WATER CONSERVATION MEASURES AND CROPPING PATTERN FOR A WATERSHED USING GEOSPATIAL TECHNIQUES AND SWAT MODELLING

By

PANCHAMY BALAN

(2018-18-003)

Department of Irrigation and Drainage Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR, MALAPPURAM-679573

KERALA, INDIA

2020

WATER CONSERVATION MEASURES AND CROPPING PATTERN FOR A WATERSHED USING GEOSPATIAL TECHNIQUES AND SWAT MODELLING

By

PANCHAMY BALAN

(2018-18-003)

THESIS

Submitted in partial fulfilment of the requirements for the degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Soil and Water Engineering)

Faculty of Agricultural Engineering &Technology

Kerala Agricultural University

Department of Irrigation and Drainage Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR, MALAPPURAM-679573

KERALA, INDIA

2020

DECLARATION

I, hereby declare that this thesis entitled **"WATER CONSERVATION MEASURES AND CROPPING PATTERN FOR A WATERSHED USING GEOSPATIAL TECHNIQUES AND SWAT MODELLING"** 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**.**

Panchamy Balan

(2018-18-003)

Tavanur

Date:

CERTIFICATE

Certified that this thesis entitled **"WATER CONSERVATION MEASURES AND CROPPING PATTERN FOR A WATERSHED USING GEOSPATIAL TECHNIQUES AND SWAT MODELLING"** is a record of research work done independently by **Ms. Panchamy Balan (2018-18-003)** 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 her.

Dr. Asha Joseph
Professor
(Major Advisor, Advisory Committee)
Department of Irrigation and Drainage Engineering
Kelappaji College of Agricultural Engineering & Technology, Tavanur
Malappuram- 679573

Tavanur

Date:

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Panchamy Balan (2018-18-003), a candidate for the degree of **Master of Technology in Agricultural Engineering** with major in Soil and Water Engineering, agree that the thesis entitled "**WATER CONSERVATION MEASURES AND CROPPING PATTERN FOR A WATERSHED USING GEOSPATIAL TECHNIQUES AND SWAT MODELLING"** may be submitted by Ms. Panchamy Balan (2018-18-003), in partial fulfilment of the requirement for the degree.

Dr. Asha Joseph
(Chairman, Advisory Committee)
Professor
Dept. of IDE
KCAET, Tavanur

Dr. Sasikala D.
(Member, Advisory Committee)
Professor & Head
Dept. of IDE
KCAET, Tavanur

Dr. Anu Varughese
(Member, Advisory Committee)
Assistant Professor
Dept. of IDE
KCAET, Tavanur

Dr. Mini Abrahim
(Member, Advisory Committee)
Professor, Agronomy
ARS, Chalakudy

EXTERNAL EXAMINER

ACKNOWLEDGEMENT

Completion of my work was not possible without the help and support from many people throughout this venture. I take this opportunity to express my sincere gratitude to everyone who has supported me with their kind effort and perseverance.

I would firstly like to bow my head before **The Almighty** for the loving and blissful showers throughout journey of this venture. I also express my deep sense of gratitude to Kerala Agricultural University for financial and technical support for this research work.

My heartfelt gratitude to my guide **Dr. Asha Joseph**, Professor, Department of IDE, KCAET, Tavanur for the constructive criticism, constant help, support and guidance provided for my entire work. Her timely interventions, knowledge, confidence and blessings were the main source and cause for the timely and successful completion of this entire work.

I am extremely indebted to **Dr. Sathian KK,** Dean (Agrl.Engg), Kelappaji College of Agricultural Engineering and Technology, Tavanur for all the support offered during the course of my research work. The data acquisition was made possible by his timely intervention. I also indebted to him, for providing me all facilities to work in the Geospatial laboratory of the college.

I avail this opportunity to express my sincere thanks to my advisory committee members, **Dr.Sasikala, D.,** Professor and Head, Department of Irrigation and Drainage Engineering, KCAET, Tavanur, **Dr.Anu Varughese**, Assistant Professor, Department of Irrigation and Drainage Engineering, K.C.A.E.T, Tavanur and **Dr. Mini Abrahim,** Professor, Agronomy, ARS Chalakudy, for their valuable suggestions, encouragement and motivation throughout this study. I am also thankful to **Dr. Rema K.P.** Professor, Department of Irrigation and Drainage Engineering, K.C.A.E.T, Tavanur for her sincere support during my study.

I wish to record my sincere thanks to **Dr. Anitha, B**., Executive Director, Centre for Water Resources Development and Management (CWRDM), Kunnamangalam, Kozhikode for giving all technical helps during my training period there. The valuable knowledge from the reputed scientists **Dr. Celine George, Dr. Drissia T.K., Dr. Girish Gopinath, Anas sir and Denji sir** have also aided in my work in a major way. I am really thankful to **Smt. Renu. P.D,** Soil Survey Dept. Trivandrum and **Shri. Sasilal M.** Kerala State Landuse Board Thrissur for providing me necessary data required for my work.

I take this opportunity to thank **Er. Rohith John and Er. Anjana S.R** who have shown interest to clarify the doubts in ArcGIS and given timely helps to move forward during my research work very confidently. I greatly appreciate and thank them for their most sincere and lovable approach towards me.

With immense pleasure, I express my heartfelt thanks to my batch mates **Er. Riyola**, **Er. Smegha, Er. Fousiya,** and **Er**. **Nchumbeni** for the great support and encouragement provided throughout my study. I whole heartedly thank my respected seniors **Er. Mamatha, Er. Pasha** and **Er. Namitha** for their timely supports and helps during my research. I am also thankful to my friends **Adarsh, Oormila and Anees** for providing me the valuable information about agronomic aspects required for my study. I am thankful to my senior **Er. Kari Venkata Sai** and my friend **Er. Harisankar O.P** for their timely support and helps during the research.

I engrave my deep sense of gratitude to **Shri L.P. Chither sir** and **Shri P.C. Balagopal sir** for their immense motivation and support for the timely completion of my work.

I have no words to express my gratitude and love to my dearest parents **M.S. Balan Nair** and **Jyothilakshmi** and sister **Pavithra** who constantly supported me throughout this venture. I can't count the immense blessings, encouragement, sacrifices, prayers, patience, help, inspirations, motivations and love they have showered on me which were the major source of power for me to complete this venture.

Once again I am expressing my heartfelt thanks to each and everyone those who helped me in one way or the other in carrying out this endeavour.

Panchamy Balan

Dedicated to

Agricultural

Engineers

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATE

SYMBOLS AND ABBREVIATIONS

%	:	Percentage
<	:	Less than
>	:	Greater than
∑	:	Sum
≤	:	Less than or equal to
≥	:	Greater than or equal to
&	:	And
°C	:	Degree Celsius
AEU	:	Agro Ecological Unit
ASCII	:	American Standard Code for Information Interchange
CN	:	Curve Number
DEM	:	Digital Elevation Model
ERDAS	:	Earth Resources Data Analysis System
ET	:	Evapotranspiration
ET_C	:	Crop evapotranspiration
ET_0	:	Reference crop evapotranspiration
et al.	:	and others
FAO	:	Food and Agriculture Organization
Fig.	:	Figure
GIS	:	Geographical Information System
h	:	hour
ha	:	Hectare
HRU	:	Hydrologic Response Unit
HSG	:	Hydrologic Soil Group
Int.	:	International
IR	:	Irrigation Requirement

J.	:	Journal
KAU	:	Kerala Agriculture University
km^2	:	Square kilometre
K_C	:	Crop coefficient
Landsat	:	Land Satellite
LU/LC	:	Landuse/Landcover
m	:	meter
mm	:	millimeter
Mm^3	:	Million meter cubic
MCM	:	Million cubic meter
MSL	:	Mean sea level
N	:	North
NASA	:	National Aeronautics and Space Administration
No.	:	Number
NSE	:	Nash Sutcliffe Efficiency
Nurs/LPr	:	Nursery/land prepatration
PBIAS	:	Percentage Bias
Proc.	:	Proceedings
R^2	:	Coefficient of Correlation
RCP	:	Representative Concentration Pathways
RMSE	:	Root Mean Square Error
RS	:	Remote Sensing
s	:	second
Sci.	:	Science
SCS	:	Soil Conservation Service
SD	:	Standard Deviation
SI units	:	International System of units
Soc.	:	Society

SOI	:	Survey of India
SPAW	:	Soil Plant Atmosphere Water
SRTM	:	Shuttle Radar Topography Mission
SUFI-2	:	Sequential Uncertainty Fitting - 2
SWAT	:	Soil and Water Assessment Tool
SWAT-CUP	:	SWAT Calibration and Uncertainty Procedures
USGS	:	United States Geological Survey
UTM	:	Universal Transverse Mercator
viz.	:	Namely
WGS	:	World Geodetic System

INTRODUCTION

CHAPTER I

INTRODUCTION

Water is considered as one of the most important and precious natural resource for sustaining life on earth. It is an essential component for meeting daily requirements of humans, livestock, industries, agricultural purposes etc. Since 1980s global water use has increased by one per cent per annum. This is due to the enormous population growth, developmental activities and changes in the consumption patterns. Global water demand is expected to continue increasing at similar rate until 2050. Increasing demand in the domestic and industrial sectors cause tremendous increase in global water demand and it accounts about 20-30 % increase than current water use level by 2050 (UNWWDR-2019).

In contrast to increasing demand of water, the availability of water is decreasing day by day. Though there is no change in the quantum of water available in hydrological cycle, the amount of fresh or good quality water, which is capable of meeting the various requirements, is decreasing. That is, on a global scale, it is abundant in quantity, but spatial and temporal availability of fresh water is still a problem. According to various reports in India, one billion people live in areas of physical water scarcity, of which 600 millions are in areas of high to extreme water stress. It was predicted that by 2040, thirty three countries are likely to face extremely high water stress (15 countries in Middle East, Spain, Afganisthan, Pakisthan, Turkey, most of North African countries) and high water stress (India, China, USA, Australia, South Africa).

In order to meet the agricultural and industrial demand and thereby creating income and wealth in rural areas there is a paramount importance to water, hence every drop of water must be conserved which contributes to the sustainability of resources and environment. The water can be conserved effectively by adopting various water conservation measures on watershed basis. It is because watershed is considered as the natural boundary for doing all developmental and conservation activities. Various kinds of water conservation measures can be provided based on different prevailing criteria of watershed. In-situ conservation, engineering practices, agronomical measures, groundwater recharging etc. can be done for watershed management. Hence availability of enough quantity of water with an effective cropping system will definitely improve the income of people and thereby elevates their living standards.

Water availability is an exigent factor for deciding water resource conservation. Hydrological studies in basins are important because they help to understand the processes that control the water movement and the likely impacts on water quantity and quality. In this sense, the quantitative understanding of hydrological parameters and its spatial and temporal variability in regions or river basins are essential for efficient planning and management of water resources (Arai *et al*., 2012). Estimation of water balance components is a significant tool to determine the current status and trends in the availability of water resources in the area under consideration. But the direct measurements of water balance components are not always feasible. Various researches showed that geospatial techniques backed by hydrological modelling can be effectively utilised for assessing water balance components. Modelling of different components of watershed management can be done efficiently with geospatial techniques.

