands available. Using this tool it is possible load the soil and land use layers into the project in order to analyse the slope characteristics and to find the land use/soil/slope class combinations and distributions for the delineated study watershed. The multiple HRU option was selected in the section and threshold values of 5%, 5% and 10% was given for land use, soils and slope respectively. These datasets can be ESRI grid, shape file or geodatabase feature class format. This analysis mainly consists of following steps

1. Define land use dataset
2. Reclassify the land use layer
3. Define the soil dataset
4. Reclassify the soil layer
5. Edit the slope values

6. Finally, overlay land use, soil and slope layers.

When the overlay process is over, a detailed report of the same is obtained which describes the land use, soil and slope class distribution within the watershed and each sub watershed (sub basin). The SWAT interface for HRU analysis is shown in Fig. 3.6.



Land Use Grid: no location

☐ Create HRU Feature Class
☑ Create Overlay Report

Fig. 3.6 SWAT interface for HRU analysis

3.5.4 Write input tables

This menu mainly consists of “weather data definition” and “Write SWAT input table” features. In the weather data definition, there is a need to import weather data into SWAT database. It allows users to add the required files such as rainfall, temperature, solar radiation, relative humidity and wind speed. The “Write SWAT input table” command acts as an interface to store SWAT input values in the Arc SWAT geodatabase tables. Initial SWAT ASCII input files are also generated.

3.5.5 Edit SWAT input

The “Edit SWAT input” menu permits user to edit the available databases in the SWAT model as well as the watershed database files which contain the detailed inputs for the new SWAT model.

3.5.6 SWAT Simulation

The SWAT Simulation menu allows user to make final set up of input and run for SWAT model. The first command in the simulation consists of set up and run SWAT model dialogue box containing several sections such as period of simulation and filling the Number of Years to SKIP (NYSKIP). After defining all the sections, clicking the “Set up SWAT Run” button, the final input files based on the settings will be generated. Then the user can run the model by clicking the “Run SWAT” button. After this, Read SWAT Output dialogue box provides tools needed for importing the text files created by SWAT into the database in Access format.

SWAT simulation was done for the period of 28 years ranging from 1st January 1989 to 31st December 2016 with two years of warm up period using observed meteorological data. After successful running of SWAT, the files which are needed to be imported to the database were selected and finally the simulations were saved. The procedures of sensitivity analysis, calibration and validation were done to prepare the model for the area.

Later simulation was done for the period of 35 years ranging from 1st January 1979 to 31st December 2013 with 6 years of warm up period using CFSR data. The simulation was again done two times for assessing the land use change for the year 2000 and 2017 for the period of 28 years ranging from 1st January 1989 to 31st December 2016 with two years of warm up period using observed meteorological data.

3.6 SENSITIVITY AND UNCERTAINTY ANALYSIS

The complex hydrological model is commonly characterized by a indefinite number of parameters. Therefore over-parameterization is often described issue in hydrological models, especially distributed models such as SWAT. In order to avoid this type of situations, there are certain methods to reduce the number of parameters via sensitivity analysis which are significant for the efficient use of these models (Van Griensven *et al.*, 2006). The sensitivity analysis is the initial step in the calibration and validation process of SWAT for the determination of most sensitive parameters for a watershed. The sensitivity analysis is the process of determining the rate of change in model output with respect to the changes in model inputs. The parameter selection for performing one at a time sensitivity analysis was based on the literature review (Thampi *et al.*, 2010; Varughese, 2016; Tejaswini and Sathian, 2018). One at a time sensitivity analysis was performed to get the most sensitive parameters for the area.

The sensitivity analysis can be usually done in SWAT CUP software using different algorithm techniques. The most commonly used SUFI-2 algorithm is taken for the study area. Generally, two types of sensitivity analysis are allowed using SUFI-2 (i) Global Sensitivity (ii) one at a time sensitivity analysis. In order to apply parameter identifiers, parameters must be changed that have physical meanings which should reflect physical factors such as land use, soil, elevation *etc*, hence the following scheme is suggested.

x_<parname>.<ext>_<hydrogrp>_<soltext>_<landuse>_<subbsn>_<slope>

where,

x_ indicates type of change to be applied to the parameter

v_ means the existing parameter value is to be replaced by the given value

a_ means the given value is added to the existing parameter value

r_ means the existing parameter value is multiplied by (1+a given value)

<parname> = SWAT parameter name

<ext> =SWAT file extension code for the file containing the parameter

<hydrogrp> = (optional) soil hydrological group i.e, ‘A’, ‘B’, ‘C’, ‘D’

<soltext> = (optional) soil texture

<landuse> = (optional) name of the land use category

<subbsn> = (optional) sub basin number(s)

<slope> = (optional) slope

Any combination of the above factors can be used to describe a parameter identifier that provides the possibility for a detailed parameterization of the system.

Uncertainty analysis is needed to perform the best estimation and uncertainty identification of hydrologic models. The uncertainty test and analysis was done using SUFI-2 uncertainty analysis techniques. In SUFI-2, uncertainty is defined as the difference between the observed and simulated variables. The model uncertainty is quantified at the 95 PPU in the SUFI-2 technique. A elaborative approach of uncertainty analysis of the SUFI-2 algorithm is depicted graphically in the given Fig. 3.7. This figure illustrates the single parameter value leads to single model response shown by point in “a” and the propagation of uncertainty in parameter which is shown by line in “b” leads to 95 PPU illustrated by shaded region. If the parameter uncertainty increases, the output uncertainty also increases which is shown in “c”. The cumulative distribution of output variable is obtained through Latin hyper cube sampling. Mainly, this algorithm starts by large parameter uncertainty within a physically meaningful range, so that the measured data initially fall within the 95 PPU, which narrows this uncertainty in steps while monitoring p_factor and r_factor. Parameters are updated in such a way that the new ranges are smaller than the previous ranges which are centred around the best simulation. The p_factor is the percentage of data bracketed by 95 PPU and r_factor is the ratio of average thickness of 95 PPU band to the standard deviation of the corresponding measured variable. A p-factor of 1 and r-factor of zero is a simulation that exactly corresponds to measured data.

The SWAT CUP provides the two types of sensitivity analysis. They are (i) Local sensitivity analysis and (ii) Global sensitivity analysis. These are described briefly with their respective advantages and disadvantages.

3.6.1 Local (One at a time) sensitivity analysis

The local sensitivity analysis is performed for one parameter at a time by keeping the value of all other parameters constant. This method is very simple to execute and perform which represents the sensitivity of a variable to the changes in parameter. The main draw back within the OAT sensitivity analysis is that the correct values of other parameters that are fixed are never known (Abbaspour, 2015).

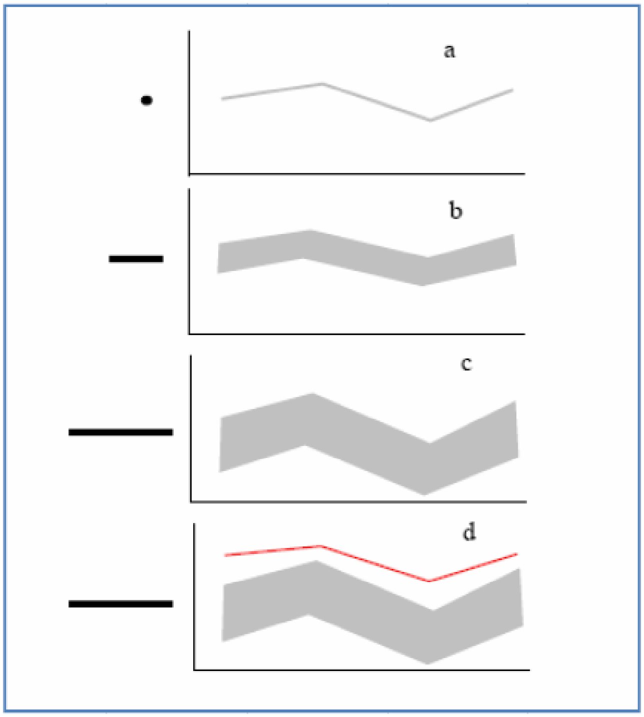


Fig. 3.7 Conceptualization of the relationship between parameter uncertainty and prediction uncertainty

3.6.2 Global sensitivity analysis

Global sensitivity analysis performs the sensitivity of one parameter while the values of other related parameters are also varying. It ultimately estimates the collective effect of all inputs on the variation of output based on many model runs. This type of sensitivity must be performed after iteration. The major disadvantage in this analysis is that it needs more number of simulations.

3.7 CALIBRATION AND VALIDATION

In order to assess the hydrological characteristics of the watershed, calibration and validation are the important processes to be carried out for process based hydrological models. This processes plays a major role in determining the actual calibrated parameters and checking accuracy of the model.

3.7.1 Model Calibration

Model calibration is an effort to better parameterize a model to a given set of local conditions in order to overcome prediction uncertainty. It is performed by carefully selecting values within their respective uncertainty ranges for model input parameters by comparing the model predictions for a given set of assumed conditions with observed data for the same conditions. The model was calibrated using observed daily flow data at the Pulamanthole gauging station for a period of 25 years from 1st January 1989 to 31st December 2013. The number of years skipped (NYSKIP) was 2 years. The values were changed manually on the basis of trial and error. This was done for a monthly series. The steps involved in the linkage between the SWAT and SWAT-CUP are

1. Calibration program writes model parameters in model.in,
2. Swat_edit.exe edits the SWAT’s input files with new parameter values.
3. SWAT simulator run, and
4. Swat_extract.exe program extracts the desired variables from SWAT’s output files and write them to model output.

Calibration was performed by changing most sensitive parameters for achieving the simulated values of the runoff to exactly match with observed river flow data. The SUFI-2 program was used for calibration, validation and uncertainty analysis.

Methodology for calibration in SWAT-CUP using SUFI-2 technique:

1. Create a new project in SWAT-CUP and load a swat TxtInOut directory into the project.

2. After creating a project, choose the swat and processor versions. Then, select the calibration method SUFI-2 from the list provided in dialogue box.
3. Choose a name to the project and provide location which it can be saved in the SWAT-CUP project.
4. Then edit the calibration input files such as Par_inf.txt, SUFI-2_swEdit.def, Observation.rch, Extraction and Objective function files.
5. In Par_inf.txt, the number of parameters is selected for the optimization and number of simulations should be specified in the present iteration. SUFI-2 is iterative, each iteration consists of a number of simulations in which around 500 simulations are suggested in each iteration and a minimum of 4 iterations are necessary for a accurate solution.
6. In the SUFI-2_swEdit.def, the starting and the ending simulation numbers must be added.
7. In Observation.rch file, the observed data for the required period should be copied and compared with the output.rch file. Edit the content in this section such as number of observed variables, name of the sub basin number and number of data points.
8. In the extraction function, there are two files that contain some information should be altered such as Var_file_rch.txt and SUFI-2_extract_rch.def files. In the Var_file_rch.txt, the observation file names in the “Observed_rch.txt” should be defined. In SUFI-2_extract_rch.def file defines about how the variables should be extracted from the output.rch file should be defined.
9. The two files under objective function, observed.txt and Var_file_name.txt are required to define the information.
10. After the completion of the above steps, “Execute all items” is used in which the simulation starts and after the completion of this process, the iteration is saved in the calibration outputs. Iterations should be done by changing the parameters until an acceptable solution is reached. Based on the new parameters obtained from the last iteration (New_par.txt) and by

observing the 95 PPU plot, the parameters need to be adjusted can be known.

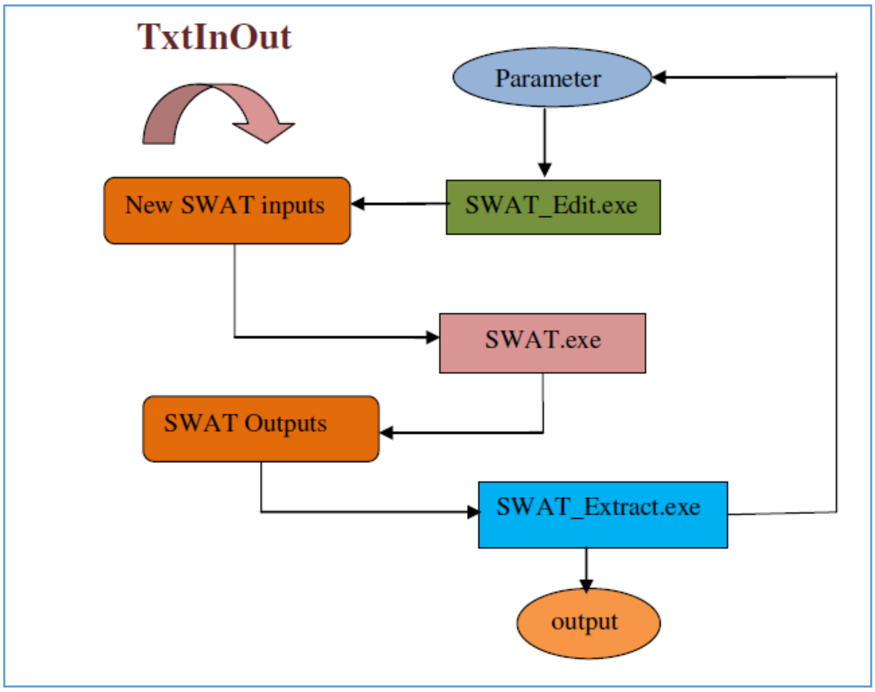


Fig. 3.8 Relation between SWAT and SWAT CUP

3.7.2 Manual Calibration

In order to obtain the accurate values of parameters and to achieve the best correlation between the calibrated and simulated values with statistical indicators, the manual calibration is used. For this, there is a need to adjust the parameters in the user defined group of HRU's and sub basins during this calibration process using "manual calibration helper" dialogue box in SWAT simulation command. The final parameters obtained from the automatic calibration were evaluated using NSE and R^2.

3.7.3 Model Validation

Model validation is a process of demonstrating that the model is able to make sufficiently accurate predictions. The parameter values which are set during the calibration period is useful for simulating the response for the period other than calibrated period. The model was simulated for the period of 3 years from 1st

January 2014 to 31st December 2016. In order to perform validation in SUFI-2, the validation period should be changed in the respective files and the model is run with the parameters obtained in calibration.

3.8 EVALUATION OF MODEL PERFORMANCE

The model performance for this study area can be evaluated by Nash-Sutcliffe efficiency and Coefficient of determination.

3.8.1 Nash-Sutcliffe efficiency

The Nash-Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970) is used to evaluate the predictive power of the hydrological models. The value of NSE ranges from 1.0 to -∞. The NSE value of 0 indicates the model predictions are as precise as the mean of the observed data, where as the NS value 1 indicates the perfect fitting. The major disadvantage is the variations between the observed and simulated values are calculated as squared values which causes over estimation of the model performance during peak flows and under estimation during low flows. The equation for NSE is as follows:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{mean})^2}\right] \quad \ldots\ldots \text{ Eq. (7)}$$

Y_i^{obs} - i^{th} observation for the constituent being evaluated

Y_i^{sim} - i^{th} simulated value for the constituent being evaluated

Y_i^{mean} - mean of observation data for the constituent being evaluated

n - Total number of observations

3.8.2 Coefficient of determination (R^2)

The coefficient of determination computes the fraction of the variation in the measured data that is replicated in the simulated model results. It is the squared value of the coefficient of correlation which is given by the equation

$$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i - O_{aver})(P_i - P_{aver})}{\left[\sum_{i=1}^{n}(O_i - O_{aver})^2 \sum_{i=1}^{n}(P_i - P_{aver})^2\right]^{.5}}\right] \quad \ldots\ldots \text{ Eq. (8)}$$

Where,

O is measured values
P is predicted outputs and
i is number of values.

The value of R^2 ranges from (0-1) where a value close to 1 represents good performance of the model where as the value close to 0 represents a poor performance of the model. The major drawback of R^2 is that it only quantifies dispersion.

3.9 COMPARISON OF SWAT OUTPUTS FOR OBSERVED METEOROLOGICAL DATA AND CFSR DATA

The main SWAT output taken for the comparison is stream flow. The methodology for comparing the SWAT outputs with the observed meteorological data and CFSR data is explained below.

The model was first simulated with the help of the input data such as DEM, land use map, soil map and observed weather data for the period ranging between 1st January 1991 and 31st December 2013. For comparison of the SWAT outputs, the model was again simulated by changing the weather inputs with CFSR data by keeping the spatial inputs constant. The simulation was done on a monthly basis and the SWAT outputs were obtained on a monthly basis using the observed meteorological data and CFSR data.

Stream flow was considered as the main SWAT output for comparison. The comparison and evaluation was done with the help of statistical measures such as NSE, R^2 and RMSE. The comparison was also done with the help of graphs plotted between the simulated discharge using observed meteorological data, simulated discharge using predicted meteorological data (CFSR data) and observed discharge.

3.10 IMPACT OF LANDUSE CHANGES ON THE HYDROLOGY OF THE WATERSHED

For analysing the impact of land use changes on the hydrology of the watershed, land use maps were prepared for the year 2000 and 2017 in the month of October. The imageries for the area were downloaded from the USGS earth explorer website. The main platform used for the preparation of land use was ArcGIS 10.3.

3.10.1 Land use map preparation

1. The USGS pan images of the respective land use year maps were downloaded from the earthexplorer.usgs.gov.
2. The pan image with the different bands for the respective land use were overlapped on each other and converting it into the composite image with the help of the data management tools (data management tools_ Raster_ Raster processing_ Composite bands). This process is called layer stacking.
3. Then the composite image which consists of different coloured bands will be produced which is then useful for identifying the different land uses. The WGS_1984_UTM_Zone_43N coordinate system was used.
4. Then the composite image was classified based on the supervised classification procedure. With the help of the image classification tool bar, the image was classified based on the available options present in the tool bar.
5. In the image classification, “training sample manager” and “Draw polygon” options are available for classifying the image. Using the “Draw polygon” option, a training sample is created in training sample manager by selecting the necessary pixels with the help of the polygon.
6. Then the pixels are carefully selected on the image based on the ground truthing and visual analysis. In the training sample manager, the same types of pixels are merged using “merge training samples” option.