In this study the water balance components were estimated by using the distributed hydrological model, SWAT (Soil & Water Assessment Tool). Spatial analysis capability of GIS was used to make improved watershed modelling in this study. Single watershed or system of multiple hydrologically connected watersheds can be simulated by using SWAT model. Based on land, soil and slope conditions watershed can be divided into sub basins and hydrologic response units. Dynamics between different components like runoff, percolation, ET, lateral flow, base flow etc. were solved by the model. SWAT model have high flexibility to combine the upland and channel processes. Hence this model was effectively utilized in this study for estimating the water balance components and there by the availability of water in the watershed.

Water demand in a watershed includes domestic requirements, agricultural requirements, industrial requirements and livestock demand. Agricultural water demand corresponds to the total amount of water to be supplied to meet the crop irrigation requirement. Domestic water requirement includes the total amount of water needed for the human beings for carrying out their day to day activities. Also other water demands for industrial, commercial, wastage or losses and theft were also taken into account for estimating total domestic water demand in the watershed. The monthly water availability and water demand analysis were carried out to find the water status of the watershed.

Surface runoff is a major component of the hydrological cycle and it is a prime source to satisfy the needs of human being. Hence managing this component is very important and it is possible through the conservation of soil and water on a watershed scale. Available water can be stored to solve the water scarcity problem by constructing water conservation measures like check dam, percolation pond, farm pond, contour bunding and contour trenching. The locations of these measures are usually done by practical field experience. But they may not be installed at proper location and more over such works may be tedious and time consuming. In order to speed up such activity and to find an optimized location, remote sensing integrated with GIS can be used effectively. It is through the units called 'layers' the space-time information can be managed in GIS. In traditional maps a wide varieties of information are bounded in a single sheet. But in GIS techniques each theme of map can be represented in different layers. These maps can be combined or overlaid after assigning weightages to each map and ranks to each parameter in a GIS environment and get the locations of water conservation measures. Based on water availability suitable cropping pattern can be adopted in the watersheds. It aids increased cultivation of various crops and thereby satisfies the needs of watershed.

Hence reliable and timely information on the available natural resources is very much essential to formulate a comprehensive land use plan for sustainable development. The land, water, minerals and biomass resources are currently under tremendous pressure in the context of highly competing and often conflicting demands of an ever expanding population. Consequently over exploitation and mismanagement of resources are exerting detrimental impact on environment. Therefore each watershed management program must be based on the objective of optimum utilisation of natural resources integrated with development of the area which enhances the standard of the people living in the area. Hence this study entitled "Water conservation measures and cropping pattern for a watershed using geospatial techniques and SWAT modelling" was taken up with the following specific objectives.

1. To estimate the water balance components of a watershed using SWAT model.
2. To assess the total water demand of the area.
3. To plan suitable water conservation measures and cropping pattern in the study area.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

An attempt has been made in this chapter to review the various research conducted in the relevant fields with respect to the objectives of the study. The reviews are grouped under the following subheads

1. Use of geospatial techniques and hydrological modelling in watershed management
2. Calibration and validation of SWAT model and estimation of water balance components
3. Estimation of water demand
4. Analysis of water availability and water demand in a watershed
5. Planning of conservation measures and cropping pattern in a watershed

2.1 USE OF GEOSPATIAL TECHNIQUES AND HYDROLOGICAL MODELLING IN WATERSHED MANAGEMENT

He (2003) stated that hydrologic models often need to be combined with GIS or remote sensing technologies to develop input parameters and to analyze and visualize simulation results.

Jha *et al.* (2007) described that Geoinformatics technology can be considered as one of the prominent tool for assessment, monitoring and management of natural resources. Spatial, temporal and spectral availability of data coverage of large and inaccessible areas within a very short time period are the main advantage of GIS and remote sensing

Chowdary *et al*. (2009) remarked that planning for watershed management can be done effectively by using Geographical Information System (GIS) because it helps for the integration and analysis of spatial, multi-layered information obtained in a wide variety of formats both from remote sensing and other conventional sources. Data obtained from Remote sensing satellites along with other field and collateral data on lithology, soil, slope, well inventory etc. have been used for generating land use/land cover and hydro geomorphology of the study area, which are the essential prerequisites for water resources planning and development.

Brooks *et al.* (2013) described that hydrologic models simulate the dynamic behavior of flow and storage processes and generate water balance information (quantity and associated hydraulic characteristics, source and pathway, residence time, etc.) for past, present, and future streamflow regimes

Lee *et al*. (2013) revealed that watershed simulation modelling, or hydrologic simulation, is a useful tool to achieve optimal management strategies that balance several benefits of land and water resources in a watershed. This is done through the analysis of watershed processes and their interactions and the development and assessment of management scenarios that simultaneously consider upstream soil conservation, midstream land use, and downstream reservoir level sediment control

Geospatial techniques were proved to be a best decision making tool for the optimum utilization of natural resources and devising suitable systems for judicious use and management practices of resources. Narmada *et al.* (2015) mentioned that generation and integration of various layers like slope, land use land cover, geomorphology, relief etc. can be done in most accurate way which can be further used for making proper action plan for optimum resource utilization.

The scope of GIS technology in processing, analysis, management and presentation of digital data makes this technology more popular. Pantoja *et al*. (2015) reported that spatial processing of data in GIS is needed for the analysis and modelling of water resource systems. Integration of modelling techniques with GIS platform has been practiced from early 21^{st} century and studies which integrate GIS and modelling are increasingly popular in recent days.

2.2 CALIBRATION AND VALIDATION OF SWAT MODEL AND ESTIMATION OF WATER BALANCE COMPONENTS

Shawul *et al*. (2013) studied about calibration and validation of SWAT model and estimation of water balance components of Shaya mountainous watershed, South Eastern Ethiopia. SWAT 2005 with ArcGIS interface was used for determining the effect of spatial variability of the watershed on streamflow. Model applicability and performance were evaluated by sensitivity analysis, model calibration and validation and water balance components were estimated. Subsurface flow parameters were found to be more sensitive and there by implied groundwater availability. SWAT model was found to produce a reliable estimate of monthly runoff for Shaya watershed.

An attempt was made by George and Sathian (2016) to assess the water balance components of Kurumali basin in Thrissur district with the help of SWAT model. SRTM DEM was used for watershed delineation. Land use map, soil map and slope map were the inputs used for modelling. Sensitivity analysis was done with ten selected parameters. Alpha Bf (Baseflow alpha factor) was found to be the most sensitive factor and least sensitive parameter was GwRevap (Revap coefficient). Calibration and validation of the model was found statistically good. The water balance components obtained from the model was used for efficient water resource management.

Yin *et al.* (2016) assessed variation in water balance components in mountainous Inland river basin by using SWAT model. Nash-Sutcliffe efficiency (NSE) and determination coefficient (R^2) were over 0.90 for the calibration and validation periods. The water balance components presented rising trends at the watershed scale, and the total runoff increased by 30.5% during 1964 to 2013 period. Hence they concluded that proper watershed management is needed for this watershed which will be properly addressed with the help of SWAT model.

Anoh *et al.* (2017) conducted a study on modelling freshwater availability using SWAT model at a catchment-scale in Ivory Coast to determine the different fresh water resources. Fresh water of the basin was simulated for 12 years which includes warm-up period, calibration period and validation period. SUFI-2 algorithm was used for optimization of parameters. The number of sensitivity parameters, stop iterations criteria, and objective functions were eight, two and two respectively. Model gave good results during calibration but, not well represented during validation period. Blue water was found less than the green water in the study area. Surface water near to the stream was used as the drinking water in the basin.

Bhatu and Rank (2017) estimated the water balance component in Rangmati river basin using SWAT model. The average of mean seasonal and annual water balance component showed that seasonal rainfall, seasonal runoff and seasonal groundwater recharge were found increasing at 75.65 mm/decade, 47.32 mm/decade and 10.91 mm/decade while seasonal potential evapotranspiration and annual potential evapotranspiration was found decreasing at 4.76 mm/decade and 2.71 mm/decade respectively.

Byakode *et al.* (2017) conducted a study on application of SWAT model for generating surface runoff and estimation of water availability for Balehonnuru catchment area for Badhra river basin by SWAT modelling. Water balance components were simulated by using the model. Study also focused on assessing the effect of climatic variations on water availability in the watershed. LU/LC, soil map, slope map and meteorological data were used as input parameters to the model. Model calibration and validation were done successfully. Water availability estimation was done by downscaling the obtained GCM (Global Circulation Model) values by appling appropriate multiplying factor. Future prediction of water availability was also done in their work.

Poojari *et al.* (2017) carried out a comparison of runoff estimation using ArcSWAT and conventional method for different catchment scales of Ghataprabha sub-basin using empirical models and SWAT model. Water balance components and thereby surface runoff were calculated for the catchments. Inglis and Lacey's method were the two empirical models used for assessing the runoff. The results showed that there was significant influence of catchment size and land use on the surface runoff generated. All the models gave comparable results and they concluded that, empirical methods can also be used effectively for runoff estimation in case of limited data availability.

Suryavanshi *et al.* (2017) conducted a research on hydrological simulation of the Betwa river basin (India) using the SWAT model. A seasonal water budget analysis was carried out to quantify various components of the hydrological cycle. Satisfactory model performance ratings were obtained for calibration and validation of the model. Seasonal linear trend analysis of water balance components was done and it resulted in an increasing trend in rainfall and a decreasing trend in ET during monsoon season. They claimed that, this resulted in an increasing trend in groundwater storage and surface runoff. A decreasing trend was observed in summer season rainfall. The study evokes the need for conservation structures in the study area to reduce monsoon runoff and conserve it for basin requirements in water-scarce seasons.

Ayivi and Jha (2018) assessed water balance of Reedy Fork-Buffalo Creek Watershed in North Carolina using SWAT model. The result showed good agreement between the observed and simulated flow. Both NSE and R^2 were found to be greater than 0.7 for the calibration and validation period. Surface runoff, groundwater flow and evapotranspiration were estimated as 131.87 mm, 185.71 mm and 677.7 mm respectively. A scenario analysis was also performed to determine the effect of future land use change on runoff which showed 13.9% increase in the surface runoff for the year 2030. The results obtained from the model suggested that SWAT model could be a promising decision support tool to assess and predict water balance of a watershed.

Farsana *et al*. (2019) assessed water balance components of Surma river basin using SWAT Model. Spatial and temporal assessment of Surma watershed hydrology was done successfully. Calibration of model was done for the period from 2003 to 2008. Statistical model performance measures such as Percent bias value, Nash-Sutcliffe Index and R^2 value were obtained as 53.5%, 0.47, 0.780 respectively duringr calibration where as it was found 31.7 %, 0.878 and 0.74 respectively during validation. Satisfactory performance of model was obtained and hence they concluded this model can be effectively used for hydrological studies.

Tabares *et al.* (2019) evaluated water availability in sub-arid Mediterranean watersheds through SWAT model. The study assessed the water balance and agricultural water demand of Cega Eresma Adaja watershed for the period 2004-2014. Nash-Sutcliffe efficiency values of calibration and validation were found as 0.86 and 0.67 respectively. This showed good performance of the model for the study area.

Gupta *et al*. (2020) conducted a research for analyzing the water balance components for the upper Sabarmati basin by using SWAT model. The river basin was delineated to 31 sub-basins consisting of 116 hydrologic response units (HRUs). Monthly calibration (1992–1999) and validation (2000–2005) of the SWAT model were carried out using observed discharge data. Trend analysis results over the period of 1992–2005 for run-off and evapotranspiration shows an insignificant decreasing trend, along with decrease in precipitation with a magnitude of 21 mm/year. The model simulation results showed a reduction in surface run-off (323.49–232.14 mm) and potential evapotranspiration (1935.71–1875.71 mm) between years 1992 and 2005. The present study also revealed a considerable decrease in water yield (493.2–317.6 mm) for same duration.

2.3 ESTIMATION OF WATER DEMAND

Surendran *et al.* (2015) carried out a research on modelling the crop water requirement using FAO-CROPWAT and assessment of water resources for sustainable water resource management. The irrigation requirement of major crops in Palakkad district in Kerala was estimated. The gross irrigation demand of Palakkad district was found 1146 Mm^3.Water balance analysis was done for the current scenario and future agriculture, domestic and industrial demands. The projected water demand was estimated as 3841 Mm^3. But the utilisable water resources of Palakkad were less which created a deficit scenario. They suggested deficit irrigation and reduction in command area is necessary for management of water resources in future.

Shahul *et al*. (2016) conducted a study to determine irrigation requirement of salad cucumber inside a polyhouse using CROPWAT model. Four main datasets were used as the inputs to CROPWAT namely climatic, crop, soil/substrate media and rainfall. Total irrigation requirement was computed by adding irrigation requirement of each stage of the salad cucumber and the value obtained was 30.45 cm.

Bhat *et al.* (2019) studied water requirements and irrigation scheduling of maize crop using CROPWAT Model. The study focused to find an optimum irrigation schedule for increasing the crop production in water scarcity conditions. Irrigation requirement and crop water requirement of maize in the area was found 288.2 mm and 304 mm respectively. They found out that irrigation must be given at critical depletion for zero percentage yield reduction. CROPWAT model which is an irrigation management model was found successful in this study.

Ewaid *et al.* (2019) determined crop water requirements and irrigation schedules for some major crops in southern Iraq by using CROPWAT 8 model. The study results showed that ET_0 varied from 2.18 to 10.5 mm/day and the effective rainfall varied from 0.0 to 23.1 mm. The irrigation requirements were 1142, 203.2, 844.8, and 1180 mm/dec for wheat, barley, white corn, and tomatoes, respectively. They revealed that CROPWAT model can be effectively used for estimating irrigation demand and thereby facilitating proper management of resources.

Nivesh *et al.* (2019) conducted a research on irrigation water requirement modeling of major crops using CROPWAT model in Balangir district of Odisha. Modelling of crop evapotranspiration and irrigation water requirements were carried out using climatic, crop and soil data. The modeling results showed that actual irrigated area in the district was 17794 km^2 and net irrigation demand of the actual irrigated area was 0.9 BCM.

Surendran *et al.* (2019) carried out a research on FAO-CROPWAT model to find out irrigation requirements of coconut to improve the crop water productivity in Kerala. It was done based on the agro-ecological zones (AEZ). The quantity of water required per palm varied between 115 to 200 LPD per palm, which was found lower than the existing recommendations of 175 to 300 LPD per palm.

2.4 ANALYSIS OF WATER AVAILABILITY AND WATER DEMAND IN A WATERSHED

Ramachandra *et al*. (2014) carried out a research on modelling of hydrologic regime of Lakshmanatirtha watershed, Cauvery river using GIS and remote sensing techniques to estimate the water availability and water demand. Water demand was estimated by summing up the crop water requirement, domestic water requirement and livestock water requirement. The available water in the watershed was taken as the sum of different water balance components such as surface runoff, base flow and ground water storage contributing to streamflow. The results were represented spatially by creating maps of water availability (surface runoff, base flow and ground water recharge) and water demand (crop water requirement, domestic water requirement and livestock water requirement and evapotranspiration) and the final map of total demand and water deficiency map were also made. Based on the monthly supply and demand of water, the water balance in the catchment was assessed and it was found that the water availability in the watersheds to cater the demand was higher in those areas with higher forest cover and less in that areas wherein forest cover was very sparse and accompanied by variations in the rainfall.

Mirrah and Kusratmoko (2018) carried out a research to assess the water availability and demand of water in Cianten Watershed, West Java. Water availability assessment of each sub-watershed was done based on water balance equation. Spatial water availability was mapped with the help of geographical information system. Water demand was also found in this study by summing up agricultural demand, livestock demand and domestic demand. The water availability ranges from 9266 m^3 / ha to 15,991 m^3 / ha during wet season, while the dry season values ranges from 2285 m^3/ha to 4147 m^3 / ha. While comparing the water availability and water demands it was found that, during the dry season most of sub-watersheds in the study area experienced a high to low water deficit.

A research was conducted by Abrahim and Mathew (2018) to assess surface water availability of Tank watershed using hydrologic modelling. Surface runoff estimation was done by USDA-NRCS model to find water availability. Water demand was taken as the sum of domestic water demand and irrigation water demand. The volume of water accessible for fifty percent dependable flow of the year was obtained as 2.46 MCM and 50% of it was effectively harnessed as water available (1.23 MCM) in the watershed. The water demand of the area was estimated as 0.148 MCM for domestic purpose and 0.171 MCM for irrigation purpose, which was much lower than the available runoff that can be harnessed from the watershed. Thus there was a scope to harvest 1.23 MCM of water which was more than the demand of the watershed. Hence the study revealed that it is feasible to harvest and manage water effectively if its availability and demand are computed accurately.

Ganiyu *et al.* (2019) assessed water resources availability and demand in Malete watershed, North Central Nigeria using SWAT model. The water availability was estimated as the product of water yield obtained from SWAT model and area of the watershed. They calculated water demand as the water demand of population in the watershed. Water availability and demand obtained was projected for the future year 2048 and the future water demand was estimated as 3.05×10^4 m^3 /day while the available water resources were 1.89×10^5 m^3 /day. The result indicated that the water availability in the watershed was not sufficient to cater for the projected water demand.

2.5 PLANNING CONSERVATION MEASURES AND CROPPING PATTERN IN A WATERSHED

Singh *et al*. (2009) proposed suitable location for water harvesting structures in Soankand watershed. Different thematic maps such as soil, land use, drainage and contour were generated in ArcGIS workspace for making site suitability map. Check dams, farm ponds, water harvesting structures, percolation tanks and nala bunds were proposed as per

IMSD guidelines. Detailed water balance study of the area was done by using TM model for proper management and best utilization of water harvesting structures proposed in the watershed.

Mangrule and Kahalekar (2013) worked on watershed planning by using RS and GIS of Khultabad Taluka of Aurangabad District. The main purpose of their work was to make an integrated watershed development plan by proposing water harvesting and soil conservation measures in the sub-watershed. The themes used were hydro geomorphology layer, land use/land cover layer, soil layer, slope classes and stream order raster. All thematic layers were converted into raster format for assigning different weightages. Calculation of these themes was done by raster calculator with assigned weightages. Formula used was: [{Hydrogeomorphology*0.2} + {Land Use/Land cover*0.2} + {Soils*0.1} + {Slope*0.2} + {Drainage*0.3}]. Location priority raster was made by evaluating the above said formula and conservation measures such as check dams, contour trenches and gully plug were suggested for the watershed.

Abineh and Teferie (2015) conducted a research on GIS based slope analysis for recommending soil and water conservation techniques in Sekela District, Ethiopia. The conservation measures suggested were bunds, FanyaJuu (embankment along the contour made of soil and/or stones), runoff diversion and hillside terracing. Bunds were provided in the areas having slope less than 30 %. FanyaJuu was suggested in the areas having slope between 5-50%. Slight slopes of 1-8 % were recommended for runoff diversions and hillslopes greater than 30 % was suggested for hillside terracing.

Kolekar *et al.* (2017) carried out a research on, site selection of water conservation measures by using RS and GIS in Warvadi village, Maharastra to improve water resource availability. SCS-CN method was used in this study to locate water conservation measures in appropriate sites. Land use map from satellite data, hydrological soil group classification from soil map, slope map from DEM were made. From land use map and rainfall data SCS-CN map was made. SCS-CN map and slope map was overlaid to get runoff coefficient map. SCS-CN map and runoff coefficient map helped to site the potential water harvesting locations. Drainage network map was also made and all these thematic layers combined together for proposing different water conservation measures like farm pond, percolation pond, check dams, bunds and trenches

Kumar *et al.* (2017) conducted a site suitability analysis for water storage structures using remote sensing & GIS for a small watershed of Lormi block in Mungeli District, Chhattisgarh state. Various maps such as land use map, soil map (hydrologic soil group), slope map, lineament map and drainage map were prepared. With the help of ArcGIS interface, weighted overlay analysis was done using spatial analyst tool by giving percentage of influence and weightage to each layer. IMSD guidelines are applied to the resultant map generated through weighted overlay analysis and thereby site suitability map of water harvesting or storage structures were generated. There were about 93 numbers of sites identified, which were highly suitable for creating water storage structures.

Patode *et al.* (2017) conducted a study in the Patur Taluka at Akola district in Maharashtra on planning of conservation measures for watershed management and development by using geospatial technology. The LU/LC map, geological map, geomorphologic map and slope map were made and integrated with the help of geospatial techniques to propose conservation measures in the study area. From the final output of these study different conservation measures/structures like recharge wells, farm ponds, CNB (Cement Nala Bandh), gully plug, CCT (Continuous Contour Trench) and other soil and water conservation structures have been suggested for groundwater recharge, environmental management and soil erosion control for the watershed.

Regulwar and Ambore (2017) conducted a study at GP IV watershed of Aurangabad district in Maharashtra. They carried out water balance of the watershed using TM model and also located suitable sites for check dams and soil conservation structures. Runoff and total runoff volume were calculated using the model. Based on land capability map and slope parameter, soil conservation measures were suggested. Thematic maps of land use/ land cover, soil, slope and were overlaid together to identify the location for conservation measures. The selection of type of structure was done based on IMSD guidelines. 15 check dams were proposed for the watershed at different sites.

Krishna *et al.* (2018) conducted a study on planning of soil and water conservation measures in a micro-watershed at College of Agricultural Engineering (CAE) Campus Madakasira. QGIS software was used for spatial data analysis. Delineation of watershed was done with the help of google earth map. Land use was plotted using GPS and slope of the area was measured using Abneys level. Longitudinal section and cross-section of streams was made using dumpy level and staff in order to provide drainage line treatments. Contour map was generated using Surfer software. Land use map, slope map and proposed engineering structure maps were generated in QGIS workspace. Farm ponds and check dams were proposed based on the overlay analysis of these layers.

Ahamad and Goparaju (2019) conducted a research on seasonal (Kharif, Rabi and Zaid) long term (1970-2000) monthly climatic parameters such as precipitation, potential evapotranspiration, aridity index with respect to various agro ecological zones of India. The analysis of long term mean precipitation during Kharif, Rabi and Zaid season was found to be in the range of 14-7463, 0-914 and 0-1722 mm respectively. The analyses of the long term mean potential evapotranspiration in all seasons was found notably high in arid/semiarid zones. The Aridity Index during Kharif, Rabi and Zaid seasons was found to be in the range of 0.19-4.27, 0.03-0.73 and 0.01-1.48 respectively. Based on the aridity index ranges, a general cropping pattern was suggested for the various agro ecological zones.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

This chapter encompasses details of study area, sources of various data used, software and tools aided to carry out the research. The description of SWAT model, its input data, model development and model performance are detailed. An overview of CROPWAT 8 model for estimation of agricultural water demand, its input data, model equations, description of outputs are explained. The estimation of non-agricultural water demand is also detailed. The different steps involved in planning of water conservation measures and cropping pattern in Manali watershed is briefly explained. The details of above said items are described under following subheads.