7. Then the respective training samples were created based on the above mentioned points. The signature files created based on the selected training samples have a ".gsg" extension.
8. Then the image is classified with the help of the signature file using "Maximum likelihood classification" option and finally the classified image is created for the two different years, 2000 and 2017.

3.10.2 LAND USE CHANGES IMPACT

The land use changes cause severe impact in altering the hydrology of the watershed. In order to assess the impact of land use change, the procedure as discussed below was used.

The prepared land use for the years 2000 and 2017 was used as input in the SWAT simulation by replacing the land use used for developing the model and the model was run with both land uses separately without changing the other input data. The simulation was done from 1st January 1991 to 31st December 2016 on monthly basis for both the land uses.

The discharge obtained from the SWAT outputs is mainly considered for analyzing the land use change. Based on the graphical analysis of simulated discharge from different years of land use, changes were identified. Also, the percentage area of different training samples present in the different land use maps were obtained from the HRU analysis reports.

CHAPTER IV

RESULTS AND DISCUSSION

This study was mainly envisaged to enhance a hydrological model SWAT for the chosen study area and also to study whether the CFSR data can be used as an alternative for the data scarce regions. The chapter discusses about the results obtained and brief discussions from the specific objectives such as calibration and validation of SWAT model for the study area, comparison of SWAT model outputs between CFSR data and observed meteorological data and the impact of land use change on the hydrology of the watershed.

4.1 SWAT MODEL SET UP FOR THE STUDY AREA

Input datasets DEM, land use map and soil map prepared for smooth running of SWAT model are shown in Figures 4.1, 4.2 and 4.3. In the DEM, the elevation for the study area ranges between 4 and 2367 m. The land use map represents the major area of paddy (24.23%) followed by agricultural land with close growing trees (23.34%) and rubber trees (19.37%). The soil map shows the major geographical representation of different soil series *viz*. Kottamala series (21.18%) followed by Karinganthodu (19.75%) and Vettakode (11.60%).

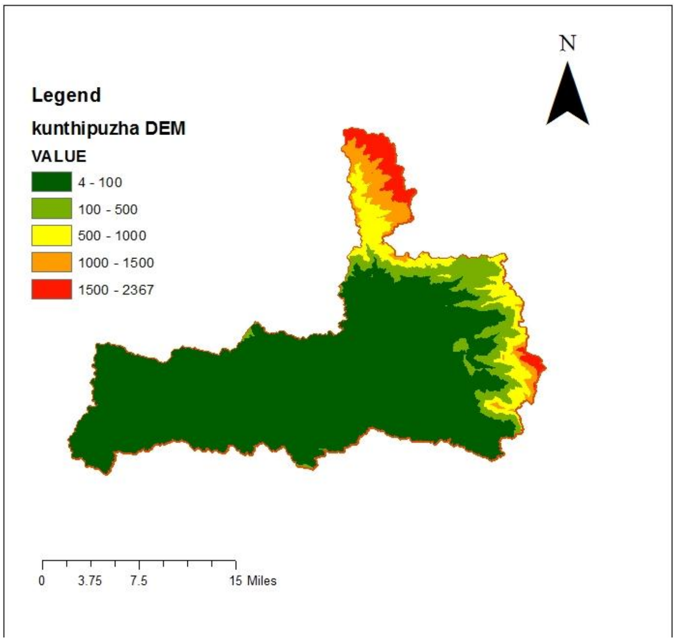


Fig. 4.1 Digital elevation of Kunthipuzha basin

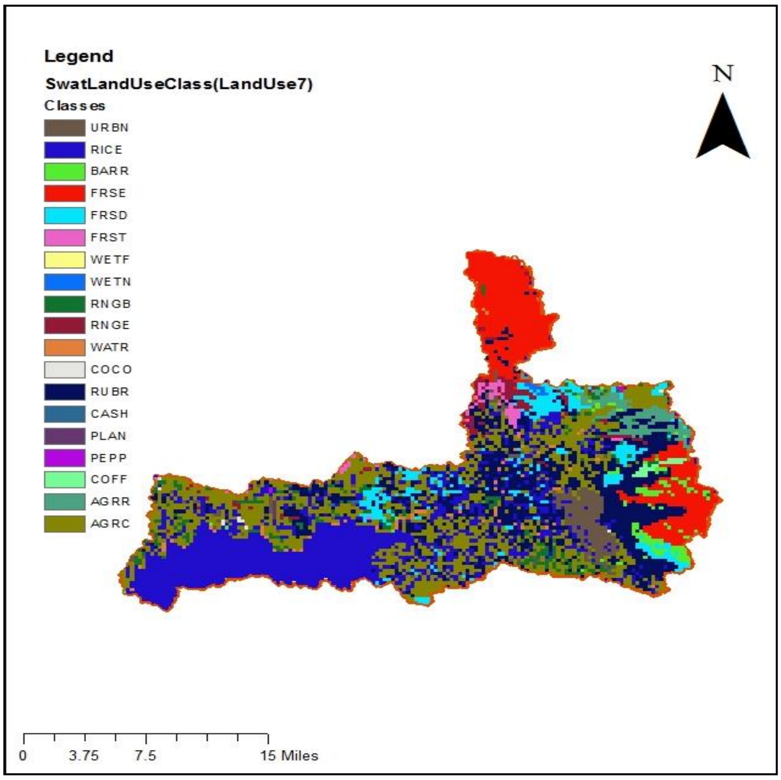


Fig. 4.2 Land use map of Kunthipuzha river basin

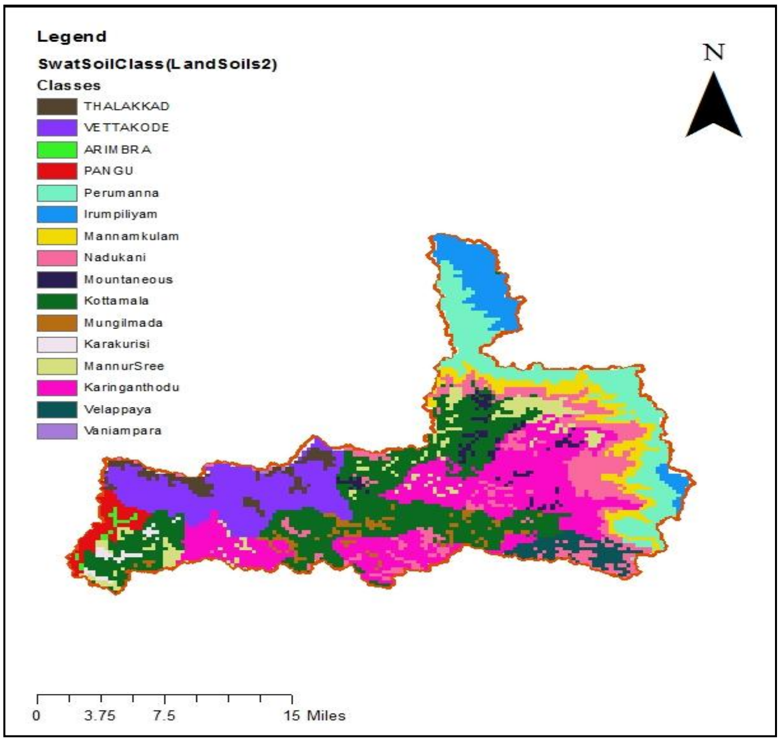


Fig. 4.3 Soil map of Kunthipuzha river basin

4.2 SWAT MODEL SET UP

A brief description about different steps such as watershed delineation, HRU analysis, writing SWAT input tables and SWAT simulation during the process of developing the SWAT model is given below.

4.2.1 Watershed Delineation

The DEM obtained from the USGS earth explorer was prepared using data management tools and converted to the projected coordinate system WGS_1984 UTM_ZONE_43N in ArcGIS 10.3. The DEM downloaded from different web portals may have some errors. In order to minimize these errors, using the "burn in" option in SWAT a drainage network can be superimposed on the DEM for making the watershed delineation more precise (Anand *et al.*, 2018). By selecting the "DEM based" option in the stream definition, the area obtained can be changed to 5000 ha in order to avoid the minor stream networks. Then the streams are created and the outlet is selected manually at the joining point of Kunthipuzha stream to the main Bharathapuzha river in the stream network option. After delineation process, the entire basin was divided into the 9 sub basins. The watershed delineation of the Kunthipuzha river basin is shown in Fig 4.4. The minimum and maximum elevation for the entire basin ranges between 4 and 2367 m.

Table 4.1 Topographic report of sub basins generated by SWAT

Sub basin no	Minimum elevation (m)	Maximum elevation (m)	Mean elevation (m)	S.D of elevation (m)	Area (ha)
1	30	1199	395.57	281.95	7537.55
2	16	2367	738	636.54	18824.54
3	34	111	63.72	12.85	209.77
4	14	2076	363.19	418.13	12226.67
5	17	153	70.28	19.58	1103.27
6	17	509	74.55	28.29	11230.96
7	24	1709	198.20	254.59	16534.27
8	17	448	81.87	40.72	6440.47
9	4	524	54.68	37.53	29092.82

The topographic details such as minimum elevation, maximum elevation, mean elevation, S.D of elevation and area of the study area is shown in Table 4.1. The mean elevation of the 9 sub basins ranges between 54.68 and 395.57 m.

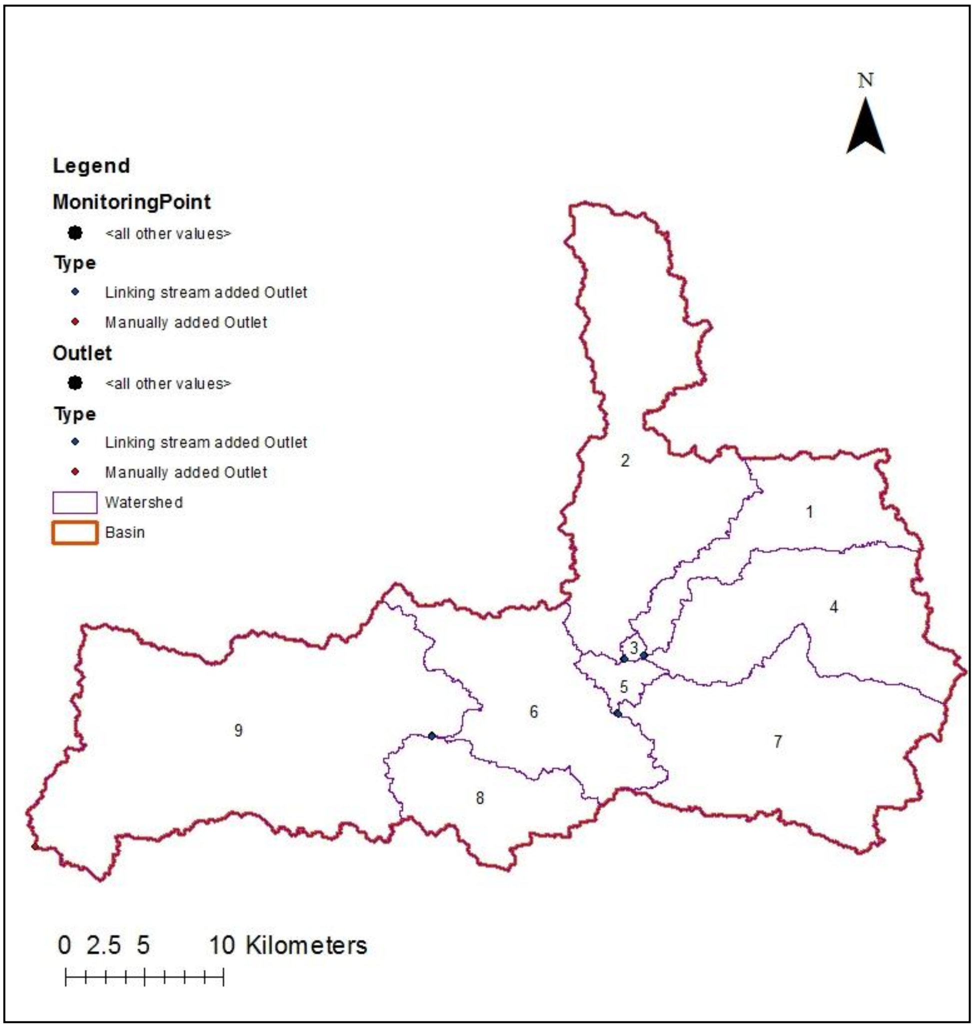


Fig. 4.4 Watershed delineation of Kunthipuzha river basin

4.2.2 HRU analysis

4.2.2.1 *Land/soils/slope definition*

The land use map and soil map are uploaded in this step and are reclassified using SWAT look up tables. The three slope classes are selected for slope definition. After reclassification of all these classes, they are overlaid. The area occupied by different land use types and soil series are shown in the Tables 4.2 to 4.4.

Table 4.2 Land use classes of Kunthipuzha watershed

CLASSES	Area (ha)	Watershed Area (%)
Forest-Deciduous	4173.86	4.04
Rubber Trees	21813.54	21.14
Agricultural Land-Row Crops	2272.10	2.20
Agricultural Land-Close-grown	26051.83	25.24
Rice	26551.86	25.73
Forest-Evergreen	13381.72	12.97
Range-Grasses	1446.25	1.40
Water	12.31	0.01
Barren	1851.45	1.79
Range-Brush	2890.58	2.80
Residential	2754.81	2.67

Table 4.3 Soil classes of Kunthipuzha watershed

CLASSES	Area (ha)	Watershed Area (%)
Karinganthodu	22116.00	21.43
Kottamala	24312.96	23.56
Manamkulam	4699.48	4.55
Perumanna	10937.38	10.60
Nadukani	10273.60	9.96
MannurSree	4541.87	4.40
Mountaneous	848.94	0.82
Irumpiliyam	5460.57	5.29
Mungilmada	1181.32	1.14
Vettakode	12152.51	11.78
Velappaya	2768.98	2.68
Pangu	1571.40	1.52
Thalakkad	2335.31	2.26

Table 4.4 Slope classes of Kunthipuzha watershed

Classes (%)	Area (ha)	Percentage of Watershed Area
0-5	9588.74	9.29
5-15	42173.58	40.87
15-9999	51438.00	49.84

4.2.3 HRU definition

In this step, HRUs were created which are useful in quantifying the spatially varying ET and other hydrologic conditions for various land covers and soils. After that, a total of 352 HRUs were defined within the basin.

4.2.4 Writing input tables and SWAT simulation

In this step, commands in this section generate Arc SWAT geodatabase files which are used by the interface to store the input values for the SWAT model. Then, the model is ready for the simulation.

SWAT simulation was done for the period of 28 years ranging from 1st January 1989 to 31st December 2016 with two years of warm up period using observed meteorological data. Later simulation was done for the period of 25 years ranging from 1st January 1979 to 31st December 2013 with 6 years of warm up period using CFSR data. The simulation was again done two times for assessing the land use change for the year 2000 and 2017 for the period of 28 years ranging from 1st January 1989 to 31st December 2016 with two years of warm up period using observed meteorological data. The SWAT simulation analysis was briefly described in 4.4, 4.5 and 4.6.

4.3 SENSITIVITY ANALYSIS, CALIBRATION AND VALIDATION

The results got from the sensitivity analysis, calibration and validation using SUFI2 algorithm in the SWAT-CUP package is briefly discussed under this section.

4.3.1 Sensitivity Analysis

The results of sensitivity analysis are presented in the Table 4.1.

Table 4.5 Sensitive parameters and their rankings for Kunthipuzha river basin

Sensitivity Rank	Parameter	Parameter Description
1	CN2	Initial SCS runoff curve number for moisture condition II
2	ALPHA_BF	Base flow alpha factor (1/days)
3	ESCO	Soil evaporation compensation factor
4	CH_K2	Effective hydraulic conductivity in main channel alluvium (mm/hr)
5	RCHRG_DP	Deep aquifer percolation fraction
6	SOL_Z	Dept from soil surface to bottom of layer (mm)
7	SURLAG	Surface runoff lag coefficient

The most sensitive parameters for the river basin are CN2 (Initial SCS runoff curve number for moisture condition II), followed by ALPHA_BF (Base flow alpha factor) and ESCO (Soil evaporation compensation factor). The most important influencing factor was the CN2, ranked as the first sensitive parameter which is a function of soil permeability, land use and antecedent soil water conditions. A higher value indicates a high runoff potential and has a major effect on the surface runoff. ALPHA_BF was the most dominating factor of river flow, ranked as the second sensitive parameter which mainly represents the base flow for the Kunthipuzha river basin. These parameters were mainly modified during the calibration process. George and Sathian (2016) reported similar results for the sensitivity analysis that the ALPHA_BF and CN2 are the most sensitive parameters for the Kunthipuzha watershed of central Kerala. Tejaswini and Sathian (2018) also reported similar results in which ALPHA_BF and CN2 were obtained as the most sensitive parameters for Kunthipuzha basin.

4.3.2 Calibration of the model

Curve Number (CN2) parameter influences the runoff while using the model for hydrologic simulation. After calibration, there is a certain improvement in the model prediction which is represented by the values of statistical measures. From the analysis, observed and simulated stream flow values are somewhat correlated to each other before calibration. After calibration, improvement in the observed and simulated stream flow values correlation is increased slightly. From the Fig. 4.5 to 4.8, it can be seen that the major variation between the simulated and observed graphs is in case of the peaks. Some of the peak flows were under estimated and over estimated before calibration process. After calibration process, there is improvement in the correlation between the two in most of the years. It was also noticed that some of the peak flows were not exactly simulated by SWAT even after the calibration process. Stehr *et al.* (2008) has explained that over long time periods and in case of extreme events (peak flows), the model prediction of runoff is imprecise. According to the Varughese (2016), these model uncertainties can be accounted due to the large variations in topography and rainfall, some errors in data input sources like land use and soil, data preparation etc.