3.1 DESCRIPTION OF STUDY AREA

3.1.1 Location

Manali watershed in Thrissur district was selected for the study. Manali river, one of the main tributaries of Karuvannur river is located in Thrissur district which lies between 10°30’25’’-10°31’40’’N and 76°20’56’’-76°16’39’’E. Manali watershed has a drainage area of 140.94 km^2 and is confined to Kerala state only. Origin of Manali River is from Ponmudi, in the boundary of Palakkad and Thrissur district at an elevation of +524 meters. The Manali river flows westward up to Mundanchira and then southwards up to Nenmanikkara. It then turns towards the west and subsequently to the south and reach at Palakadavu and then forms the Karuvannur river. The river catchment spreads in three block panchayaths such as Ollukkara, Kodakara and Cherp. Based on climatic variability, landforms and soil, the Kerala state has been divided into 23 agro-ecological units (AEUs). The Manali watershed comes under agro-ecological unit 10 (AEU 10): North Central Laterites. This unit spreads almost 62 panchayats, three municipalities and a corporation in Thrissur and Palakkad districts. The location map of Manali river watershed shown in Fig. 3.1 and view of Manali river in different parts of watershed is shown in Plate 3.1, Plate 3.2 and Plate 3.3.

3.1.2 Climate

The climate of the watershed is tropic humid monsoon type. The temperature in the area ranges from 22°C to 35°C. The hot season is from March to May and it is followed by south-west monsoon during June to September. Post monsoon or retreating monsoon season is from October to November and rainy season ends by December. On an average there are 124 rainy days in a year (District Spatial Plan Thrissur, 2011). The humidity ranges from 56 to 86 % depending on the atmospheric conditions. The average annual rainfall of the basin is 2769 mm. The average wind velocity is 7.84 km per hour. The area receives sufficient amount of rainfall and have medium temperature.

3.1.3 Soil and Crop

As the Manali watershed is coming under AEU: -10- North Central Laterites, it shows a midland laterite terrain with longer dryer period than the southern counterpart, but less than that of northern parts. Major crops grown in Manali watershed are rice, rubber, cashew, coconut and banana. Arecanut, pepper, turmeric, coffee etc are also cultivated in some areas. The highland area is characterized by forest vegetation and plantation crops. Crops like coconut, arecanut, banana, cashew etc are cultivated in moderately sloping lands. The low lying area which is coming under Kole land premises consists of paddy cultivation.

3.1.4 Physiography and Relief

Depending on physiographic variation noticed, the watershed area comes under midland, mid-upland and lowland. The four physiographic divisions are rocky elongated ridges and hillocks on the eastern and south-eastern part of the district, the mid-undulating region characterized by narrow and broad valleys and elevated plains located in between the eastern high lands and the backwaters in the west. Elevation of Manali watershed ranged from 10 to 524 m, mean elevation was found to be 66.00 m and the standard elevation as 70.98 m.

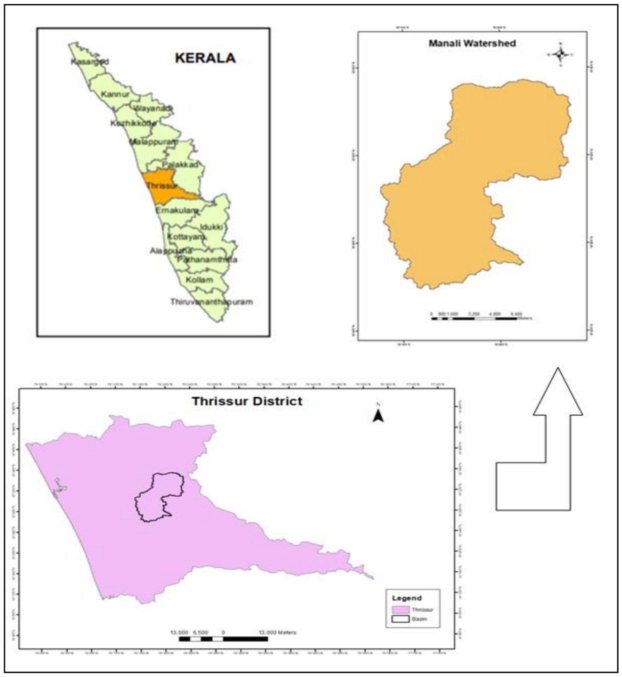

Fig. 3.1 Location map of the study area

Plate 3.1 A close view of Manali river at Paliyekkara

Plate 3.2 Manali river at Amballur, Thrissur district

Plate 3.3 Manali river at Maraickal-Aalpara bridge

3.2 DATA USED

The details of type of data, its utility and source are shown in Table 3.1.

Table 3.1 Data type, its utility and source of data

Data type	Utility of data	Source of data
Meteorological data: (rainfall, relative humidity, maximum and minimum temperature, wind speed and sunshine hours (1988-2017)	Input to SWAT model and CROPWAT model,	Kerala Agricultural University, Vellanikkara.
Hydrological data: Daily stream flow data (1997- 2017)	Calibration and validation of SWAT model	Irrigation Design and Research Board (IDRB), Thiruvanthapuram
Digital elevation model (DEM)	Input to SWAT model and planning conservation measures	NASA LPDAAC Collections data sets of USGS Earth Explorer.
Land use/land cover (LULC) map	Input to SWAT model and planning conservation measures	Kerala State Land Use Board, zonal office, Thrissur district.
Soil map	Input to SWAT model and planning conservation measures	Directorate of Soil Survey and Soil Conservation, Kerala State.
Soil and crop data	Input to CROPWAT 8 model	Package of Practices, KAU (2016), FAO website and literatures review

3.3 SOFTWARES AND TOOLS USED

3.3.1 ArcGIS 10.3

ArcGIS is proprietary commercial software which is maintained by ESRI. It is a geographical information system which aids to work with maps and geographic information. Spatial data creating, managing, sharing and analysis can be done with the help of this software. Basic, Standard, Advanced and Pro are the four-license level of ArcGIS for Desktop suite. Arc Catalog, Arc Toolbox, ArcMap etc. are some integrated applications included in ArcGIS for Desktop version. ArcMap is the significant component of ESRI's ArcGIS suite for geospatial processing programs. Table of contents and data frame are two sections of this program in which the user can explore data, symbolizes features and create maps. Information or data is spatially applied in data frame and data is aligned and symbolized in table of contents. Usual way to view the layers is from top to bottom. It can be also viewed by listing layers by source, selection and visibility. Views are of two types: data view and layout view. Final design of the map can be viewed in layout view and geographic view of the data imported by the user can be viewed in data view. ArcMap can be run using primarily shape files and geodatabases which stores larger sets of data in recent versions.

ArcGIS 10.3 released in December 2014 was used in this study. Setting up of projection for all inputs for SWAT model, processing of DEM, digitizing of soil and land use map, preparation of maps etc. was done using this workspace.

3.3.2 SPAW (Soil Plant Atmosphere Water)

Soil Plant Atmosphere Water (SPAW) is a hydrologic budget model developed by United States Department of Agriculture (USDA) - Agricultural Research Service (ARS) which calculates the characteristics properties of soil. It is used in this study to prepare soil database for SWAT model. Hydraulic conductivity, available water content and bulk density were determined based on the soil characteristics of each layer and they were fed to the model.

3.3.3 SWAT Model

SWAT model is a watershed modelling tool and can be used for a wide range of scales and environmental conditions. It is a river basin or watershed scale model developed Dr. Jeff Arnold of USDA Agricultural Research Service (ARS) in the year 1998. SWAT model includes distinctive attributes of various ARS models and outgrowth of SWRRB (Simulator for Water Resources in Rural Basin) model. Development of SWAT model is significantly contributed by specific models such as CREAMS, GLEAMS and EPIC. The model interface can also be developed in GRASS, ArcView and Windows (Visual Basics). The hydrologic modelling of Manali watershed was done by SWAT model and the monthly water balance components were estimated.

3.3.4 SWAT- CUP (SWAT Calibration and Uncertainty Procedures)

The calibration of large-scale distributed models has become difficult due to large model uncertainty, input uncertainty, and parameter non-uniqueness. SWAT-CUP is an interface developed for SWAT which makes the calibration procedure easy and provides a faster way to do the time-consuming calibration operations. It provides capabilities in the complex calibration, validation and sensitivity analysis of SWAT model. The program is written in 'C' programming language. It involves several methods such as Particle Swarm Optimization (PSO), Sequential Uncertainty Fitting (SUFI-2), Generalized Likelihood Uncertainty Estimation (GLUE), Parameter solution (Parasol) and Markov Chain Monte Carlo (MCMC) (Griensven and Meixner, 2006). SUFI-2 approach with SWAT-CUP is the most widely used semi-automated approach (Abbaspour *et al*., 2007), that makes the calibration process easier (Sloboda and Swayne, 2011). SWAT-CUP with SUFI-2 is used for sensitivity analysis, calibration and validation in this study. The program accesses the SWAT input files and runs the SWAT simulations by modifying the given parameters. User can save calibration iterations in the iteration history for later use. Also, it is possible to create charts of observed and simulated data and the predicted uncertainty about them.

3.3.5 CROPWAT 8. Model

CROPWAT is a computer program for irrigation planning and management, developed by the Land and Water Development Division of FAO. Crop water requirement and irrigation requirements can be calculated using this computer program. Irrigation scheduling for different management conditions and scheme water supply for varying crop patterns can also be done with this. In this study this model is used for calculating irrigation water requirement of major crops in the study area.

3.4 DEVELOPMENT OF SWAT MODEL

3.4.1 Overview of SWAT model

SWAT (Soil and Water Assessment Tool) is a river basin scale model which has wide application in large and complex watershed for quantifying the impact of land management practices. It is a physically based semi-distributed deterministic continuous daily time step model, otherwise known as long term yield model. SWAT model can be used effectively for the hydrologic assessment studies of a watershed. It is a promising tool for simulating runoff, sediment, nutrients etc. Impacts on water quality because of non-point source pollution can be done with the help of this model. It is a freely available model which can be used widely for watershed management, water resource planning and decision making. This model has eight major modules such as hydrology, climate, sedimentation, agriculture management, water quality, land cover, water bodies and main channel processes.

Watershed can be divided into number of sub-basins or sub-watersheds in this model. And this can again be sub-divided into HRUs (Hydrological Response Units) which have similar or homogenous soil characteristics, land use, topographical features and management. The basic driving equation used in SWAT modelling is the water balance equation. Whatever be the problem to be solved modelling is done based on this equation. Simulation of watershed hydrology consists of two major divisions. First one is land phase of hydrological cycle and second one is routing phase of hydrological cycle.

3.4.2 SWAT Model Development steps for Manali Watershed

3.4.2.1 *SWAT input data preparation*

This section deals with the details of input data and their pre-processing steps to be done before it is fed to SWAT model. Preparation of various spatial input data sets such as DEM, land use/land cover map and soil map and preparation of meteorological and hydrological data base are explained as follows.