The graphs of simulated and observed monthly stream flows before and after calibration for the Pulamanthole gauging station were shown in Fig. 4.5 to 4.8. According to the figure, simulated peak flows are slightly underestimated during 1992, 1994, 1998, 2005 and 2011 for the model calibration and vice-versa for the remaining years. Basically, the main cause of these errors is due to the lack of precise information regarding input data. Similar results were obtained by Abraham *et al.* (2007) & Tejaswini and Sathian (2018), in which peak flows for the simulated flow were under estimated and over estimated. The calibration results ranged in the category ‘good’ according to the criteria given by Moriasi *et al.* (2007) for the prediction of discharge.

4.3.2.1 Evaluation of model performance using statistical measures

The statistical measures adopted for evaluating the model performance on a monthly basis (comparing the observed and simulated flow) are Nash Sutcliffe Efficiency (NSE) and coefficient of determination.

Table 4.6 Performance indices before and after calibration period

Statistical criteria	Before calibration	After calibration
NSE	0.81	0.82
R^2	0.83	0.85

The performance indices before and after calibration period were shown in Table 4.6. The calibration statistics shows that the simulated flow has a very good correlation with the observed stream flow. According to the Shawul *et al.* (2013), calibrated SWAT model performed well for monthly stream flow. The NSE and coefficient of determination (R^2) before and after calibration ranges from 0.81 to 0.82 and 0.83 to 0.85 respectively. The results showed that the NSE and R^2 were categorised under "very good" (Moriasi *et al.*, 2007). From the statistical analysis, it was observed that the statistical criteria before calibration shows the high predictive ability of the model even without calibration. After calibration, there is slight increase in the model statistical parameters which represents that there is some improvement in the model prediction. The definition of NSE statistic implies that it puts more emphasis on the peak values (extreme events) than on the average flows (Malago *et al*., 2015). Also the timing of simulation influences the statistic (MacLean, 2005) and since the simulation here was done on a monthly basis the improvement in the statistic is less.

Another graphical form for evaluating the model is based on scatter plot. The scatter plot of monthly stream flow before and after calibration is shown in Fig 4.9 to 4.10. It mainly represents the relationship between observed and simulated values with the statistical measure of coefficient of determination.

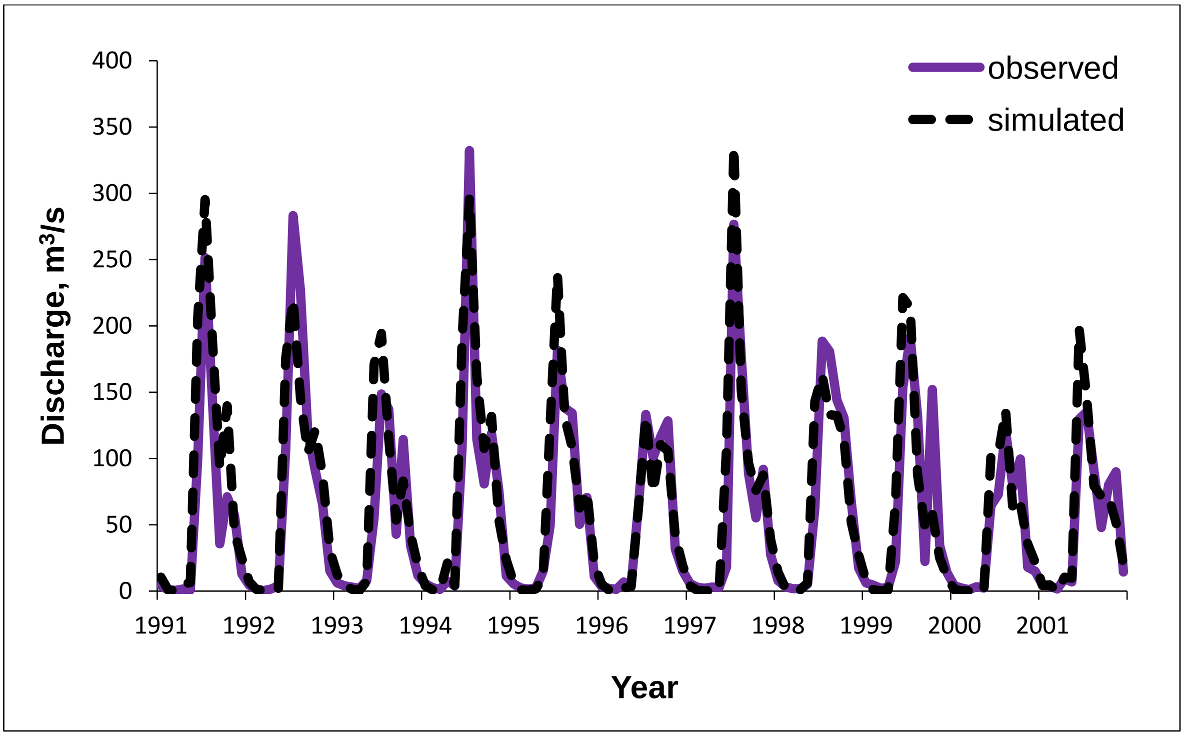


Fig. 4.5 Average monthly discharge for the period of 1991 to 2001 before calibration

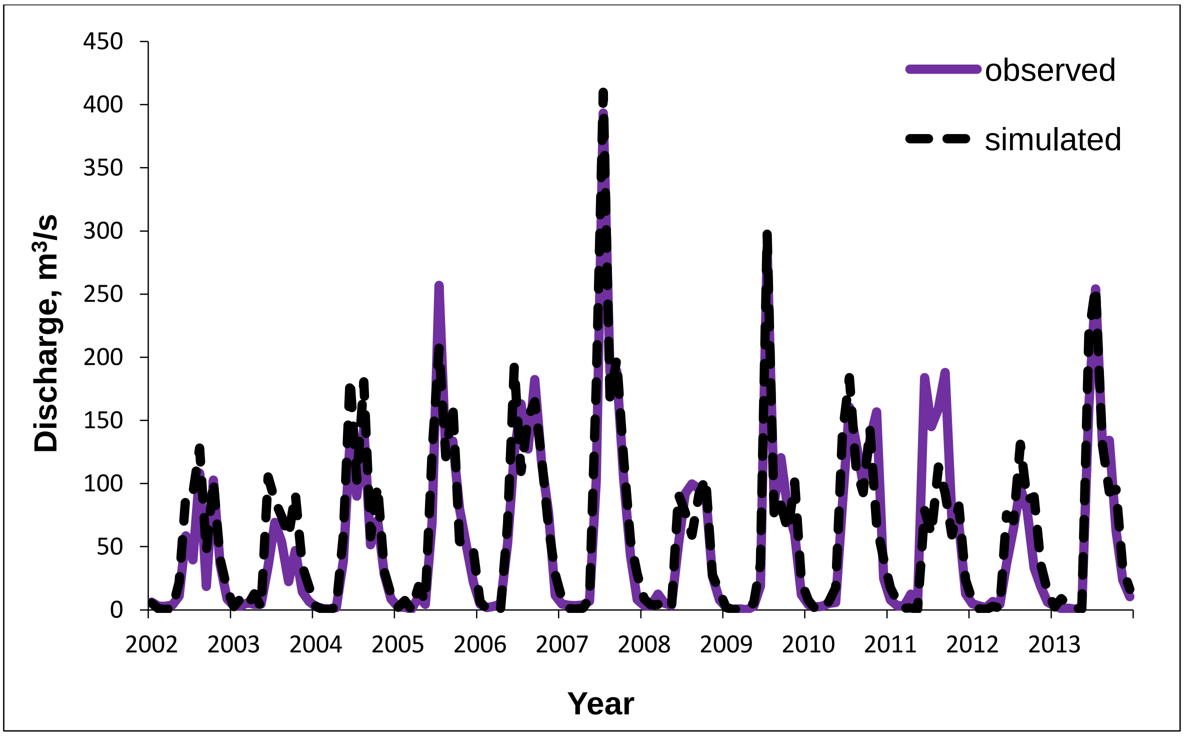


Fig. 4.6 Average monthly discharge for the period of 2002 to 2013 before calibration

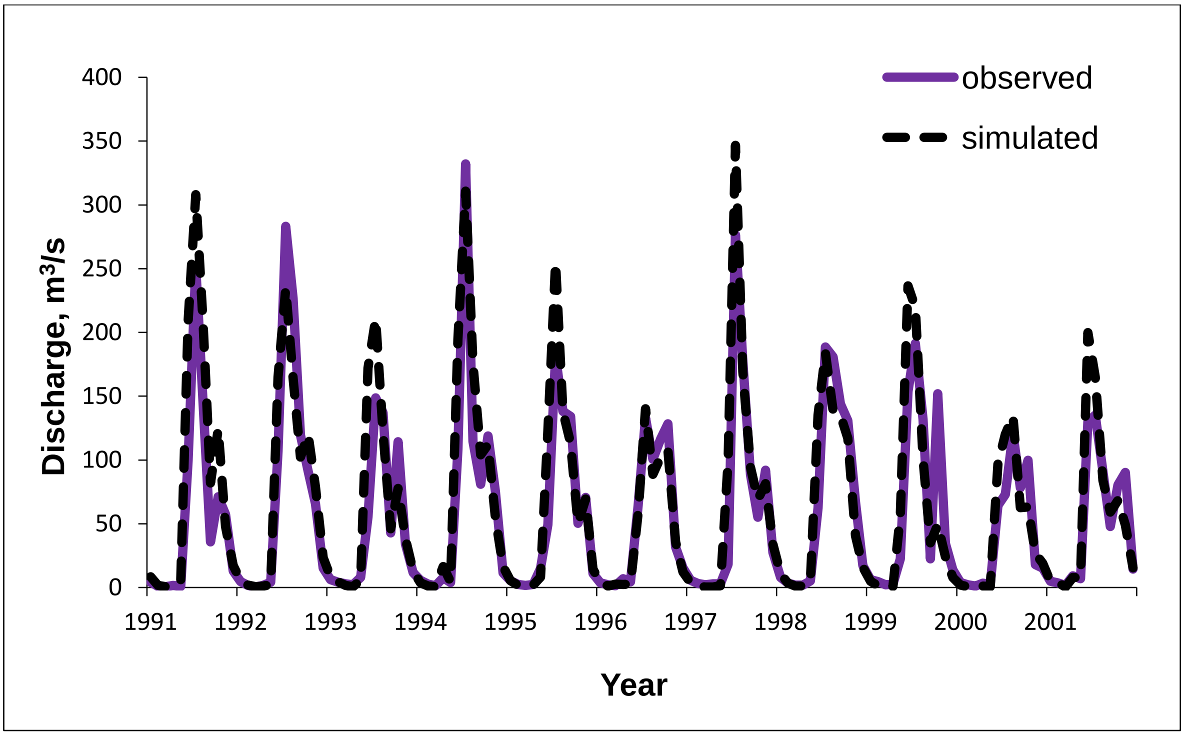


Fig. 4.7 Average monthly discharge for the period of 1991 to 2001 after calibration

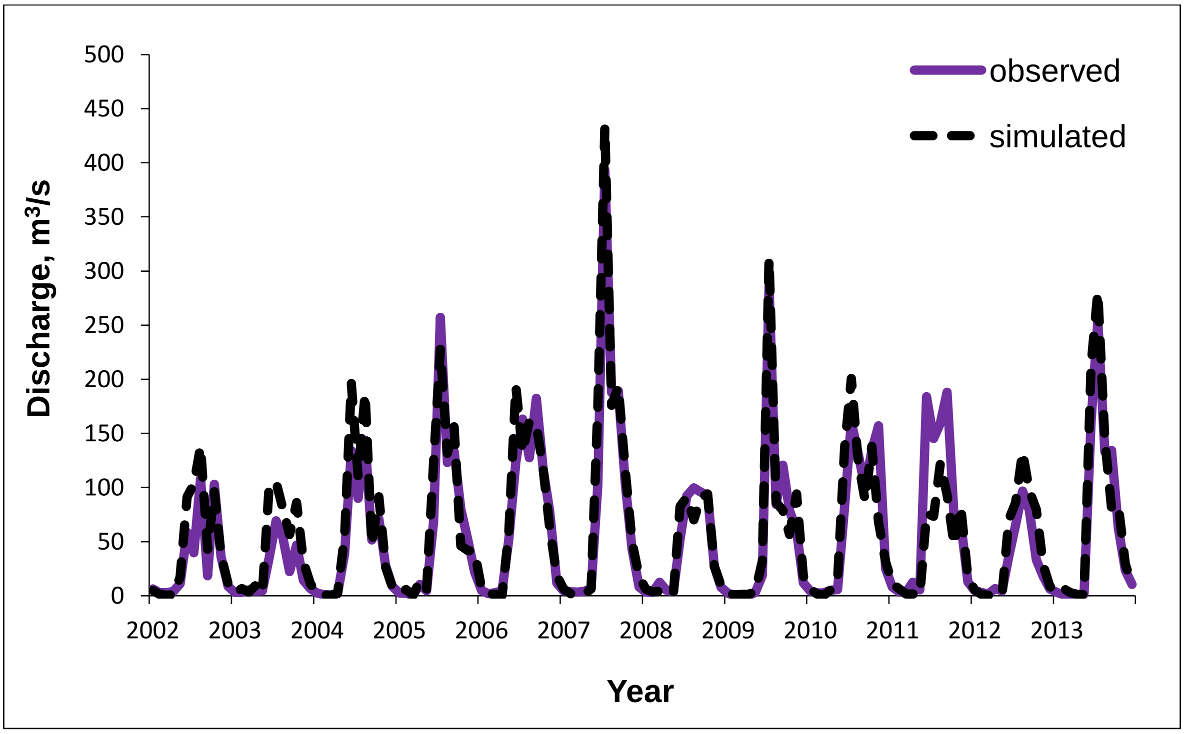


Fig. 4.8 Average monthly discharge for the period of 2002 to 2013 after calibration

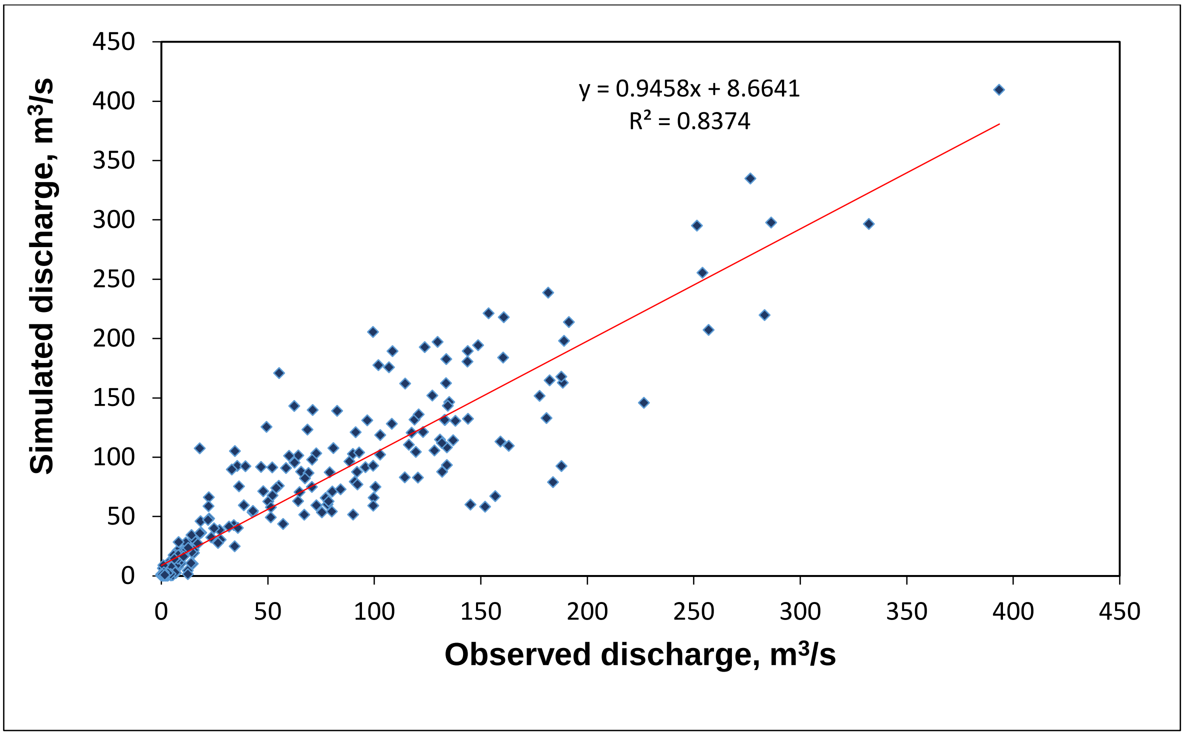


Fig. 4.9 Scatter plot of observed and simulated monthly discharge at Pulamanthole gauging station before calibration

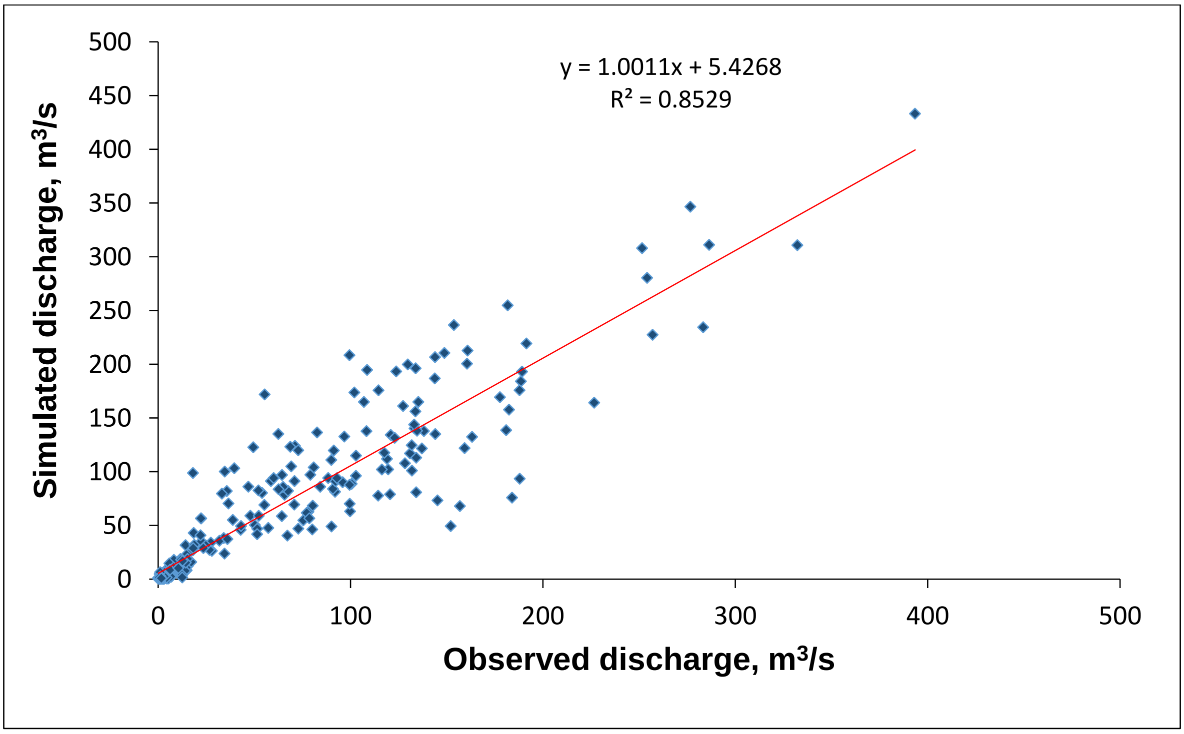


Fig. 4.10 Scatter plot of observed and simulated monthly discharge at Pulamanthole gauging station after calibration

4.3.3 MODEL VALIDATION

The model validation is useful for improving the accuracy of the model performance. The graphs of simulated and observed monthly stream flows of validation period for the Pulamanthole gauging station were shown in Fig 4.11. According to the figure, simulated peak flows are underestimated during 2015 for the model validation. Similar results were obtained by the Abraham *et al.* (2007) in which peak flows for the simulated flow were under estimated and over estimated. The validation results seem to be satisfactory for the prediction of discharge.

Table 4.7 Performance indices for the validation period

Statistical criteria	Validation period
NSE	0.70
R^2	0.87

The performance indices for the validation period on a monthly basis were shown in Table 4.7. The validation statistics shows that the simulated flow has a correlation with the observed stream flow. The NSE and coefficient of determination (R^2) for validation are 0.7 and 0.87. The results showed that the NSE and R^2 were performed "good" in validation of the model (Moriasi *et al.*, 2007). This also shows that the calibrated model will be considered good for the model prediction which is outside the calibration period.

Another graphical form for evaluating the model is based on scatter plot. The scatter plot of monthly stream flow before and after calibration is shown in Fig. 4.12. It mainly represents the relationship between observed and simulation values with the statistical measure of coefficient of determination.

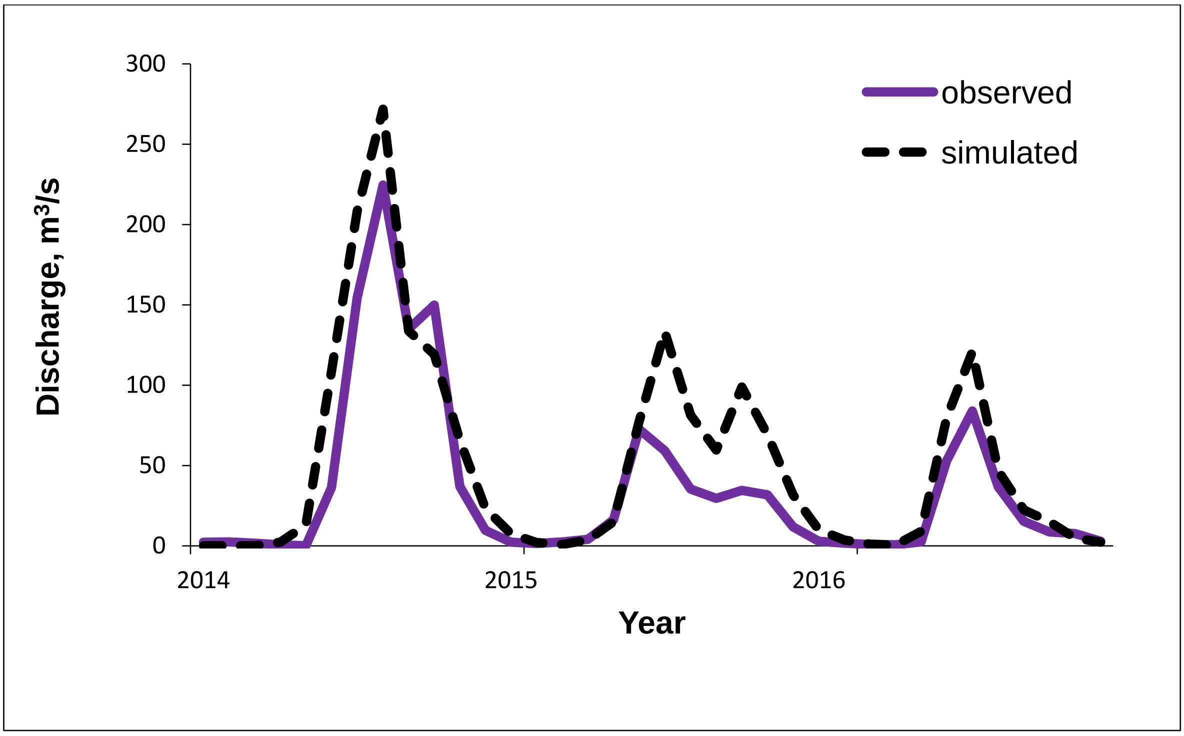


Fig. 4.11 Average monthly discharge for the period of 2014 to 2016 for validation

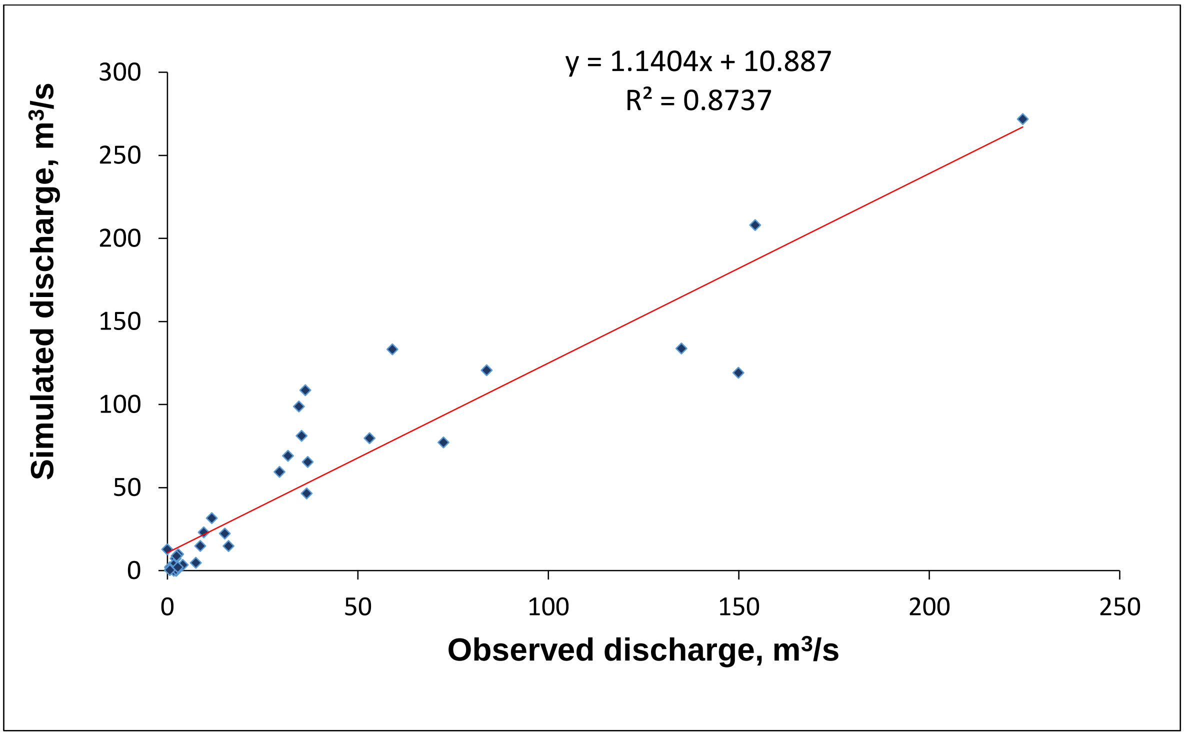


Fig. 4.12 Scatter plot of observed and simulated monthly discharge at Pulamanthole gauging station during validation period

4.4 COMPARISON OF SWAT OUTPUTS USING CFSR DATA AND OBSERVED METEOROLOGICAL DATA

Mainly, stream flow was taken as a major component for comparing the CFSR data and observed meteorological data. The stream flow is simulated using CFSR data and observed meteorological data using SWAT model. The model has been simulated for the period 1st January 1991 and 31st December 2013. The SWAT outputs using both data are compared with the observed data. The comparison of SWAT outputs for the different climate data can be evaluated using different statistical measures like Nash Sutcliffe efficiency, coefficient of determination and Root Mean Square Error. The observed meteorological data has given a better performance when compared with the CFSR data.

The graphs of average monthly simulated discharge of CFSR and observed meteorological data for the Pulamanthole gauging station were shown in Fig 4.13 to 4.14. From the results it can be seen that the simulated discharge of CFSR data are underestimated during 10 years among the 23 years for which simulation was done. In the graphs, it is clearly noticed that the simulated discharge of observed meteorological data are underestimated during 1996, 2003, 2008, 2011 and 2012. These results show that there is clear dominance of observed meteorological data for the simulated stream flows except in some years. According to Roth and Lemann (2016), simulations with conventional data resulted in better results for discharge and soil loss than the simulations with the CFSR data. From the Fig. 4.15, monthly simulated discharge of CFSR data shows a high correlation except at peaks. Hence, CFSR data can be used as a reliable data source in data scarce situations. According to Tomy and Sumam (2016), CFSR data gives better results when the number of rain gauge stations available are 3 or less in an area.

Table 4.8 Performance indices for the CFSR data and observed meteorological data

Statistical criteria	Observed meteorological data	CFSR data
NSE	0.82	0.70
R^2	0.85	0.72
RMSE	29.25	37.18

The performance indices for the CFSR data and observed meteorological data were shown in Table 4.8. The NSE, coefficient of determination (R^2) and RMSE for monthly simulated discharge of observed meteorological data and CFSR data ranges from 0.82 & 0.70, 0.85 & 0.72 and 29.25 & 37.18. The results showed that the simulated discharge of observed meteorological data and CFSR data performed “very good” and “good” for NSE and R^2. For the RMSE, monthly simulated discharge of observed meteorological data performed better than the CFSR data.

The graph of mean monthly discharges between simulated discharges using the observed meteorological data, simulated discharge using predicted meteorological data (CFSR) and observed discharge were shown in the Fig. 4.15. From the figure, it was clearly identified that the simulated discharge using observed meteorological data was highest at the peaks and simulated discharge using predicted meteorological data was lowest at peaks when compared with the observed discharge. So, the simulated discharge using observed meteorological data clearly influencing the other data mostly in the month of July. The simulated discharge using predicted meteorological data (CFSR) was clearly dominating in some months and overlapping in the other months expect at the peaks when compared with the other data. So, CFSR data can be considered as a reliable data which was used in the data scarce regions.

Another method for comparing the observed meteorological and CFSR data is on the basis of scatter plot. The scatter plot for the comparison of monthly simulated discharge of observed meteorological data and CFSR data is shown in Fig 4.16. It mainly represents the relationship between respective values with the statistical measure of coefficient of determination.

The scatter plot of observed and simulated monthly discharge at Pulamanthole gauging station for CFSR data was shown in Fig. 4.17. It mainly represents the relationship between observed and simulated values with the statistical measure of coefficient of determination.

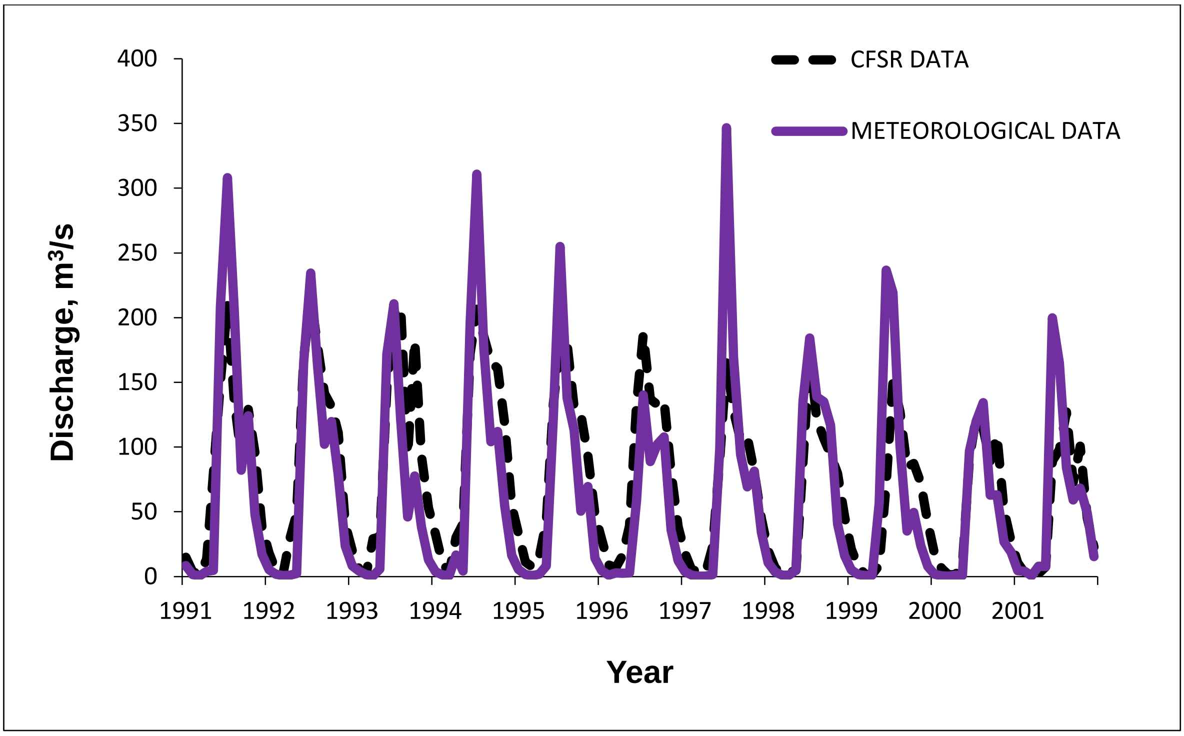


Fig. 4.13 Average monthly simulated discharge of observed meteorological data and CFSR data for the period 1991 to 2001

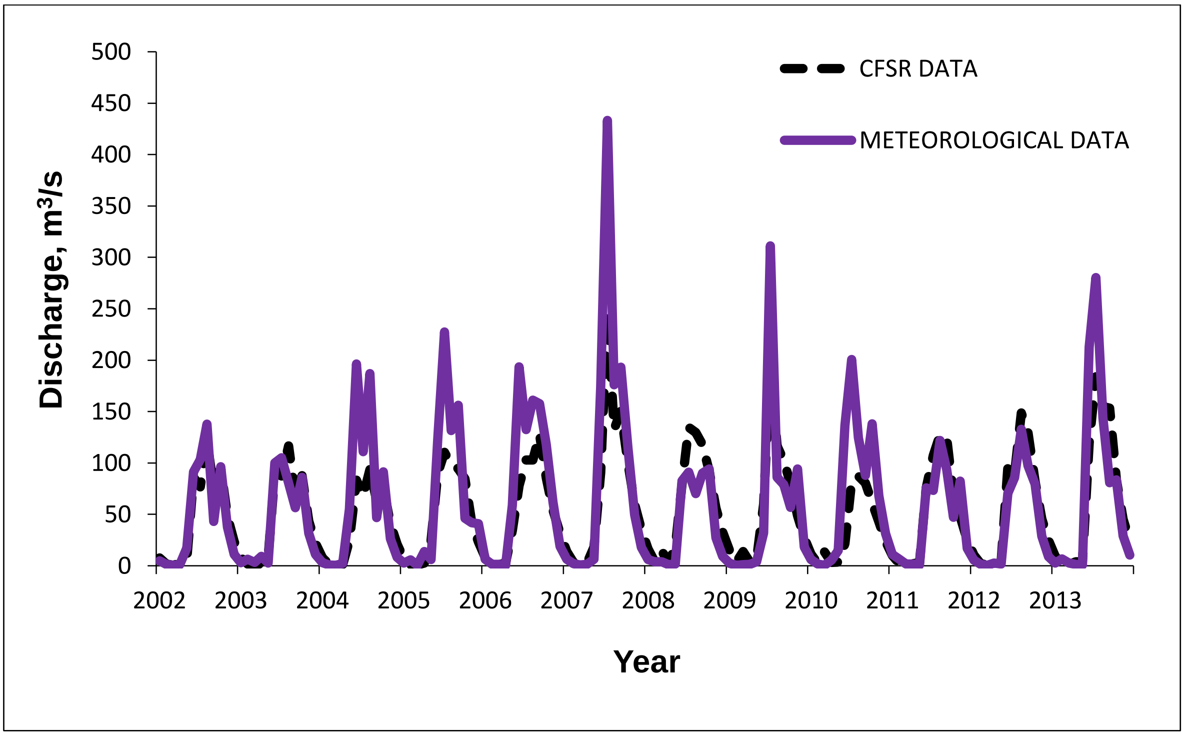


Fig. 4.14 Average monthly simulated discharge of observed meteorological data and CFSR data for the period 2002 to 2013