- **Topography data/Digital Elevation Model (DEM)**

For the hydrological simulation using SWAT modelling Digital Elevation Model (DEM) is needed. NASA (National Aeronautics and Space Administration) DEM downloaded from NASA LPDAAC Collections data sets of USGS Earth Explorer was used in this study. LPDAAC (Land Processes Distributed Active Archive Centre) operates in partnership with USGS (U.S Geological Survey) and NASA. The DEM used has a resolution of 30 m and coordinate system of WGS_1984_UTM_Zone_43N. It was used for delineating watershed, creating reach networks, calculating sub-basin parameters and slope map creation which were necessary for HRU definition process.

- **Land use/Land cover (LULC) map and soil map**

The land use/ land cover map of Manali watershed purchased from Kerala State Land Use Board, zonal office at Thrissur district and soil map collected from Directorate of Soil Survey and Soil Conservation, Kerala State was used for the study. The various description regarding different soil association with in the watershed were also obtained. Both these maps were digitized and converted in to grid file with the help of ArcGIS 10.3.

- **Preparation of meteorological data base**

SWAT model requires input data of meteorology in proper format and units. Two files are required for each parameter, one containing the gauge location and the other containing the data and both were prepared in database format (.txt files). The gauge location table were prepared to specify the location of gauges. It holds the gauge name, its location data and elevation. The data table store the corresponding data. Data table contains date and amount of data. The meteorological data for a period of 11 years were prepared for calibration and 10 years for validation.

3.4.2.2 *SWAT modelling procedure*

SWAT modelling was done to estimate the water availability of the watershed. The water availability was assessed based on the SWAT water balance. The various steps involved in the SWAT model set-up (modelling procedure) consists of :

- SWAT project set up
- Watershed delineation
- HRU analysis
- Writing input tables
- Editing SWAT input and
- SWAT simulation

Detailed description of each step is narrated as follows.

- **SWAT project set up**

Setting up of new SWAT project is the first step while working with SWAT model. The various steps involved are as follows.

Step 1: Click on SWAT Project Setup and then New SWAT Project.

Step 2: In the dialogue box which comes after a few seconds is the Project Setup dialogue box in which the directory to which the project is to be saved.

Step 3: SWAT Project geodatabase, raster storage geodatabase and SWAT parameter geodatabase get names automatically.

Step 4: And after specifying directory, project.mdb and rasterstore.mdb were created in the same directory. Within a few minutes project set up was done.

- **Watershed delineation**

After setting up the SWAT model, the location was selected to store further model operation details and outputs. The DEM with UTM projection was used to delineate the watershed boundary. It also allowed DEM based stream definition, flow direction and flow accumulation. The automatic watershed delineation tool was selected. In low slope area DEM data showed some variation in drainage lines. Hence burn in option was used to incorporate drainage polyline shape file which was already processed in ArcGIS for proper watershed delineation and division of watershed into sub-watersheds. The watershed outlet was located manually by the edit option in SWAT model and watershed delineation was done based on the selected outlet.

- **HRU analysis**

Hydrologic Response Units (HRUs) are the smallest spatial unit and it helps to lumps similar land use, soil and slope conditions within the watershed under consideration as per the threshold values provided. The HRU analysis involves subdividing the watershed into areas having unique land use, soil and slope conditions. Threshold values are assigned to land use, soil and slope and arranged in the order of land use percent over sub-watershed area, soil class over land use area and slope class percent over the soil area. The land use, soil or slope that cover a percentage of sub watershed area less than the threshold level were eliminated. After the elimination process, the area of land use, soil or slope is reallocated so that the 100 percent of land use area, soil area and slope area are included in simulation run.

HRU analysis in the model consists of loading of land use/land cover layer, soil layer and slope layer and classification of watershed into different HRUs. Land use, soil and slope characterisation for the watershed was performed using commands from the HRU analysis menu. The land use map and its look up table and soil map and its look up table and slope map and their lookup tables were fed into the model in the order mentioned. The tables must be in dBase format. The land use map, soil map and slope map were further reclassified into SWAT defined classes. All the three maps were then overlaid to create the HRUs. Thus, the hydrologic response units (HRU) were created by the model. Multiple HRU option was selected to create multiple HRU within each sub-watershed. The threshold given was five percent for land use and soil each and ten percent for slope. This threshold helps to determine the number and kind of HRUs needed. After eliminating the areas lesser than this threshold percent, the area is reapportioned so that the 100% of watershed is modelled properly. This was applicable to land use, soil and slope classes and HRU definition was thus completed.

- **Importing weather data**

After the HRUs creation, the model allows the user to import the weather data tables (both location table and data table which are already prepared). Weather generator station, rainfall, minimum and maximum temperatures, wind speed, solar radiation and humidity were the inputs uploaded. Two kinds of tables are needed, location table and data table. Location of gauging station was given in gauge location table and should have .txt format extension. Daily data from individual gauging station is stored in the data table. If we choose gauge option from weather data dialogue box, then only we need this table. Daily data table must be formatted as an ASCII text file. Daily data file and gauge location table must be in same folder. All weather parameters data must be in ASCII file format and weather gauge location must have .txt extension. Daily records must be in a sequential order. Then the weather data files and location file were uploaded into the model in the text format. The exact naming convention specified by Neitsch *et al*., 2005 was followed for the input text files.

- **Writing SWAT input tables**

All the input files required for running the model stored in ArcSWAT geodatabase files, which were generated from the commands contained in write input table menu were entered into the model. All the weather data were processed in text format as required by the model. After all the weather data were fed, writing input tables were done. While writing the input tables, the values were set automatically based on the watershed delineation and land use\soil\slope characterization or from defaults. The method of estimation of runoff and evapotranspiration can also be selected here. In this study SCS curve number method was chosen for runoff estimation and Penman-Monteith method for evapotranspiration. Parameters may be modified at this stage if needed. After default inputs generation, the model was ready for simulation and SWAT run was performed.

- **Editing SWAT inputs**

Editing SWAT input menu helps to edit SWAT model databases and other files which were already fed as input into the model once and to re-enter the modified data. There are eight items enlisted in the drop-down list of the menu. They are databases, point source discharges, inlet discharges, reservoirs, sub-basin data, watershed data, re-write SWAT input files and integrate APEX model. Depending upon the needs editing in any of these sections may be done.

- **SWAT model run (simulation) and output**

Four items are presented on the drop-down list of SWAT simulation menu. They are:

"SWAT Simulation Menu: Run SWAT" - The Run SWAT option in SWAT model simulation gives the option for selection of time period for which simulation is to be done. The model gives various options for the users to select rainfall distribution and time step (daily/monthly/yearly) of rainfall-runoff routing. Run SWAT option executes the simulation. After all the weather data are fed and input tables are created and the SWAT model is ready to run. The dates for starting and ending the simulation were selected and performed the SWAT run. In this study the starting date was first January 1997 and ending date was 31st December 2007 for calibration. For the validation, simulation started from first January 2008 to 31st December 2017. Three years, 1997-1999 and 2008-2010 were taken as the warm up years in calibration and validation respectively (Mengistu *et al.*, 2019). Monthly time step was adopted in this study. After the model run, the model output was read. The required files needed to import to database were selected and the simulation was saved with a suitable name. Totally, the simulation was run for a period of 21 years with monthly time steps in which 11 years data were for calibration and 10 years data for validation.

"SWAT Simulation Menu: Read SWAT Output" - Read SWAT Output menu allows importing the primary text output files written by SWAT into an access database. In addition, the dialogue opened by the command allows the user to save a SWAT simulation to a permanent folder on disk. After successful running of the model, the output of the model were read with SWAT output menu. The output for different HRU and sub-basin were imported in the data base file format (.mdb). The average water balance components of the watershed be viewed by SWAT RUN. After every simulation, it can be saved in different names.

“SWAT Simulation Menu: Set Default Simulation” - Allows resetting SWAT simulation inputs to use as the active default simulation. If a simulation has been saved through the Read SWAT Output interface, then they will be able to use the Set Default Simulation interface to later reset that simulation as the default model run.

“SWAT Simulation Menu: Manual Calibration Helper” - Command opens a dialogue that provides a tool to allow users to make parameter changes to specified HRUs during manual calibration.

3.5 SENSITIVITY ANALYSIS, CALIBRATION, VALIDATION AND UNCERTAINTY ANALYSIS OF SWAT MODEL

In the present study sensitivity analysis, calibration and validation of SWAT model and uncertainty analysis was carried out using SWAT- CUP with Sequential Uncertainty Fitting (SUFI-2) technique which was an interface developed for SWAT model. This method was used because of its faster, robust and versatile nature and it can supply the widest marginal parameter uncertainty interval of model parameter among the different approaches. The SULFI-2 technique needs only minimum number of simulations to obtain high quality calibration and uncertainty results. The model calibration and validation are evaluated through sensitivity analysis and uncertainty analysis.

3.5.1 Sensitivity Analysis

Hydrology components of SWAT model involve so many numbers of parameters. So, sensitivity analysis involves the identification of key parameters and helps to determine the influence of each parameter in the stream flow simulation. So, the complexity caused due to the large number of parameters in calibration will be solved when the sensitivity analysis is performed. Sensitivity analysis establishes the relative importance of different parameters to the model output. It is the pre-requisite for model calibration which help in pruning the number of parameters to be optimised during calibration. SWAT-CUP has the provision to perform sensitivity analysis and it can be done in two ways: 1. Global sensitivity analysis and 2. One at a time analysis. Global sensitivity analysis was used in this study.

Global sensitivity analysis performs the sensitivity of one parameter while the values of other related parameters keep of change. This method is commonly used to find the sensitive parameters responsible for stream flow. The parameters which effecting the 'FLOW_OUT' were selected for sensitivity analysis based on the study area characteristics and the available literatures related to SWAT modelling. The parameters with highest sensitivity were used to calibrate and validate the model. 12 parameters were selected for sensitivity analysis and then the most sensitive 10 parameters were taken for calibrating the model in this study. The parameters considered for the global sensitivity analysis are shown in Table 3.2. The upper and lower bound values of parameters were taken from SWAT user manual. Sensitivity analysis was performed and the parameters were finalised based on the ranking of the parameter. The t- test provides measure of sensitivity and p values gives significance of sensitivity respectively. The parameters which have larger absolute values of p-value and t-stat value close to zero are the more sensitive parameters.

Table 3.2 Parameters selected for the global sensitivity analysis

Sl. No.	Parameter	Description
1	ALPHA_BF.gw	Base flow alpha factor
2	CH_N2.rte	Manning's n value for main channel
3	CN2.mgt	SCS runoff curve number
4	SOL_K (..).sol	Soil hydraulic conductivity
5	CH_K2.rte	Effective hydraulic conductivity of main channel
6	SOL_AWC (..).sol	Available water holding capacity of soil
7	GW_DELAY.gw	Groundwater delay time
8	SURLAG.bsn	Surface lag coefficient
9	GW_REVAP.gw	Ground water revap coefficient
10	EPCO.hru	Plant uptake compensation factor
11	ESCO.hru	Soil evaporation compensation factor
12	GWQMN.gw	Threshold depth of water in shallow aquifer required to return flow to occur

3.5.2 Calibration of Model

Physically based distributed model should be calibrated before they are made use in the simulation of hydrologic process. Calibration is the process to set different parameter values of SWAT model that can make the relation between the observed and predicted values closer to each other. This is necessary for reducing the uncertainty associated with model prediction. It is to tune the parameters of the model. Most sensitive 10 parameters were used for calibrating the model. Calibration of the model was done for 11-year period from January 1997 to December 2007 with first three years as warm up period using observed steam flow data. Calibration was done for the monthly time series data with 500 iterations. Based on the characteristic features of study area and statistical indicators, trial and error method were used for adjusting the model parameters. The statistical parameters Nash-Sutcliffe efficiency and coefficient of determination were used for verifying the fitness and accuracy of the model for the watershed.

3.5.3 Validation of Model

Validation is the process to check whether the set parameters in calibration are in good relation between the observed and predicted values. Without any further adjustments of model parameters, the process of comparison of model results with an independent data set is called the validation. Validation of the model was done after the calibration process. The validation was done for 10 years of monthly time series stream flow data from 2008-2017 in which three years was set as warm up period. Totally 500 number of iterations were carried out during validation.

3.5.4 Uncertainty Analysis

The sources of model uncertainties could be from driving variables, the conceptual model itself, measured data, or uncertainty during parameterization. The propagation of all sources of model uncertainties to parameters and model outputs in SWAT-CUP is expressed as the 95% probability distributions. SUFI-2 algorithm hence seeks to bracket most of the measured data with the smallest possible uncertainty band. The 95% probability distributions were calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling, disallowing 5% of the very bad simulations and is called 95% prediction uncertainty (95 PPU). SWAT-CUP calculates two statistical indicators to quantify the strength of calibration and all the sources of uncertainty measures. These are the p-factor, which is the percentage of observed data enveloped by the modelling result (the 95 PPU), and the r-factor, which is the thickness of the 95PPU envelope divided by the standard deviation. There are no hard numbers exists to what extent these values should be, but as much larger these values as much the better they are. p and r factors are closely related to each other, which showed that a large p factor will be getting for a large r factor. So, when a balance between these factors is obtained, the calibrated parameter range is generated. Theoretically, the value of the p factor ranges between 0 and 100% while that of r-factor ranges between 0 and infinity. A p-factor of 1 and r-factor of zero is a simulation that exactly corresponds to the measured data.

3.6 MODEL PERFORMANCE EVALUATION

Moriasi *et al.* (2016) conducted a research about the various statistical parameters which determines the goodness of fit of a model. They found that, R^2 and NSE were frequently used indicators for modelling studies. The Nash-Sutcliffe Efficiency (NSE) and the coefficient determination (R^2) are the frequently used measures in hydrological modelling studies. Hence in the present study NSE and and R^2 were used to check the performance accuracy of the model.

3.6.1 Nash-Sutcliffe Efficiency (NSE)

Nash-Sutcliffe efficiency was proposed by Nash and Sutcliffe (1970) and is defined as one minus the sum of the absolute squared differences between the predicted and observed values normalized by the variance of the observed values during the period under investigation and is given by the equation,

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)\hat{}2}{\sum_{i=1}^{n}(O_i - O_{avg})\hat{}2}$$

Where S_i is the simulated streamflow, O_i is the observed streamflow at time step i, and O_{avg} is the average observed streamflow values in time period 1, 2, . . . , n, respectively.

3.6.2 Coefficient of Determination

The coefficient of determination (R^2) is defined as the squared value of the coefficient of correlation.

$$R^2 = \frac{(\sum_{i=1}^{n}(O_i - O_{avg})(S_i - S_{avg}))^2}{\sum_{i=1}^{n}(O_i - O_{avg})^2 \sum_{i=1}^{n}(S_i - S_{avg})^2}$$

Where S_i is the simulated streamflow, O_i is the observed streamflow at time step i, and S_{avg} and O_{avg} are the average simulated and observed streamflow values in time period 1, 2, . . . , n, respectively.

The range of NSE lies between 1.0 (perfect fit) and $-\infty$. The value of R^2 range between 0 and 1 with the value of zero meaning no correlation whereas a value of 1 means that there is a good correlation with observed and simulated values. The general performance rating of these statistical parameters as given by Moraisi, 2017 is shown in Table 3.3 and a procedural flow chart of SWAT modelling is shown in Fig. 3.2.

Table 3.3 Performance rating of NSE and R^2

Performance rating	**NSE**	**R^2**
Very good	$0.75<NSE<1.0$	$0.85>R^2$
Good	$0.65<NSE<0.75$	$0.75 < R^2 \leq 0.85$
Satisfactory	$0.5<NSE<0.65$	$0.60 < R^2 \leq 0.75$
Unsatisfactory	$NSE<0.50$	$R^2 \leq 0.60$

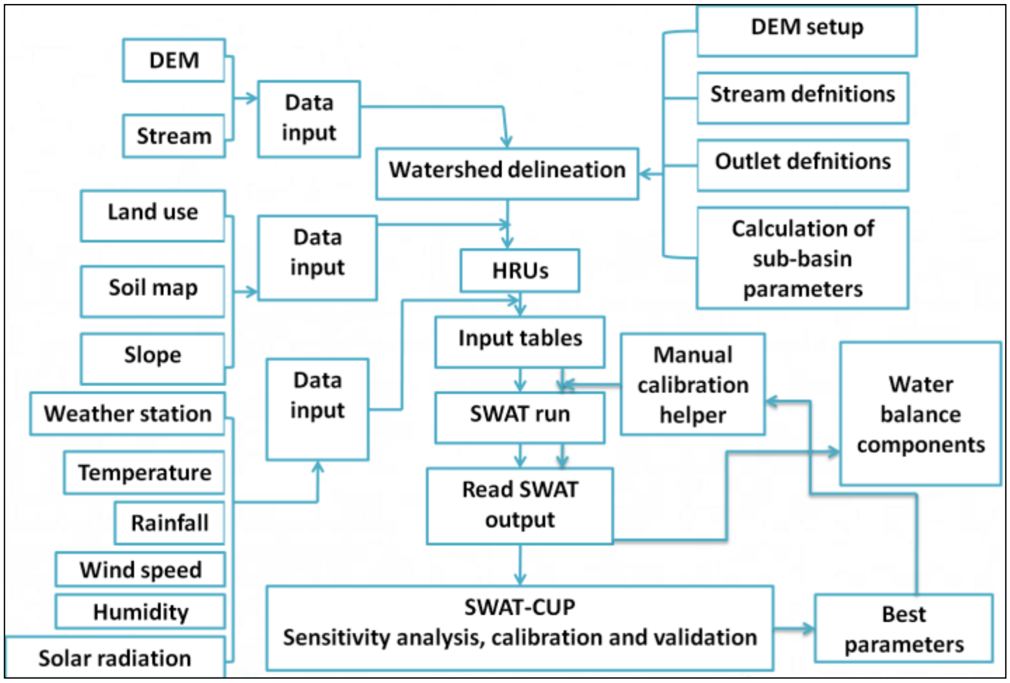

Fig. 3.2 Procedural flow chart of SWAT modelling

3.7 ESTIMATION OF WATER BALANCE USING SWAT MODEL

The developed SWAT watershed model was used for the monthly estimation of water balance components of the watershed. Land phase and routing phase are the two components of SWAT model processing. The SWAT hydrology components and their estimation methods were described as follows

3.7.1 Soil Hydrology

The soil hydrology is simulated by the water balance equation as follows

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

Where, SW_t is final soil water content (mm), SW_0 is the initial soil water content on day i (mm), t is time in days, R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from soil profile on day i (mm) and Q_{gw} is the amount of return flow on day i (mm).

3.7.1.1 ***Estimation of surface runoff volume***

Runoff volume is estimated by SCS-CN equation which is an empirical equation developed to produce a reliable basis for calculating runoff under varying soil and land use conditions. The SCS- CN equation used in SWAT (SCS 1972) is as follows.

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

Where Q_{surf} is accumulated runoff or excess rainfall (mm), R_{day} is the rainfall depth for the day (mm), I_a is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm) and S is the retention parameter (mm).

Spatial variation of retention parameter is due to changes in soil, slope, land use and management. Changes in soil water content causes temporal variation. Formula used for calculating retention parameter is given below:

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

Where, CN is the SCS curve number for the day. When rainfall depth Rday exceeds the Initial abstraction I_a, runoff will occur. Common approximation of I_a is 0.2S, hence the equation 2 changes as,

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

3.7.1.2 ***Evapotranspiration***

Evapotranspiration is a collective term which includes all processes by which water at the earth’s surface is converted to water vapour. The removal of water from a watershed is primarily due to evapotranspiration. Water available for human use and management in a watershed is the difference between precipitation and evapotranspiration. For climatic and hydrological studies, the accurate assessment of evapotranspiration is essential. There are various methods for calculating potential evapotranspiration, in SWAT model. They are Penman-Monteith method, Preistley-

Taylor method and Hargreaves method. Among these methods, Penman-Monteith method was used for PET calculation in this study which requires climate parameters solar radiation, air temperature, wind speed and relative humidity.

3.7.1.3 ***Lateral flow***

Lateral flow will be significant in areas with soils having high hydraulic conductivities in surface layers and an impermeable or semi-permeable layer at a shallow depth. Lateral flow is determined by the equation,

$$Q_{lat} = \frac{0.024SS_C Sin\propto}{\theta_d L}$$

Where, Q_{lat} = lateral flow (mm/ day), S = drainable volume of soil water per unit area of saturated thickness (mm/day), S_C = saturated hydraulic conductivity (mm/h), L = flow length (m), α = slope of the land, θ_d = drainable porosity.

3.7.1.4 ***Groundwater systems***

Water in the saturated zone under the pressure greater than atmospheric pressure is known as Groundwater. Saturated zone consists of high conductivity and low conductivity regions. High conductivity zone and low conductivity zone is made up of coarse grain and fine grain materials respectively. SWAT model simulates two aquifers in each sub-basin. Shallow aquifer is an unconfined aquifer that contributes to flow in the main channel or reach of the sub-basin. The deep aquifer is a confined aquifer. Water that enters the deep aquifer is assumed to contribute to streamflow somewhere outside of the watershed (Arnold *et al.,* 1933).

- **Baseflow**

If the quantity of water present in shallow aquifer exceeds a threshold value specified by the user, the baseflow is permitted to enter into the reach. Steady state response of groundwater flow to recharge is:

$$Q_{gw} = \frac{8000.K_{sat}}{L_{gw}{}^2} . h_{wtbl}$$

where, Q_{gw} is the base flow in to the main channel on day i (mm H_2O), K_{sat} is the hydraulic conductivity of the aquifer (mm/day), L_{gw} is the distance from the ridge or sub-basin divide for the groundwater system to main channel (m) and h_{wtbl} is the water table height (m).