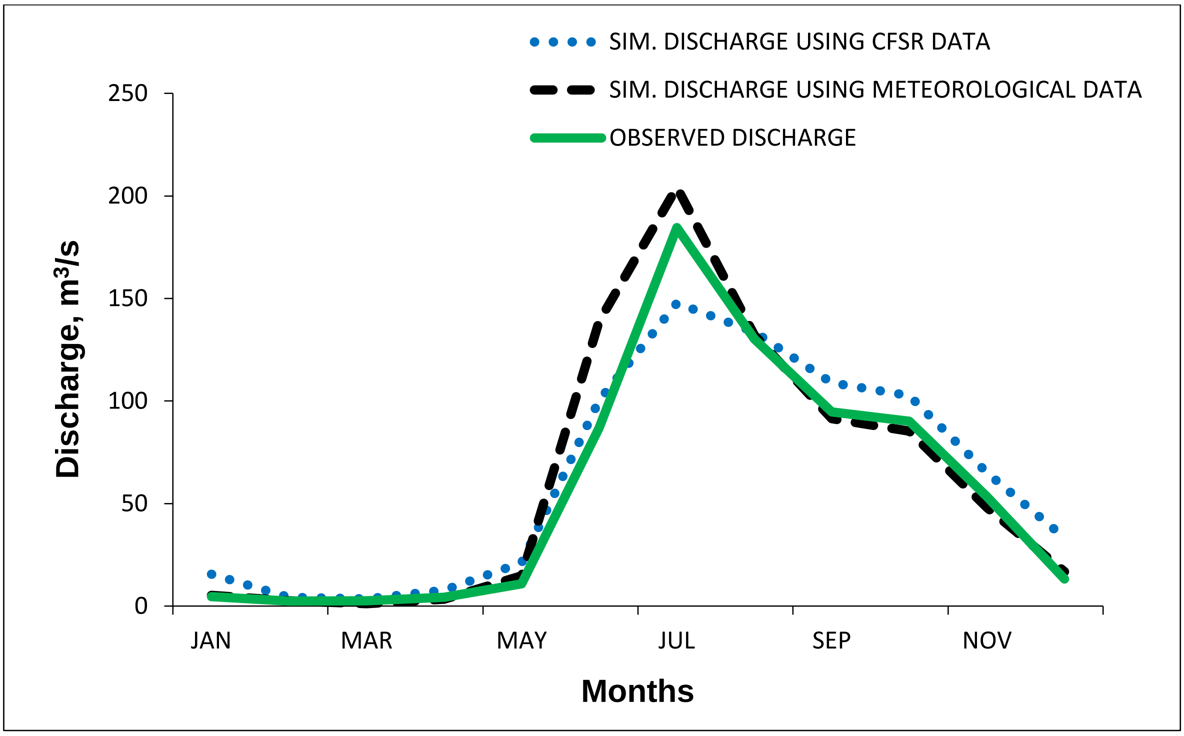


Fig. 4.15 Comparison of average monthly discharge of SWAT outputs and observed discharge for the period between 1991 and 2013

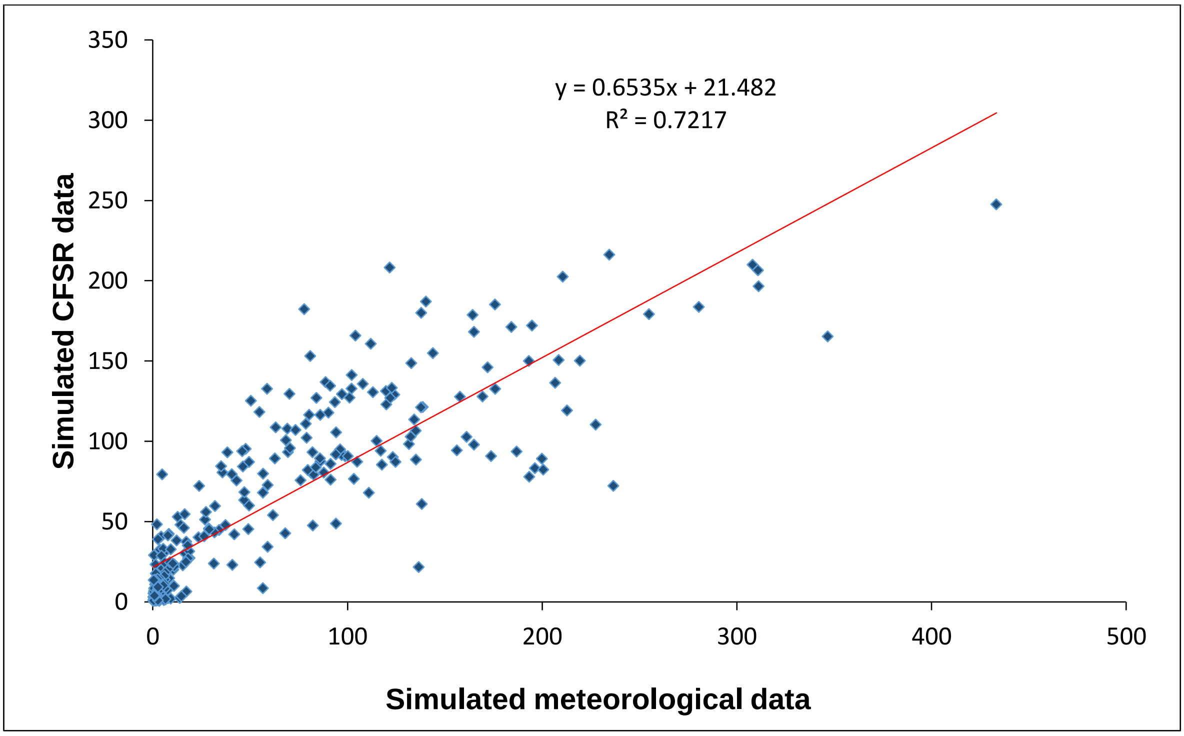


Fig. 4.16 Scatter plot of simulated meteorological data and simulated CFSR data at Pulamanthole gauging station

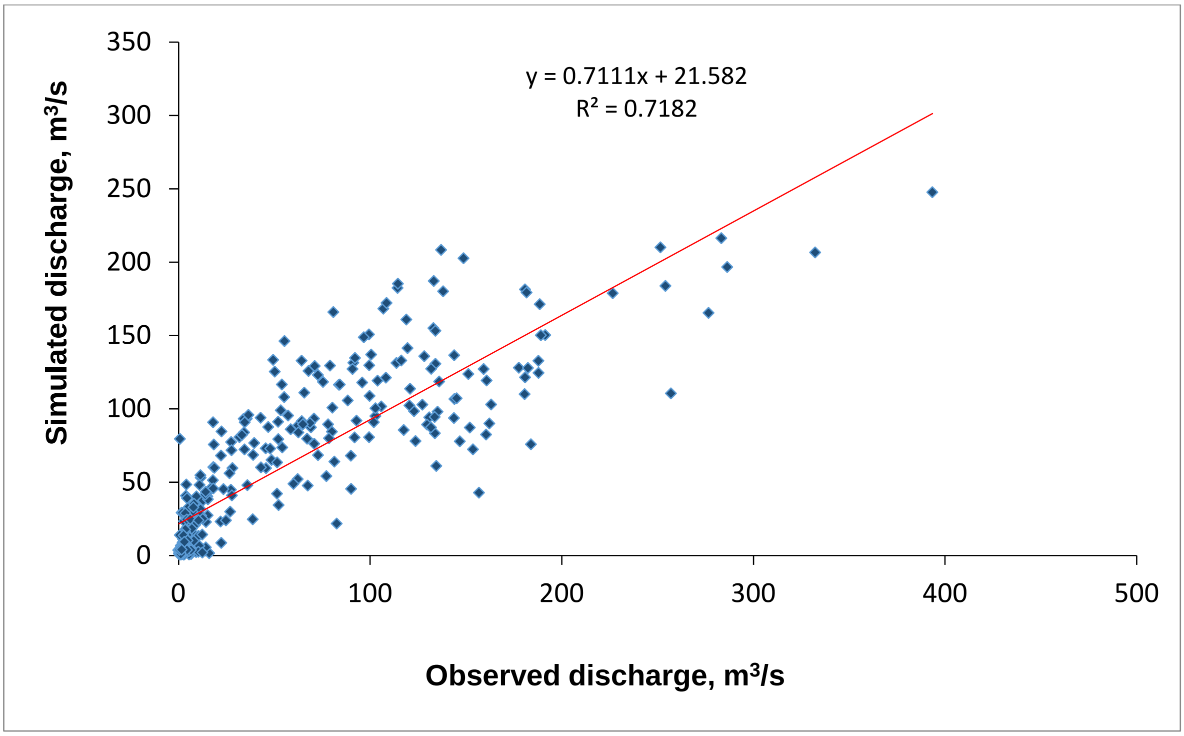


Fig. 4.17 Scatter plot of observed and simulated monthly discharge at Pulamanthole gauging station for CFSR data

4.5 IMPACT OF LAND USE CHANGES ON THE HYDROLOGY OF THE WATERSHED

The land use has played a vital role in changing the hydrology of the watershed. In order to study the impact of land use changes on the hydrology of the watershed, the present and past land use map is required for the analysis. The present land use map is prepared for the year 2017 and the past land use map is prepared for the year 2000 which were shown in the Figures 4.18 to 4.19. The model is run with the present and the past land use changes for the year 2017 and 2000 which is useful for assessing the impact of land use changes on the stream flow of the Kunthipuzha river basin.

The model is simulated for the period ranges between the 1st January 1989 to 31st December 2016 with the two years of warm up period.

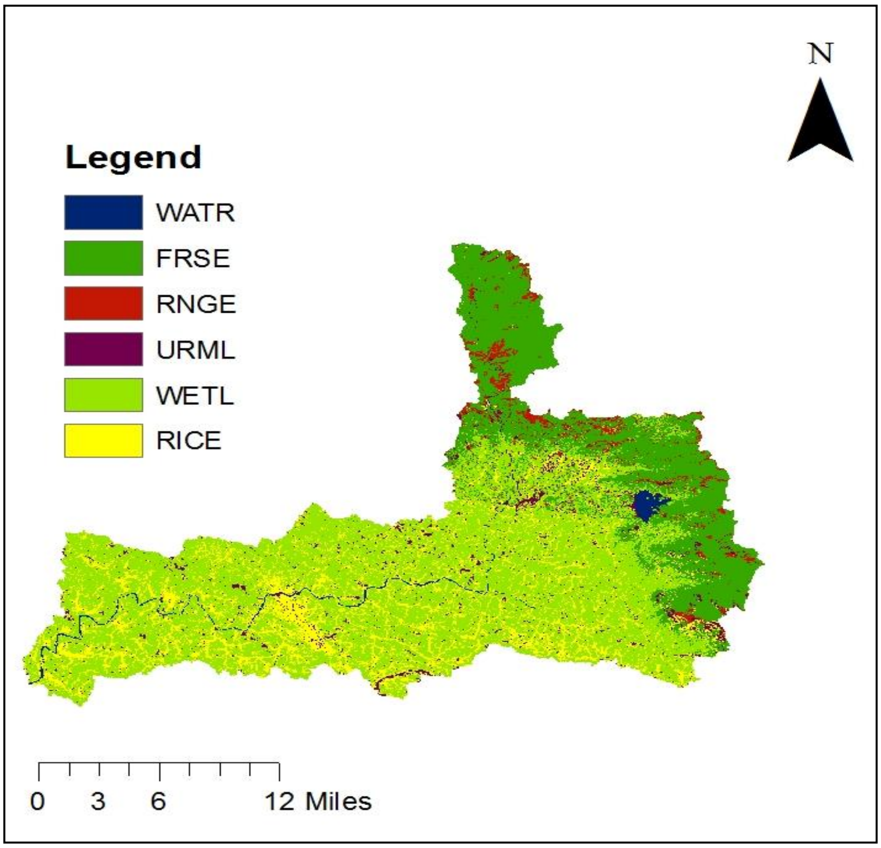


Fig. 4.18 Land use map for the year 2000

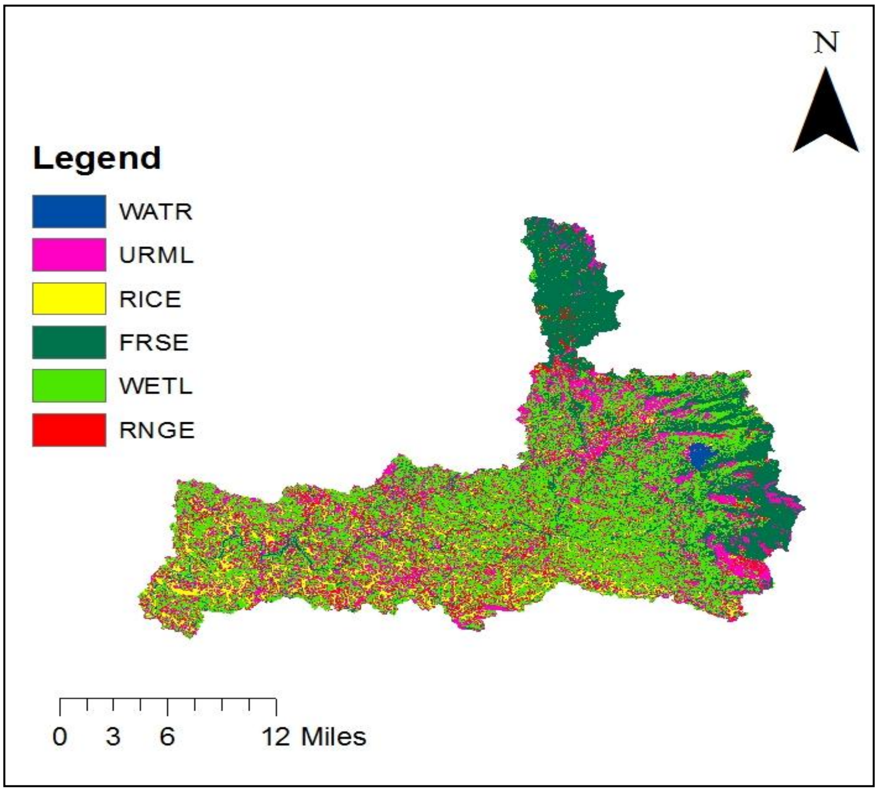


Fig. 4.19 Land use map for the year 2017

The monthly average stream flow for the different land use periods were shown in the Fig. 4.20. In June, July and August months, the flow was rapid when compared with the other months. From the months of January to May, flow was severely reduced when compared with the other months. The monthly simulated stream flow of 2000 for the land use 2000 and 2017 has a minimum discharge of 0.27 m^3/s and 0.26 m^3/s in March and 134.80 m^3/s and 134.60 m^3/s in August. The monthly simulated stream flow of 2016 for the land use 2000 and 2017 has a minimum discharge of 0.39 m^3/s and 0.36 m^3/s in April and 103.30 m^3/s and 102.40 m^3/s in July. From the Tables 4.10 and 4.11, it was clear that there is no such variation observed in stream flow. From the Fig.4.20, it was clear that there is no significant effect on the stream flow for the different periods of land use. Hence, land use change impact on the stream flow was very small in the study area. Similar results were concluded by Ashagrie *et al* (2006) that the overall impact of land use change was too small to be detected for the large river basins.

The land use change impact on the stream flow was also based on the size of basin. The size of the Kunthipuzha river basin is about 1032 km^2. Based on the analysis of the land use change impact, there was no significant effect on the change in stream flow for the different land uses considered in the study. This reveals that the land use change impact also occurs based on the basin size. Similar results were obtained from FAO (2002), which suggests that the impact of land use can be studied best in small basins (< 1000 km^2).