- **REVAP**

There will be movement of water into overlying unsaturated layer as a function of water demand for evapotranspiration. This process can be called as REVAP to eliminate the confusion that may occur with soil evaporation and transpiration. Fig. 3.3 shows the schematic representation of hydrological cycle modelled in SWAT

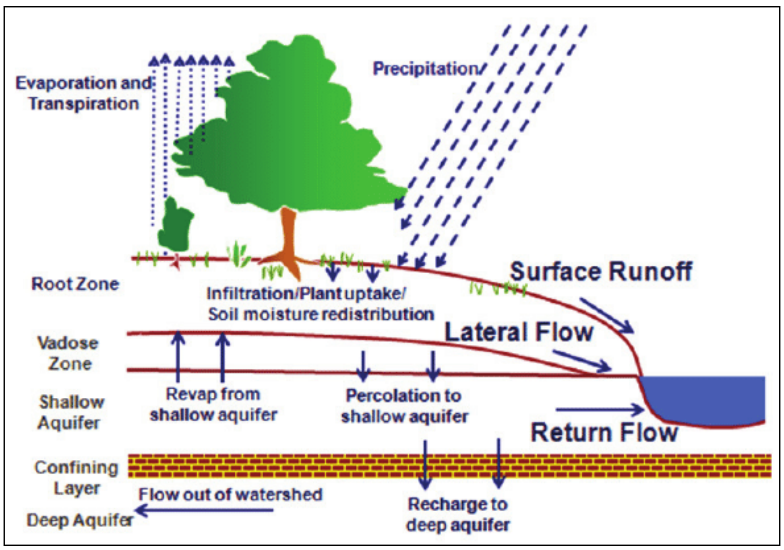

Fig. 3.3 Schematic representation of hydrological cycle in SWAT

3.8 ESTIMATION OF WATER AVAILABILITY OF THE WATERSHED

Water availability of Manali watershed was determined from the SWAT water balance components. The water yield of the basin was taken as the sum of surface runoff, lateral flow and base flow components of SWAT water balance. The water yield multiplied by the area of the watershed gives the water availability of the watershed (Ganiyu *et al*. 2019). The monthly water availability in Manali watershed was calculated.

3.9 ESTIMATION OF WATER DEMAND IN THE WATERSHED

The various water demands in a watershed include agricultural water demand, domestic water demand and livestock water demand. The methodology adopted for determining these various water demands are described as follows.

3.9.1 Agricultural Water Demand Estimation

The agricultural water demand was estimated using CROPWAT 8 model. The irrigation water requirement of major crops obtained from the model multiplied with the respective cropped area of individual crops and summing them gave the total agricultural demand. Cropped area of the major crops in the watershed was obtained from the land use/land cover map. The estimation of irrigation water requirement by CROPWAT model is detailed as follows.

3.9.1.1 *Description of CROPWAT 8 Model*

CROPWAT-8 model is a computer-based decision support system used to estimate the crop water requirement. This model also has the capability to calculate scheme water supply for varying crop patterns. It is based on FAO publications of Irrigation and Drainage series No.56 and No. 33. FAO-56 includes guidelines for computing crop water requirement and FAO-33 deals with yield response to water. Rainfall data, climate data, soil data and crop data were the input data used for CROPWAT 8 model. In case of unavailability of local soil and crop data, an in-built standard data is available in the model. Similarly, if the local climate data is not available, climate data of 5000 stations worldwide is available from CLIMWAT which is climate database attached to CROPWAT.

3.9.1.2 *CROPWAT 8. Model – input data required*

The following section describes the details of input data used for estimating the irrigation requirement.

Climate data

Climatic data includes minimum temperature (°C), maximum temperature (°C), humidity (%), wind speed (km/day), sunshine hours and rainfall. Daily data of all these meteorological parameters for a period of 30 years from 1988 to 2017 were collected from Kerala Agricultural University, Vellanikkara. The monthly average climatic parameters for the period 1988-2017 are shown in Table 3.4.

Table 3.4 Monthly average climatic parameters during 1988-2017

Month	Min_temp (°c)	Max_temp (°c)	Humidity (%)	Wind-velocity (km/day)	Sunshine (hours)
Jan	22.2	32.9	56	188	8.9
Feb	22.7	34.7	57	146	9.2
Mar	24.1	35.8	65	98	8.6
Apr	25	34.9	71	84	7.6
May	24.8	33.2	76	82	6.2
Jun	23.4	30	86	79	3.1
Jul	22.9	29.2	87	74	2.4
Aug	23.2	29.6	85	73	3.7
Sep	23.2	30.5	82	67	5.3
Oct	23.1	31.3	81	65	5.6
Nov	23.1	31.7	71	111	6.5
Dec	22.6	31.8	62	186	7.3
Average	23.4	32.1	73	104	6.3

Crop data

There are two options for inputting crop data one for dry crop and other for rice. The various crop data used were planting date, Kc values, growth stage of crop in days, rooting depth, critical depletion, yield response factor and crop height for dry crops. For rice crop, transplanting date, rooting depth, puddling depth, nursery area, critical depletion, yield response factor, crop height and different stages of crop including nursery and land preparation and Kc values of rice (dry / wet condition) are the different data used. The crop data was collected from Package of Practices, KAU (2016) and literature review. Major crops in this study area were rubber, cashew, coconut, rice and banana. The data pertaining to these crops are presented in Table 3.5, Table 3.6 and Table 3.7.

Table 3.5 Crop data of perennials

Cropping Season	Duration (Days)	Crop Coefficient (Kc)	Depth of Active Root Zone (cm)	Management Allowable Deficit (MAD)
Cashew	Perennial	0.84	90	0.50
Coconut	Perennial	0.75	90	0.50
Rubber	Perennial	0.95	50	0.40

(Surendhran *et al.*, 2015)

Table 3.6 Crop data of rice

		Date of sowing		01/04	Date of harvest		02/09
Crop parameter	**Nursery**	**Land preparation**	**Initial**	**Development**	**Mid-season**	**Late**	**Total**
Kc (dry)	0.7	0.3	0.5	1.05	1.05	0.7	
Kc (wet)	1.2	1.05	1.1	1.2	1.2	1.05	
Length, days	30	35	30	35	50	35	180
Puddling depth		0.4					
Rooting depth			0.5	0.1			
Critical depletion factor	0.2		0.2		0.2	0.2	
Yield response factor			0.5	0.5	0.5	0.5	0.5

(Vysakh *et al.*, 2017)

Table 3.7 Crop data of banana

Date of sowing		**04/08**	**Date of harvest**		**31/03**
Crop parameter	**Initial**	**Development**	**Mid-season**	**Late**	**Total**
Kc	1.0		1.2	1.1	
Length, days	60	60	75	45	240
Rooting depth	0.9				
Critical depletion factor	0.55		0.45	0.45	
Yield response factor	1.35	1.20	1.20	1.35	1.0

(Package of practices, 2016 and Allen *et al.*, 1998)

Soil data

Soil name, total available soil moisture, maximum rain infiltration rate, maximum rooting depth, initial soil moisture depletion and initial available soil moisture were the soil data used. Soil data according to the AEU-10: North Central Laterites were obtained from package of practices KAU (2016). The soil data used in this study is shown in Table 3.8.

Table 3.8 Characteristics of soil group in AEU- 10

Soil name	North central Laterites
Total available soil moisture	200 mm/meter
Maximum rain infiltration rate	40 mm/day
Maximum rooting depth	900 cm
Initial soil moisture depletion	0 %
Initial available soil moisture	200 mm/meter

(Package of practices, 2016 and Allen *et al.*, 1998)

3.9.1.3 *Estimation of ET_0 by CROPWAT 8 Model*

The Penman-Monteith equation used for calculating reference crop evapotranspiration in CROPWAT 8 model is as follows.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$

where, ET_0 = reference evapotranspiration (mm/day), R_n net radiation at the crop surface (MJ m^{-2} day^{-1}), G soil heat flux density (MJ m^{-2} day^{-1}), T air temperature at 2 m height (°C), U_2 wind speed at 2 m height (m s^{-1}), es saturation vapour pressure (kPa), ea actual vapour pressure (kPa), es-ea saturation vapour pressure deficit (kPa), Δ slope vapour pressure curve (kPa $°C^{-1}$), γ psychrometric constant (kPa $°C^{-1}$).

3.9.1.4 *Estimation of crop water requirement*

The total quantity of water required to counteract the water loss due to evapotranspiration from cropped field is known as crop water requirement. Crop water requirement includes the sum total of water to meet losses due to evapotranspiration, application losses and additional quantity of water needed for special operations. Crop water requirement is represented as ET_C in mm/day in CROPWAT model. It is defined as "the depth of water needed to meet the water loss through evapotranspiration of a disease-free crop, growing in fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment" (Doorenbos and Pruitt, 1977). Hence ETc was calculated using the equation

$$ET_C = K_C \text{ X } ET_0$$

Where, K_C is the crop coefficient and ET_0 is reference crop evapotranspiration.

3.9.1.5 *Computation of effective rainfall (P_{eff})*

USDA-SCS method was used for estimating effective rainfall. The equation used for calculating the effective rainfall is as follows

$$P_{eff} = P_{tot}(125-0.2*P_{tot})/125 \text{ for } P_{tot} < 250 \text{ mm}$$

$$P_{eff} = 125 + 0.1P_{tot} \text{ for } P_{tot} > 250 \text{ mm}$$

Where, P_{eff} = effective rainfall (mm); P_{tot} = total rainfall (mm).

3.9.1.6 ***Computation of irrigation requirement (IR)***

The CROPWAT model calculate the daily water balance of the root zone as the root zone depletion at the day's end by the equation

$$D_{r,i} = D_{r,i-1} - (P_i - RO_i) - I_i - CR_i + ET_{ci} + DP_i$$

Where $D_{r,i}$ is the root zone depletion at the day's end i (mm), $D_{r,i-1}$ is the water content in the root zone at the previous day's end (mm), P_i is the precipitation on day i (mm), RO_i is the surface soil runoff on day i (mm), I_i is the net irrigation depth on day i which infiltrates the soil (mm), CR_i is the capillary rise from the groundwater table on day i (mm), ET_{ci} is the crop evapotranspiration on day i (mm), and DP_i is the lost water of the root zone on day i (mm).

3.9.1.7 ***Net irrigation requirement***

Net irrigation requirement (NIR) is estimated as follows,

$$NIR = ET_c - P_{eff}$$

3.9.1.8 ***Estimation of total agriculture water demand***

The agriculture water demand of the watershed was estimated as irrigation requirement of major crops in the watershed. Total agricultural demand is obtained by multiplying the irrigation requirement (mm) of each crop with the corresponding cropped area and adding them together. Monthly irrigation requirement (IR) was calculated from decadal values obtained from CROPWAT 8 model. The overall workflow for the estimation of irrigation water requirement by CROPWAT 8 model is given in Fig. 3.4

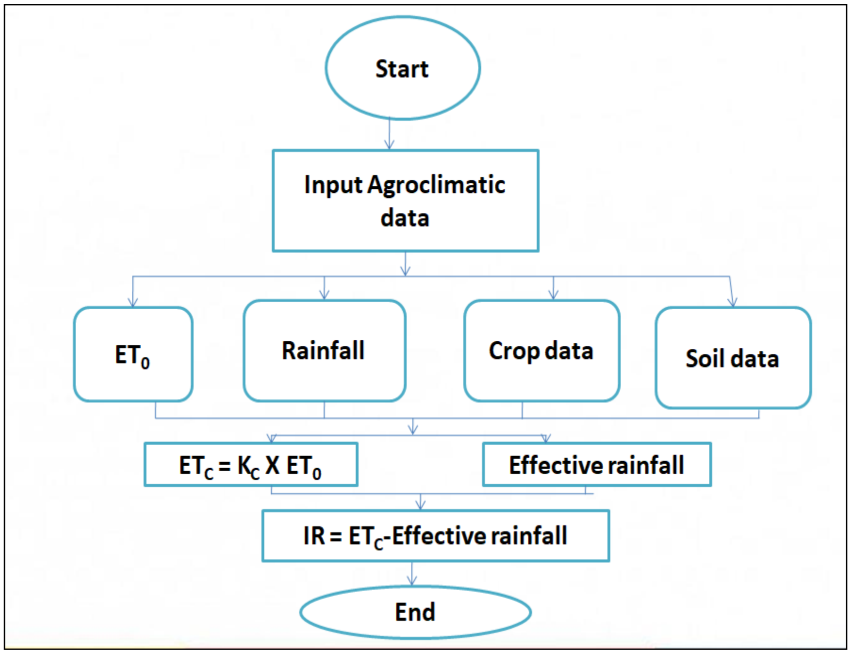

Fig. 3.4 Overall workflow for IR estimation by CROPWAT 8 model

3.9.2 Estimation of Non-Agricultural Water Demand

Per capita demand multiplied with population gave the total population demand and livestock water requirement multiplied with the corresponding livestock population gave total livestock demand. Population demand and livestock demand were added together to find total non-agricultural water demand.