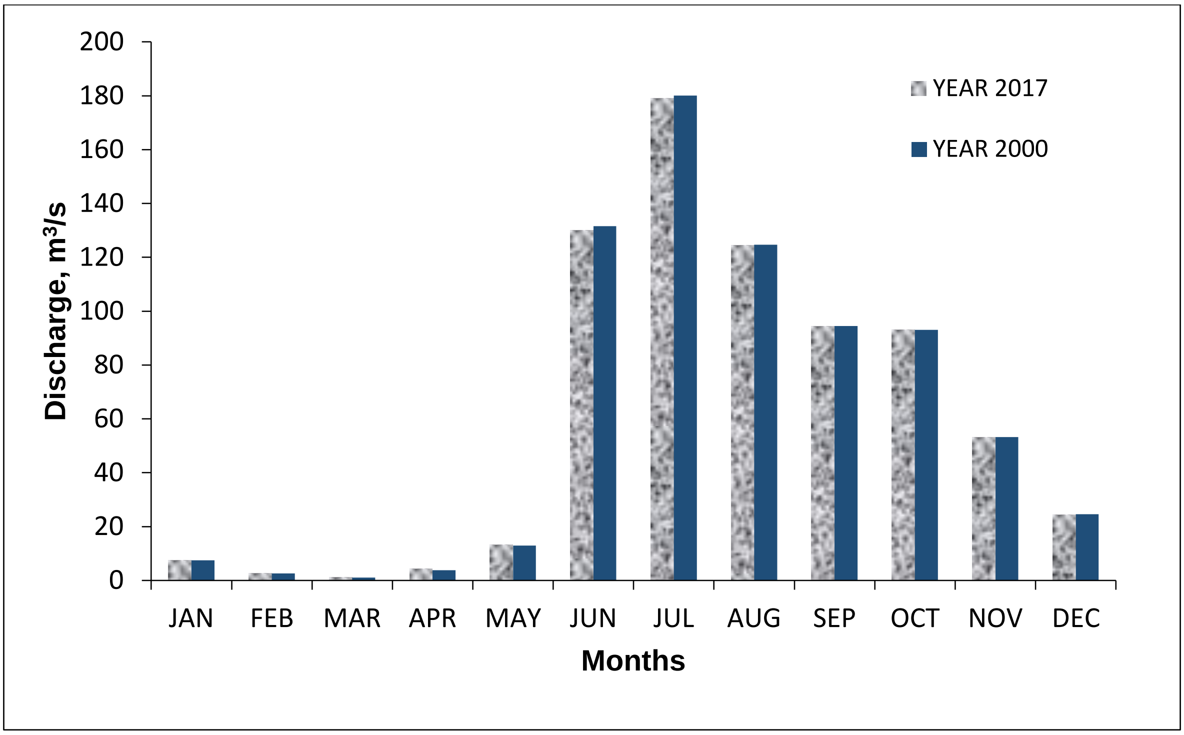


Fig. 4.20 Monthly averaged stream flow of different land use periods for the period between 1991 to 2017

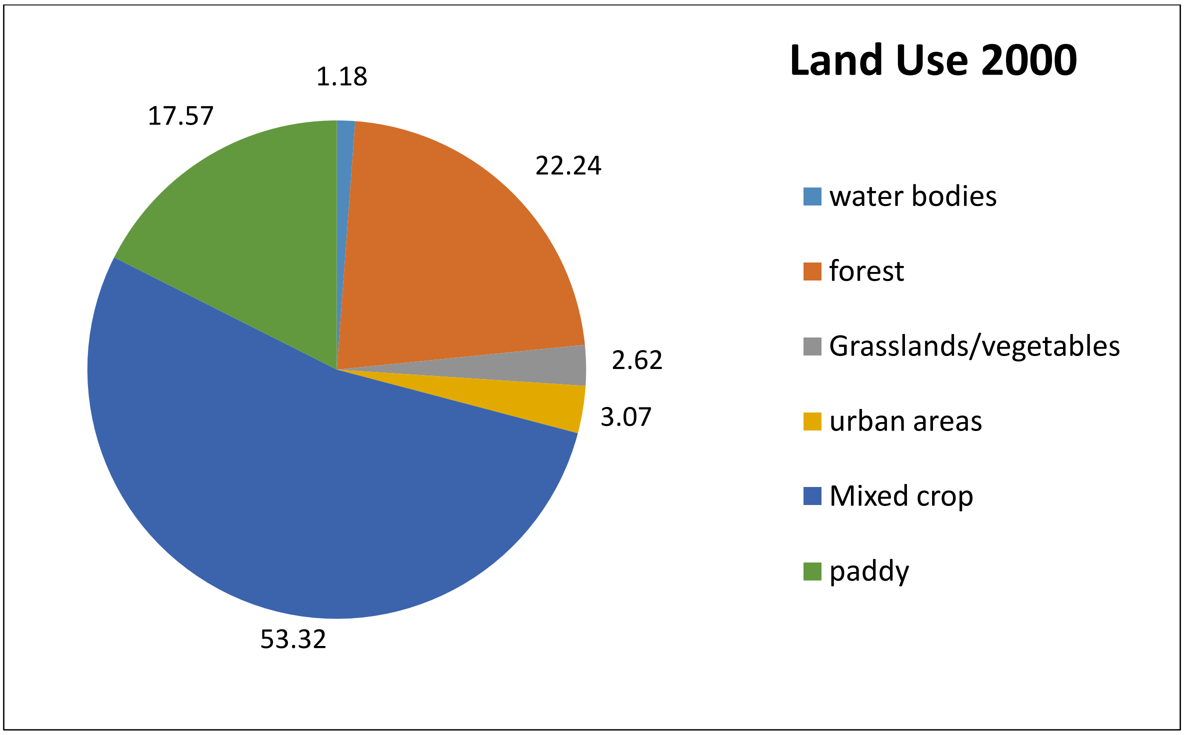


Fig. 4.21 Percentage of area for different Land uses for the year 2000

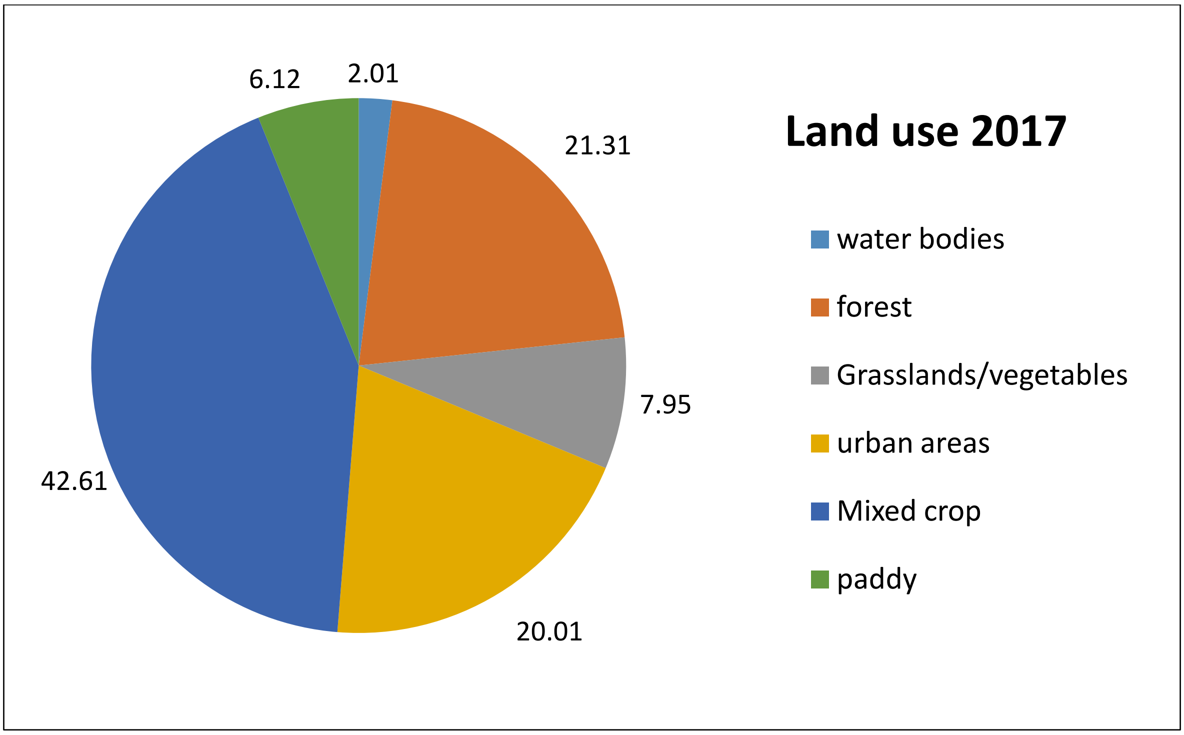


Fig. 4.22 Percentage of area for different Land uses for the year 2017

Table. 4.9 Percentage area for different Land uses

Land use	**Area in percentage**	
	2000	**2017**
Water bodies	1.18	2.00
Forest	22.24	21.31
Grasslands/Vegetables	2.62	7.95
Urban areas	3.07	20.01
Mixed Crop	53.32	42.61
Paddy	17.57	6.12

The percentage area for different land uses for the year 2000 and 2017 were shown in Fig. 4.21 and Fig. 4.22. From the Fig. 4.21, it was noticed that mixed crop occupied a large area followed by forest and paddy. From the Fig.4.22, it was noticed that mixed crop occupied a large area followed by forest and urban areas. The percentage of area under different land use during 2000 and 2017 were shown in Table 4.9. From the table, water bodies were increased from 1.18 to 2.01% which indicates that the water resources are conserved through soil and water conservation structures. Urban areas were drastically increased from 3.07 to 20.01% because of the rapid socio economic development. The forest land also reduced from 22.24 to 21.31%. Finally grasslands/vegetables, mixed crop and paddy ranges between 2.62 to 7.95%, 53.32 to 42.61% and 17.57 to 6.12%.

Table. 4.10 Comparison of simulated discharge for the year 2000 for the landuse change

Simulated discharge for the year 2000 (m^3/s)		
Months	**Year of land use**	
	2000	**2017**
January	1.36	1.33
February	0.50	0.53
March	0.27	0.26
April	0.87	1.30
May	0.61	0.93
June	97.11	96.66
July	103.40	103.00
August	134.80	134.60
September	60.86	61.00
October	66.27	66.34
November	36.10	36.37
December	22.71	22.36

Table 4.11 Comparison of simulated discharge for the year 2016 for the land use change

Simulated discharge for the year 2016 (m^3/s)		
Months	**Year of land use**	
	2000	**2017**
January	14.42	14.25
February	2.96	2.90
March	0.75	0.72
April	0.39	0.36
May	10.03	10.67
June	74.91	74.09
July	103.30	102.40
August	49.50	49.21
September	31.74	31.70
October	21.10	20.95
November	6.09	5.90
December	1.96	2.08

4.6 SWAT SIMULATION ANALYSIS

The graphs of mean monthly discharge of observed meteorological data and CFSR data at the watershed outlet for respective periods were shown in Fig. 4.23 to 4.24. From the fig., it was clear that stream flow increases in the months from June to September and decreases in the months from February to April. The peak discharge for the mean monthly discharge of observed meteorological data and CFSR data occurs in the month of July. The monthly peak discharge of observed meteorological data in the month of July was 196.61 m^3/s. The mean monthly discharge of observed meteorological data in the months of summer season varies from 3.29 to 11.77 m^3/s. The mean monthly discharge of observed meteorological data in the months of rainy season varies from 86.32 to 196.61

m^3/s. The mean monthly discharge of CFSR data in the months of summer season varies from 3.25 to 24.79 m^3/s. The mean monthly discharge of CFSR in the months of rainy season varies from 98.21 to 144.61 m^3/s. The monthly peak discharge of CFSR data in the month of July was 144.61 m^3/s.

The water balance components of the observed meteorological data for the calibration and validation period were shown in Fig. 4.25 to 4.26. Water balance components such as ET (actual evapotranspiration), PERC (water that percolates below the root zone), SURQ (surface runoff), GW_Q (ground water contribution to stream) and WYLD (water yield) are used for the analysis. It is observed that the evapotranspiration takes a huge amount of water followed by the percolation in both the calibration and validation periods. From the fig 4.27 and fig.4.28, evapotranspiration varies from 35-36% and percolation ranges between 19-20%. Mostly, major amount of river flow occurs through the base flow and surface runoff. From the Fig. 4.27 and Fig. 4.28, surface runoff varies form 14-16% and base flow varies from 17-18%.

The mean monthly water balance components for the basin for the period from 1991 to 2016 were ET-627.15 mm & ET= 608.20 mm, PERC= 987.27 mm & PERC= 904 mm SURQ= 881.17 mm & SURQ= 638.32 mm, GW_Q= 895 mm & GW_Q= 815.19 mm and WYLD= 1928.58 mm & WYLD= 1591.65 mm. From the Tables 4.12 and 4.13, surface runoff and base flow are the two major water balance components contributing discharge to the main stream through basin outlet. Some amount of water was conveyed through the process of evapotranspiration and percolation.

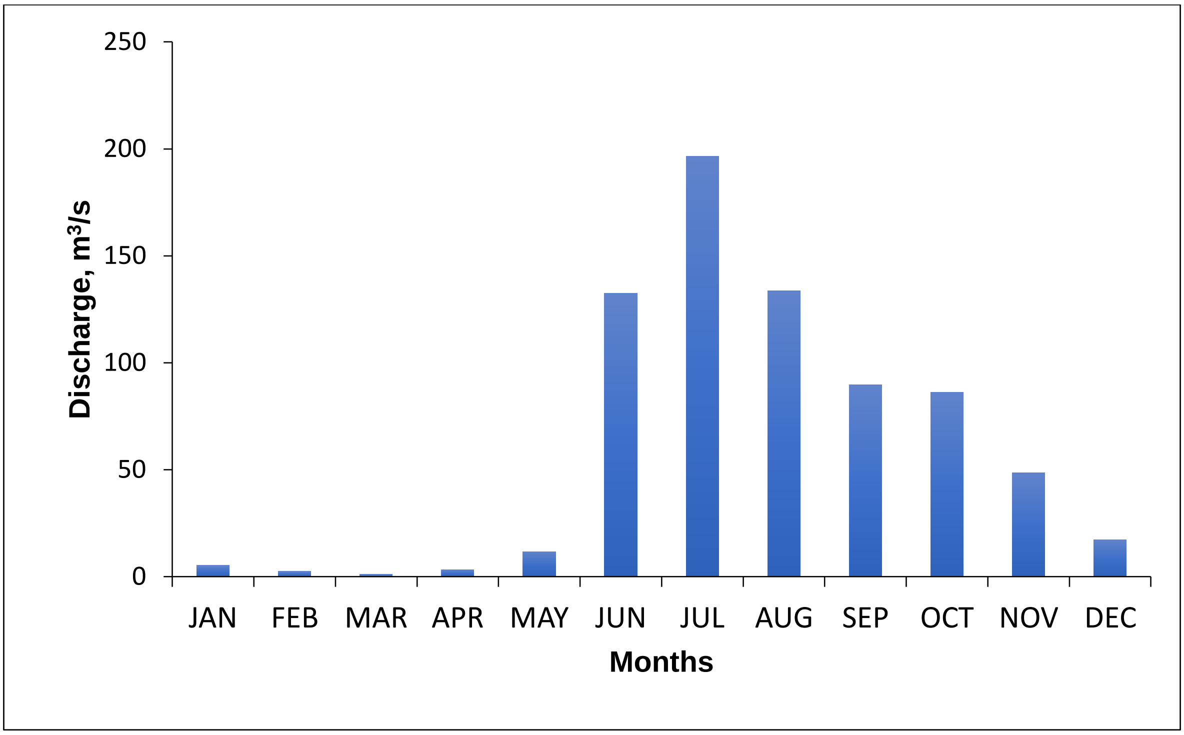


Fig. 4.23 Average monthly discharge of observed meteorological data at watershed outlet for the period of 1991-2016

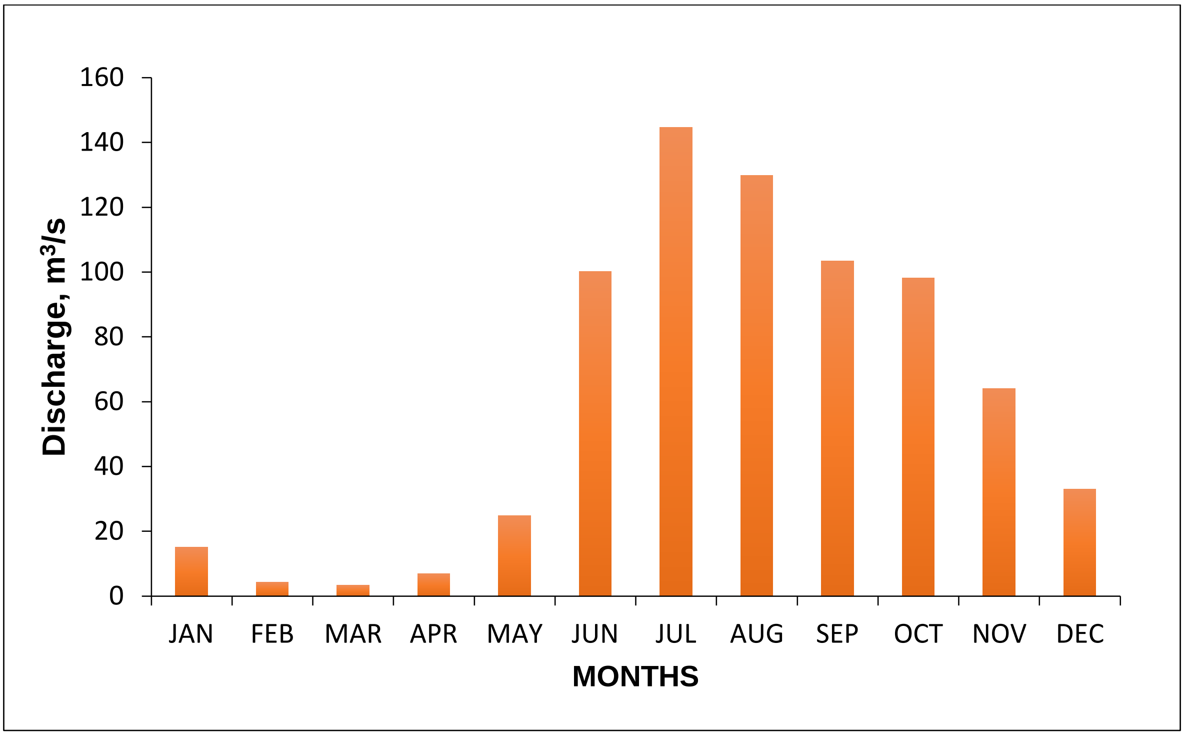


Fig. 4.24 Average monthly discharge of CFSR data at watershed outlet for the period of 1987-2013

Table 4.12 Average monthly water balance components at the basin outlet for the calibration period

MONTH	ET (mm)	PERC (mm)	SURQ (mm)	GW_Q (mm)	WYLD (mm)
JAN	10.82	0.29	0.21	12.32	17.73
FEB	42.11	0.41	2.20	2.10	8.21
MAR	71.90	0.34	0.69	0.24	4.42
APR	61.30	0.60	3.54	0.07	7.80
MAY	57.75	14.45	20.25	1.61	27.68
JUN	57.00	225.40	250.12	58.55	330.33
JUL	56.39	298.43	291.16	198.01	518.66
AUG	65.13	175.35	114.52	219.00	356.94
SEP	60.58	106.79	69.51	153.55	240.83
OCT	68.95	112.90	93.81	120.68	232.44
NOV	51.10	47.55	31.10	88.41	131.75
DEC	24.14	4.75	4.05	40.44	51.79
Grand Total	627.15	987.27	881.17	895.00	1928.58

Table 4.13 Average monthly water balance components at the basin outlet for the validation period

MONTH	ET (mm)	PERC (mm)	SURQ (mm)	GW_Q (mm)	WYLD (mm)
JAN	14.66	0.82	0.00	14.91	19.15
FEB	35.80	0.02	0.00	3.50	6.40
MAR	41.14	0.00	0.00	0.38	2.76
APR	66.94	0.00	0.24	0.00	4.05
MAY	62.32	13.37	17.58	1.37	26.50
JUN	46.29	214.20	137.73	51.46	208.05
JUL	56.43	260.33	191.45	177.07	394.33
AUG	70.13	141.93	142.14	192.04	354.08
SEP	70.00	88.29	41.77	132.93	190.58
OCT	63.00	122.45	74.38	113.88	205.80
NOV	44.19	51.36	26.92	86.03	124.58
DEC	37.30	11.22	6.11	41.61	55.35
Grand Total	608.20	904.00	638.32	815.19	1591.65

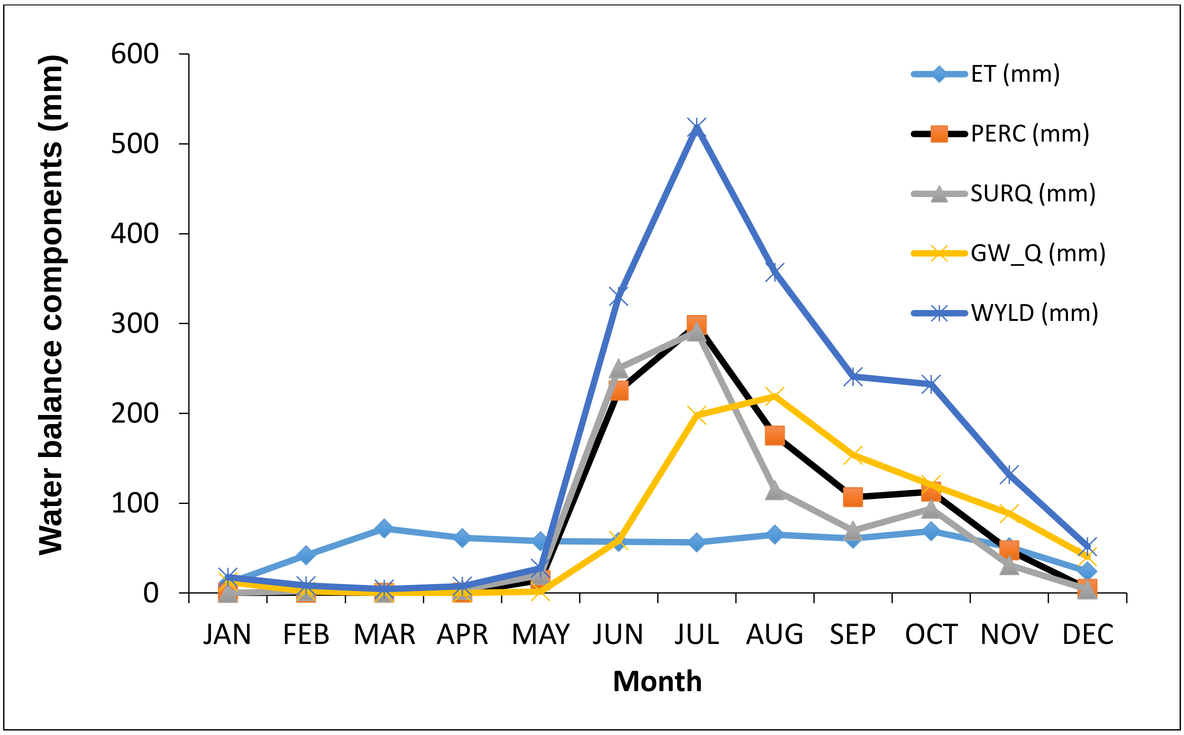


Fig. 4.25 Mean monthly water balance components at the watershed outlet for the calibration period

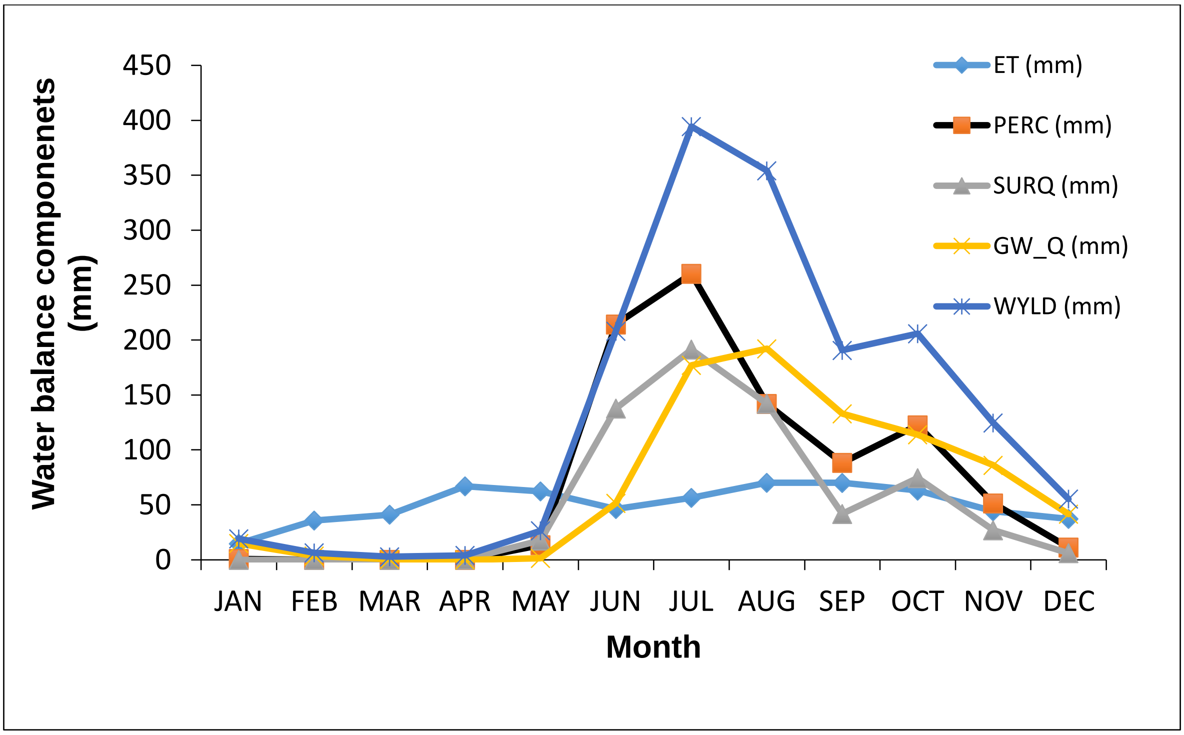


Fig. 4.26 Mean monthly water balance components at the watershed outlet for the validation period

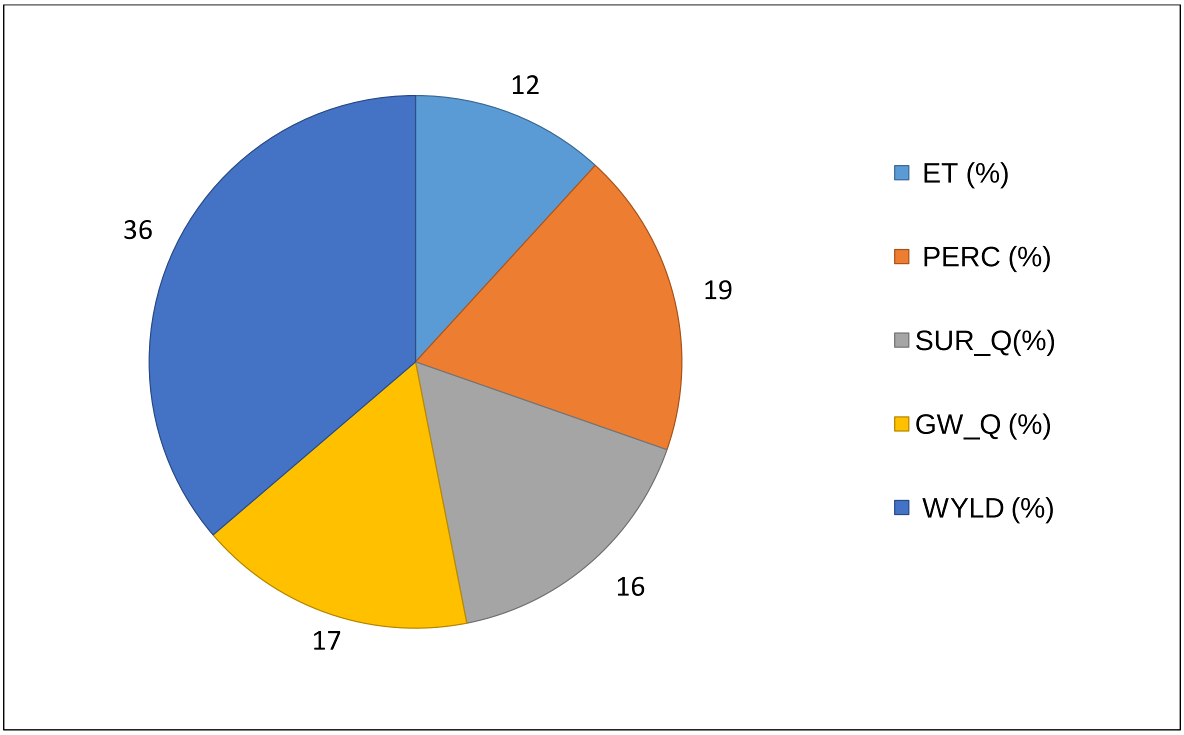


Fig. 4.27 Average annual water balance components for the calibration period

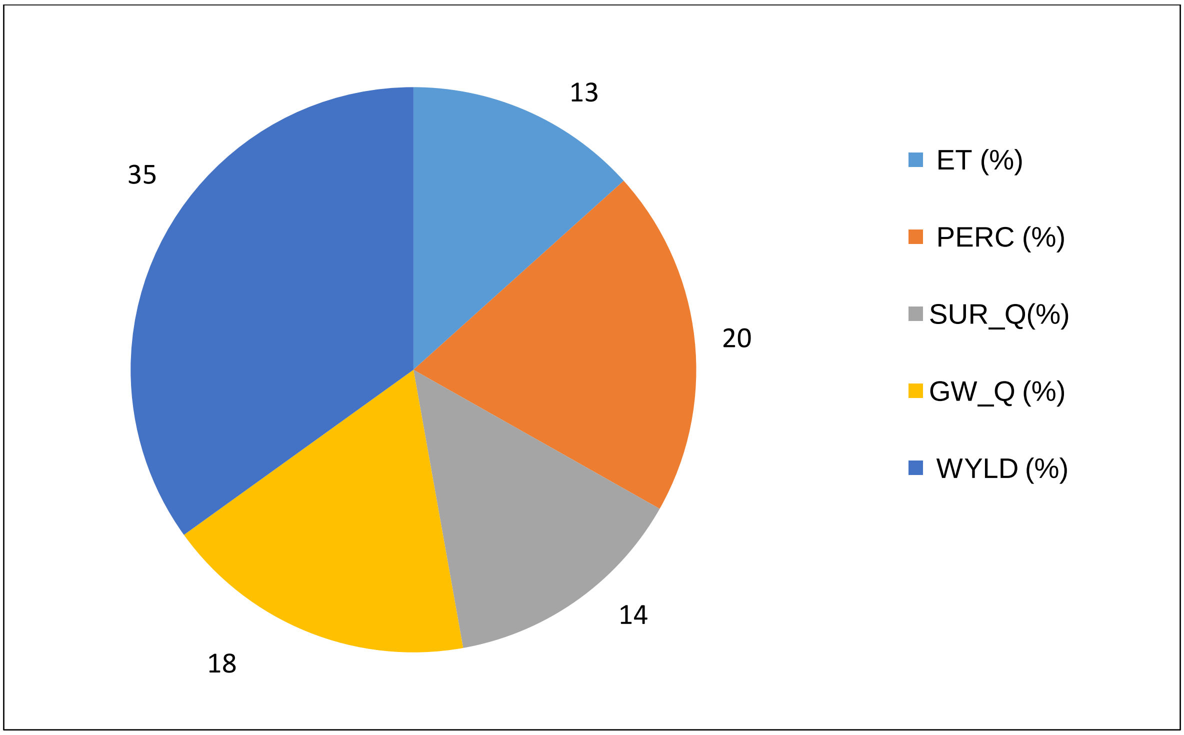


Fig. 4.28 Average annual water balance components for the validation period

4.7 OVERVIEW OF RESULTS IN THE STUDY AREA

Based on the calibrated SWAT model, water balance components were analyzed for the adopted study area. Mainly, discharge component is considered along the length of the main channel for different spatial and temporal periods. The comparison of SWAT outputs for the observed meteorological data and CFSR data was analyzed in order to overcome the data deficiency problems in the ungauged watersheds. The impact of the land use change on the stream flow also analyzed in the watersheds. The brief description of the above mentioned points is discussed below.

Using the calibrated SWAT model, assessment of the water balance components was simulated on the monthly basis. The water balance components were assessed for both the calibration and validation periods. Out of different water balance components, Evapotranspiration is considered as a major component followed by percolation, surface runoff and base flow. From those components, stream flow was considered as the main component for the analysis. The stream flow was occurred through the surface flow and base flow with the variation of 14-16% and 17-18%. The mean monthly water balance components for the basin for the period from 1991 to 2013 and 2014 to 2016 were ET= 627.15 mm & ET= 608.20 mm, PERC= 987.27 mm & PERC= 904 mm SURQ= 881.17 mm & SURQ= 638.32 mm, GW_Q= 895 mm & GW_Q= 815.19 mm and WYLD= 1928.58 mm & WYLD= 1591.65 mm.

The SWAT output comparison for the observed meteorological data and CFSR data was done separately on the monthly basis. Here, stream flow was considered as the main SWAT output. From the analysis, simulated discharge obtained from the observed meteorological data shows highest at the peaks when compared with CFSR data. Also, CFSR data was highly correlated in discharge values except at the peaks. This analysis reveals that CFSR data can also used as an alternate option in the ungauged watersheds.

The land use change impact plays an important role in altering the hydrology of the watershed. From the analysis, there is no such a impact of land use change on the stream flow that has taken place due to the selection of large area of watershed. Therefore, the land use change impact will be considered for the small area of watershed (<1000 km^2). While comparing the land use for the year 2000 and 2017, it is found that the urban areas drastically increased from 3.01 to 20.01% because of the rapid socio economic development. The forest land reduced from 22.24 to 21.31%. The percentage area under paddy decreased from 17.57 to 6.12%. The results indicate that there is no significant change in the stream flow with change in land use when analysed on a monthly basis.

CHAPTER V

SUMMARY AND CONCLUSIONS

Watershed models play a crucial role in effective utilization and management of water resources. Among the different models available, physically based semi distributed model SWAT which is efficient in simulating the catchment response is used in the study for the assessment of hydrological processes in the watershed. The model is helpful in understanding the complete hydrological behaviour of the watershed. Among the essential inputs needed, precise climatological data is very important for the development of any hydrologic model. However, there is limited availability of good quality data at the desired accuracy.

Further, to overcome the data deficiency problem, there is one possibility to use multiyear global gridded representations known as reanalysis datasets. The best one from the various reanalysis datasets available, National Centers for Environmental Prediction's Climate Forecast System Reanalysis (CFSR) which is freely available reanalysis dataset includes all the parameters required for the study, i.e. precipitation, temperature, solar radiation, humidity and wind speed. In the present study the possibility of using CFSR data as an alternative option in data scarce regions was studied.

Rapid land cover and land use changes can alter the hydrologic response of a watershed. In order to analyse these changes, the land use of two years, 2000 and 2017 was prepared and the impact of land use changes on the hydrological processes and river discharge in the watershed was studied using the SWAT model developed.

The study area selected is Kunthipuzha river basin which is the tributary of the Bharathapuzha river in the state of Kerala in India. The elevation ranges from 4 m near the outlet point of watershed to 2367 m which is situated near the Silent Valley. The maximum amount of rainfall is received from south west monsoon, average annual rainfall of catchment is 2300 mm and mean temperature of the area is about 27.3^{o}C.

In the process of model development, before doing the calibration, sensitivity analysis (one at a time analysis) is done for selecting the most sensitive parameters in the model for the study area. The main sensitive parameters identified for the study area are Curve Number (CN2) followed by Baseflow alpha factor (ALPHA_BF) and Soil evaporation compensation factor (ESCO). The calibration was done for the period of 23 years from 1991 to 2013 and validation for the period of 3 years from 2014 to 2016. The model was analysed with the help of statistical parameters such as NSE and R^2. The NSE and R^2 for the calibration period were 0.82 and 0.85, whereas for the validation period it was 0.70 and 0.87 respectively.

The calibrated model is able to assess the water balance components in order to understand the hydrological behaviour of the watershed. The evapotranspiration varies from 35-36%, percolation ranges between 19-20%, surface runoff varies from 14-16% and base flow varies from 17-18%. The major amount of river flow occurs through the base flow and surface runoff.

In order to overcome the data scarcity problems, the model was simulated with the predicted meteorological data (CFSR) and observed meteorological data. Comparison of the model simulations was done on the basis of statistical measures such as NSE, R^2 and RMSE. The NSE, R^2 and RMSE for model simulation with observed meteorological data were 0.82, 0.85 and 29.25, where as for the predicted meteorological data the values were 0.70, 0.72 and 37.18 respectively. From the analysis, it is seen that the variation between the simulated discharge obtained from the observed meteorological data and the observed discharge is mainly because of the variation between the values at the peaks. Even though the simulations with the predicted meteorological data (CFSR) had slightly less correlation than that with the observed meteorological data, the statistical indicators suggests that it can be well utilised for areas where the availability of accurate observed meteorological data is a hindrance for hydrologic studies**.**

Land use change impact on the stream flow plays a major role in changing the hydrology of the watershed. In order to assess the land use impact, preparation of land use for the year 2000 and 2017 are needed. Then the comparison of simulated discharge for the year 2000 and 2016 for the land use map 2000 and 2017. From the analysis, it is seen that there is no significant change in the stream flow with change in land use when analysed on a monthly basis.

The main conclusions obtained from the mentioned objectives are

1. The model set up, calibration and validation was performed satisfactorily based on the statistical measures.
2. The simulated discharge using the observed meteorological data gave satisfactory results on the basis of statistical measures.
3. The simulated discharge using the predicted meteorological data (CFSR data) is having satisfactory correlation with the observed discharge (based on statistical parameters NSE, R^2 and RMSE). So, CFSR data can be used as a reliable meteorological data source in areas where the availability of accurate observed meteorological data is a hindrance for hydrologic studies**.**
4. While comparing the land use for the years 2000 and 2017, it is found that the urban areas drastically increased from 3.01 to 20.01% because of the rapid socio economic development. The forest land reduced from 22.24 to 21.31%. The percentage area under paddy decreased from 17.57 to 6.12%.
5. The impact of land use change on the stream flow for the watershed was analysed with the landuse for the years 2000 and 2017 and it was found that even though there is slight decrease in stream flow during certain months, the change is not significant. The results indicate that there is no significant change in the stream flow with change in land use when analysed on a monthly basis.

SUGGESTIONS FOR THE FUTURE WORK

1. Other type of the satellite based weather data may be used for the prediction in the data scarce areas for getting more accurate results.
2. In order to assess the land use change impact, other techniques should be applied at the micro watershed scale.

APPENDIX I

Average monthly discharge at watershed outlet for the period 1991-2016 (Using Observed Meteorological data)

Month	Simulated Observed Discharge (m^3/s)
JAN	5.29
FEB	2.53
MAR	1.10
APR	3.29
MAY	11.77
JUN	132.46
JUL	196.61
AUG	133.69
SEP	89.77
OCT	86.32
NOV	48.63
DEC	17.25

APPENDIX II

Average monthly discharge at watershed outlet for the period 1987-2013 (using CFSR data)

Month	Simulated CFSR Discharge (m^3/s)
JAN	14.98
FEB	4.22
MAR	3.25
APR	6.83
MAY	24.80
JUN	100.15
JUL	144.61
AUG	129.73
SEP	103.42
OCT	98.21
NOV	64.02
DEC	32.98

APPENDIX III

Average monthly discharge of SWAT outputs and observed discharge for the period between 1991 and 2013 (Using Observed Meteorological data and CFSR data)

Months	Simulated discharge using CFSR Data (m^3/s)	Simulated discharge using Meteorological data (m^3/s)	Observed discharge (m^3/s)
JAN	15.55	5.23	4.58
FEB	4.28	2.58	2.46
MAR	3.50	1.26	2.60
APR	7.73	3.41	4.31
MAY	21.16	14.70	10.87
JUN	100.31	138.85	86.85
JUL	147.71	204.21	184.49
AUG	133.62	132.20	130.20
SEP	108.90	91.34	94.74
OCT	102.61	85.24	90.15
NOV	65.03	48.03	53.38
DEC	33.41	16.76	13.16

APPENDIX IV

Monthly discharge of observed data (m^3/s) at Pulamanthole station for the period 1991-2013

	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
JAN	4.24	4.57	6.19	5.73	5.51	3.62	5.68	7.86	6.11	3.93	4.82	6.18
FEB	0.86	1.54	4.09	2.56	2.43	2.22	3.16	3.34	4.64	2.27	3.69	2.77
MAR	0.70	0.42	2.99	1.39	1.74	1.29	2.12	1.81	2.20	1.05	1.52	2.76
APR	1.56	1.70	2.09	7.66	2.37	6.90	3.02	1.80	2.75	3.35	9.26	3.83
MAY	0.79	4.15	7.89	3.95	14.83	4.49	2.91	5.24	22.37	2.37	6.89	10.96
JUN	99.45	106.96	55.37	108.62	49.45	64.30	18.10	62.48	153.73	64.39	129.77	58.61
JUL	251.56	283.32	148.80	332.27	181.70	133.26	276.65	188.57	191.43	72.81	135.25	39.57
AUG	143.93	226.66	137.09	114.55	138.15	100.60	177.67	180.91	131.93	120.90	90.88	108.29
SEP	35.70	119.58	42.90	80.86	134.15	116.30	88.39	144.05	22.50	78.12	47.92	18.49
OCT	71.12	91.31	114.37	118.95	50.29	128.31	55.22	130.91	152.09	99.77	80.36	102.80
NOV	57.25	65.70	34.11	75.46	70.76	31.86	91.96	67.18	34.50	18.02	90.12	36.01
DEC	12.89	15.12	11.65	11.49	11.05	15.41	27.40	17.20	14.04	15.26	14.38	8.79

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
JAN	3.09	2.49	2.36	4.70	4.50	3.46	2.18	4.10	8.01	4.79	3.14
FEB	3.19	0.93	2.06	1.85	3.51	2.99	0.00	2.41	3.42	2.96	1.04
MAR	5.56	0.77	0.58	2.88	3.31	12.46	0.74	2.71	3.08	1.72	1.27
APR	4.35	1.86	10.44	4.59	3.87	5.14	0.00	5.07	12.52	6.57	0.59
MAY	4.63	38.80	4.40	52.28	7.01	3.59	2.92	5.84	5.40	4.43	1.69
JUN	34.62	133.85	68.69	123.75	101.99	52.14	18.79	82.61	183.97	36.55	160.85
JUL	69.17	90.02	257.03	163.19	393.43	92.16	286.40	160.56	145.21	64.97	254.16
AUG	54.00	143.81	122.96	127.32	187.87	99.58	84.23	131.82	159.30	96.77	133.08
SEP	22.24	51.52	133.74	182.39	189.16	95.92	120.55	99.52	187.94	79.12	134.13
OCT	46.89	70.89	80.12	117.58	102.85	92.94	78.60	134.58	72.87	33.16	62.63
NOV	14.25	27.93	51.46	77.24	43.09	26.69	60.06	156.86	67.51	18.21	23.52
DEC	6.66	8.77	22.02	11.57	8.18	7.83	11.91	24.82	12.68	6.19	10.52

APPENDIX V

Monthly simulated discharge (m^3/s) at Pulamanthole station for the period 1991-2013 before calibration (Using Obs. Meteorological data)

	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
JAN	10.53	7.12	12.45	4.05	6.35	5.15	4.07	14.31	7.57	1.20	4.30	5.38
FEB	0.94	1.26	4.53	0.81	0.97	0.63	0.63	2.45	0.96	0.42	4.83	0.83
MAR	0.36	0.46	1.35	0.58	0.55	3.52	0.21	0.62	0.52	0.20	0.28	0.28
APR	5.22	1.07	0.47	21.21	1.67	2.47	0.19	0.86	0.81	0.92	10.49	1.01
MAY	6.43	2.12	7.42	4.38	10.24	3.30	1.37	6.17	66.25	0.65	9.72	21.96
JUN	205.60	175.80	170.90	189.40	125.60	63.02	107.50	143.20	221.30	101.50	197.20	90.90
JUL	295.20	219.80	194.40	296.60	238.70	131.40	334.90	162.80	213.90	103.30	146.50	92.41
AUG	189.50	145.90	114.30	162.10	130.70	75.01	151.70	133.00	87.75	136.10	79.41	128.20
SEP	92.65	104.50	53.61	107.70	108.30	110.50	96.46	132.40	48.32	60.29	71.34	46.08
OCT	139.80	121.10	83.03	131.70	62.73	105.70	75.94	114.90	58.31	65.88	71.13	102.20
NOV	43.78	87.86	42.80	53.54	74.96	41.57	87.62	51.58	24.95	35.64	51.68	40.44
DEC	24.62	30.64	19.00	23.69	20.53	19.38	38.70	27.16	10.74	21.81	20.01	16.39

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
JAN	2.55	2.85	2.04	6.36	8.64	8.65	1.89	7.50	17.59	7.49	2.36
FEB	8.95	0.39	7.29	0.75	1.16	3.93	0.32	0.86	6.93	0.80	8.97
MAR	3.66	0.16	0.26	1.36	0.50	4.48	1.08	0.30	1.25	0.34	2.97
APR	12.68	2.34	18.51	0.38	1.21	0.78	1.24	6.73	1.49	2.95	1.21
MAY	2.15	59.50	6.77	67.79	8.69	1.85	5.26	17.47	0.56	1.63	0.80
JUN	105.20	182.70	123.30	192.80	177.60	91.42	36.40	139.10	79.00	75.46	218.00
JUL	86.71	102.80	207.30	109.60	409.70	77.05	297.80	184.00	60.10	70.59	255.50
AUG	74.04	180.60	121.30	152.00	167.90	59.20	72.96	112.00	113.20	131.10	131.50
SEP	58.76	57.81	162.40	164.80	198.10	91.61	82.84	92.83	92.55	87.31	93.40
OCT	91.83	97.95	54.27	120.70	118.70	104.00	62.84	143.40	59.50	89.66	95.44
NOV	34.41	30.49	49.30	65.72	54.73	27.77	101.20	67.21	82.20	35.87	32.42
DEC	17.93	11.85	47.17	28.08	28.48	14.45	22.02	40.11	23.68	14.38	16.32

APPENDIX. VI

Monthly simulated discharge (m^3/s) at Pulamanthole station for the period 1991-2013 after calibration (Using Obs. Meteorological data)

	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
JAN	8.45	5.32	8.22	3.70	5.37	4.48	3.66	10.62	4.98	1.87	4.56	4.88
FEB	1.63	1.87	4.35	1.20	1.62	1.03	1.04	3.45	1.42	0.63	4.01	1.36
MAR	0.57	0.68	1.53	0.71	0.77	2.66	0.37	1.04	0.71	0.34	0.47	0.45
APR	4.08	1.13	0.64	16.55	1.82	2.40	0.32	1.05	0.96	1.03	7.87	1.14
MAY	4.85	2.15	5.65	4.31	8.28	2.71	1.45	4.96	56.59	0.72	7.72	17.28
JUN	208.50	165.00	172.00	194.80	122.80	58.73	98.85	135.20	236.60	97.05	199.90	91.35
JUL	308.10	234.50	210.60	310.90	254.90	140.30	346.70	184.20	219.40	120.00	165.00	103.30
AUG	206.70	164.30	121.70	175.80	137.90	88.78	169.40	138.70	101.10	134.30	84.06	137.80
SEP	82.06	102.20	45.96	104.10	113.10	102.10	94.18	135.10	35.12	62.73	59.06	43.03
OCT	124.10	119.80	77.79	112.00	50.41	107.90	69.15	117.10	49.45	63.15	68.40	96.26
NOV	47.74	78.63	38.34	54.80	69.46	35.81	81.38	40.61	23.86	26.85	49.09	37.37
DEC	17.20	23.51	12.83	16.42	14.25	12.26	34.07	16.00	7.80	18.89	15.43	11.04

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
JAN	2.80	2.88	2.70	6.29	6.21	5.90	2.43	5.96	10.91	5.41	2.69
FEB	6.50	0.66	5.70	1.50	1.90	3.77	0.57	1.57	6.41	1.34	6.56
MAR	3.35	0.30	0.46	1.43	0.73	3.88	1.17	0.49	1.63	0.51	2.65
APR	9.25	2.25	13.86	0.55	1.37	1.00	1.26	5.39	1.67	2.51	1.35
MAY	2.54	55.16	6.09	59.01	6.43	1.56	3.92	14.73	0.70	1.57	0.89
JUN	100.20	196.30	123.30	193.40	173.80	82.67	31.98	136.60	75.92	70.48	212.80
JUL	105.00	111.00	227.50	132.50	433.30	91.12	311.20	200.60	73.35	85.90	280.50
AUG	80.32	186.90	131.60	161.20	175.90	70.23	86.03	124.70	122.00	132.80	143.90
SEP	56.60	46.96	156.20	157.80	193.20	90.24	79.03	87.87	93.56	97.17	80.90
OCT	86.14	91.35	46.31	117.70	115.00	94.05	56.69	138.20	47.07	79.65	83.73
NOV	31.69	26.40	41.90	61.75	49.50	27.35	94.11	68.06	82.23	28.84	28.99
DEC	11.06	8.17	40.89	18.75	17.98	9.27	18.16	31.38	17.07	8.81	10.32

APPENDIX.VII

Monthly simulated discharge (m^3/s) at Pulamanthole station for the period 2014-2016 for validation (Using Observed Meteorological data)

Month	Monthly Simulated Discharge (m^3/s)		
	2014	2015	2016
JAN	0.00	7.37	9.97
FEB	0.00	2.07	3.58
MAR	0.00	0.73	0.99
APR	2.14	3.52	0.45
MAY	12.89	14.89	8.91
JUN	108.70	77.26	79.79
JUL	208.10	133.30	120.70
AUG	271.90	81.23	46.56
SEP	133.80	59.53	22.40
OCT	119.20	98.88	14.93
NOV	65.50	69.20	4.81
DEC	23.13	31.68	2.13

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ABSTRACT

Land and water are the primary natural resources which are useful for all the living beings on earth surface. Degradation of the land surface and lack of water availability are the two major important problems mankind is facing in this century. In order to overcome these problems, there is a need of effective management of these resources. Watershed models are the tools which are not only useful for the effective management of these natural resources, but also useful for the proper understanding of the hydrological behaviour of the watershed. These models play a vital role in simulating the hydrology of the watershed. Among the different categories of the model, a physically based, semi distributed hydrologic model SWAT was used for the study. The Kunthipuzha river basin was selected as a study area for the assessment of the calibration and validation of the hydrologic model SWAT adapted to the study area.

The data scarcity is one of the major problems in the ungauged watersheds. In order to overcome this problem, CFSR (Climate Forecast System Reanalysis) data which is a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system is available as an alternative option for solving the data deficiency in the watershed. The land use change also plays a vital role in altering the hydrologic system and has a large impact on the stream flow. This is mainly due to the rapid socio economic development. So, based on the above mentioned problems, SWAT output comparison using CFSR & observed meteorological data as inputs was taken up. The impact of land use change on the hydrology of watershed was also studied.

The platform used for the study was ArcGIS 10.3 with the Arc SWAT interface. The SWAT model set up was done for the Kunthipuzha river basin and the calibration and validation of the model was also done to make the model suitable for use in the area. This model was later used to understand the hydrologic behaviour of the watershed. The model was simulated for the period 1991 to 2013 for calibration and validation of the model was done using the data for the period 2014 to 2016. Before the model calibration and validation, sensitive parameters were evaluated using SWAT CUP (Calibration and

Uncertainty Program). CN2 (Initial SCS runoff curve number for moisture condition II) and ALPHA_BF (Base flow alpha factor) were found to be the most sensitive parameters for the study area. The NSE and R^2 before and after calibration were 0.81 & 0.83 and 0.82 & 0.85 respectively. The NSE and R^2 for the validation were 0.70 & 0.87 respectively. Based on the statistical measures and the criteria used, the model performance is “very good” in the calibration period and “good” in validation period.

To analyse the possibility of using CFSR data instead on observed meteorological data, the developed model was run with observed meteorological data and predicted meteorological data (CFSR) was done separately without changing any other inputs for the period 1991 to 2013. The NSE, R^2 and RMSE for the observed meteorological data were 0.82, 0.85 and 29.25 respectively, where as for the predicted meteorological data (CFSR) the values were 0.70, 0.72 and 37.18 respectively. Based on the statistical measures, the performance of the observed meteorological data is better than the predicted meteorological data. From the graphical analysis, it was clear that the values of predicted meteorological data were highly correlated with the observed meteorological data except at peaks. Hence, CFSR data can be used as a reliable data source in data scarce areas.

The land use change impact play a major role in alternating the stream flow because of the rapid socio-economic development. The land use map for the year 2000 and 2017 were prepared. While comparing the land use for the year 2000 and 2017, it is found that the urban areas drastically increased from 3.01 to 20.01% because of the rapid socio economic development. The forest land reduced from 22.24 to 21.31%. The percentage area under paddy decreased from 17.57 to 6.12%. The model was simulated for the period from 1989 to 2016 with the two years of warm up period. Then the comparison of simulated discharge for the year 2000 and 2016 were evaluated. The results showed that there is no significant change in stream flow when the land use alone is changed keeping all other factors same.