3.9.2.1 *Estimation of human/domestic water demand*

The daily water requirement per person including domestic use, industrial use, commercial use, public use and wastage/losses etc. was taken as 270 litres per capita per day (lpcd). This multiplied with the human population was taken as the total human water demand. The per capita water demand of human being is shown in Table 3.9. The estimation of recent population of Manali watershed consists of three steps.

Step 1: Determination of population of Manali watershed from census data

Population of Thrissur district for the decades 1971, 1981, 1991, 2001 and 2011 were collected from official website of Economics and Statistics, Kerala Government (www.ecostat.kerala.gov.in). Population density of each decade (1971, 1981, 1991, 2001 and 2011) was calculated by dividing the population by the area of the district. The area of Thrissur district is 3032 km^2. The population of Manali watershed for the above decade were then calculated by multiplying this population density with area of Manali watershed. This estimated population data was used for forecasting the population of Manali watershed for the year 2021.

Step 2: Estimation of forecasted population for the year 2021

As the population of 2011 was last census data available, population of the year 2021 is to be forecasted to find a reliable estimate of water demand. Among the different population forecasting methods, decrease rate of growth method (decreasing rate method) was used in this study. The concept of decrease rate of growth is that, it has been seen that all life sustains within a limited space. If complete growth of a very old city is plotted, it will be seen that the curves have S-shape, which indicates that early growth takes place at an increasing rate, latter growth takes place at a decreasing rate which indicates that saturation limit is reached. Hence in this method, the average decrease in the percentage increase was worked out and is then subtracted from the percentage increase of last known decade (2011). Then the forecasted population of 2021 was estimated by adding the product of net percentage increase in population and population of 2011 to the population of 2011.

Step 3: Population interpolation and estimation of average population for the years 2012-2017

Population data of the recent 6 years from 2012 to 2017 were obtained by interpolation using the population of the year 2011 and the forecasted population 2021. The average population of these six years were taken as the population of Manali watershed. Total of population water demand was obtained by multiplying this average population of Manali watershed with per capita water demand.

Table 3.9 Average per capita demand of water

Purpose	Estimated per capita demand (litres/day/person)	As % of total
Domestic use	135	40-60
Public or civil use	10	10-20
Industrial use	50	20-25
Commercial use	20	10-30
Wastage/losses and thefts	55	20-40
Total	270	

(Source: Gupta and Gupta, 2012)

3.9.2.2 *Estimation of Livestock water demand*

The livestock population data collected from department of animal husbandry, Thrissur (Livestock census, 2012) and the average water requirement of livestock from literatures is represented in Table 3.10. The livestock water requirement multiplied with the livestock population estimated the total livestock water demand.

Table 3.10 Water requirement and population data of livestock

Livestock	Water requirement (litres/animal/day)	No. of animals (population)
Cattle	100	9684
Buffalo	105	744
Goat	22	10650
Pig	30	416
Dog	10	6870
Rabbit	2	2465
Horses	48.50	2
Poultry	146	80338
Sheep	20	45
Elephant	220	2

(Source: Ramachandra *et al*., 2014 and Livestock census, 2012)

3.10 ANALYSIS OF WATER AVAILABILITY AND WATER DEMAND IN THE WATERSHED

Total water availability was estimated from the SWAT model water balance components. Total water demand was estimated as the sum of agricultural and non-agricultural water demand. Monthly water availability and water demand analysis was performed to check whether there is surplus or deficit of water in each month. The flowchart of water availability and water demand analysis is shown in Fig. 3.5.

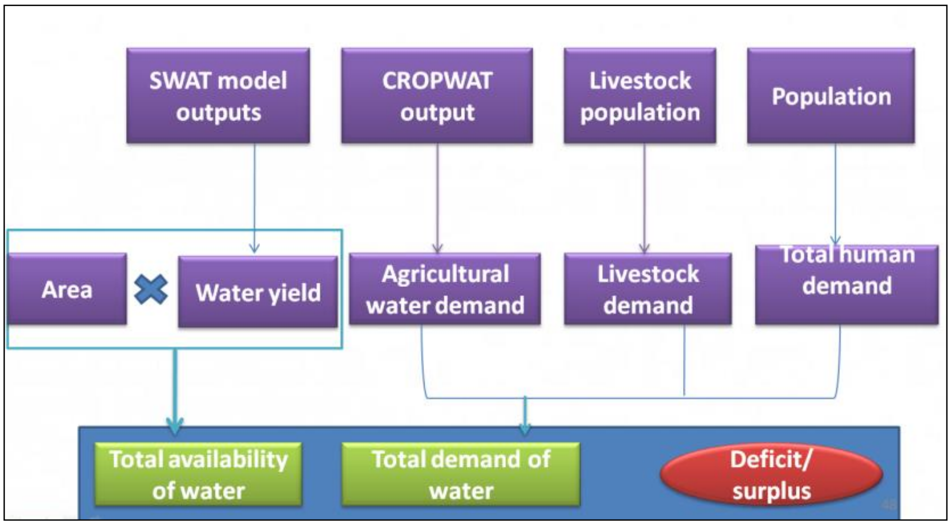

Fig.3.5 Monthly Water availability – Water demand analysis

3.11 PLANNING OF CONSERVATION MEASURES IN THE WATERSHED

The water yield in a watershed can be considered as the amount of water that is available to the meet the various water demand of the watershed. The water availability was estimated from the SWAT water balance. Though Kerala is blessed with plenty of rainfall, there experiences water scarcity in non-monsoon season in most part of Kerala. In Manali watershed also due to steep slope and undulating terrain most of the rainfall goes as runoff and there is always rise of water level in the low-lying area during monsoon season. But there is acute scarcity of water during non-monsoon months in the watershed. In order to meet the water demand round the year it is essential to trap the water yield of the watershed in monsoon season by proper conservation measures. This can increase the ground water recharge and level of water table in the area. Percolation ponds, subsurface dykes, farm ponds, check dams, bunds etc. are some of the water conservation measures that are widely used for large scale conservation of water in watershed.

The planning of conservation measures can be effectively done using GIS and SWAT hydrological modelling. For the selection of suitable sites and type of conservation measure, many guidelines put forwarded by various agencies are available such as IMSD, INCOH and FAO etc. In this study, selection of water conservation measures was done based on IMSD (Integrated Mission for Sustainable Development) guidelines (Table 3.11), put forwarded by NRSC (National Remote Sensing Centre, Hyderabad). Integrated Mission for Sustainable Development is one of the projects implemented by the department of Space for providing practical solutions to various problems through the technology of satellite remote sensing (Rao *et al.*, 1995).

Table 3.11 IMSD decision rules for selection of water conservation measures

Sl No.	SWC measures	Slope (degree)	Permeability	Stream order	Runoff	Landuse
1	Farm pond	0-5	Low	1	Medium/High	Agricultural areas
2	Check dam	<15	Low	1-4	Medium/High	River streams
3	Subsurface dyke	0-3	High	>4	Medium /low	Near river
4	Percolation pond	<10	High	1-4	Low	Open land/ waste land

Land use/land cover map, surface runoff map, stream density map, stream order map, soil permeability map and slope maps were various thematic maps used for identifying the suitable sites for water conservation measures. The map integration was done by weighted overlay analysis in GIS. The details of generation of various thematic maps are explained as follows.

3.11.1 Reclassified Slope Map

Steepness of the land is a significant component which produces runoff in a basin. The runoff, recharge, and movement of surface water depend on the slope of the area. Slope map was generated from the DEM (which was already downloaded for SWAT model development) using the surface tool under spatial analyst tool in ArcGIS environment. Slope of the area was reclassified into seven classes as per IMSD guidelines which includes nearly level (0–1), gentle (1–3), moderately gentle (3–5), steep (5–10), moderately steep (10–15), and very steep (15–30).

3.11.2 Land use/Land Cover Map

Land use/ land cover map purchased from Land use board was digitized in ArcGIS and the reclassified LU/LC map was used. The Land use/land cover map was categorised into 14 groups and they are agriculture land mixed crop, agriculture land row crops, banana, barren, cashew, coconut, deciduous forest, mixed forest, orchard, rice, rubber, urban area residential, urban area transportation and water. The LU/LC map developed for SWAT modelling was used here.

3.11.3 Soil permeability map

Permeability of soil is an important parameter which determines the rate of infiltration. The entire river basin is classified into different permeability groups based on the Hydrologic Soil Group (HSG) classification of USDA (Table 3.12) and the soil series derived from soil map.

Table 3.12 Hydrological soil group and soil texture

Hydrologic Soil Group	Runoff Description	Texture
A	Low runoff potential because of high infiltration rates	Sand, Loamy sand and Sandy loam
B	Moderately infiltration rates leading to moderately runoff potential	Silty loam and Loam
C	High/moderately runoff potential because of slow infiltration rates	Sandy clay loam
D	High runoff potential with very low infiltration	Clay loam, silty clay loam, sandy clay, silty clay and Clay

(Source: USDA, 1986)

3.11.4 Drainage Density Map

Drainage density is the length of the stream per unit area. From spatial analyst tool ‘line density tool’ was selected for making drainage density map. Reclassified into four drainage density classes as 0-1, 1-2, 2-3 and 3-4.

3.11.5 Stream Order Map

Classification system of streams or river ranks in the watershed is called stream order. Stream ordering based on Strahler method was applied to the drainage polylines in ArcGIS environment.

3.11.6 Surface Runoff Map

Surface runoff map was prepared from SWAT model output. Runoff map was prepared by calculating the surface runoff generated in each of the sub-basin of Manali watershed. Four runoff classes were categorised based on surface runoff values.

3.11.7 Site Suitability Modelling

Site suitability modelling was done by multi criteria weighted overlay analysis of the various thematic maps such as land use/land cover, soil permeability map, slope map, runoff map and stream density map for identifying the site suitability of conservation measures. Each thematic layer has its own importance and properties to determine the suitable location for conservation measures. The first step done for this purpose was rasterization of these maps. After rasterization process, these maps were assigned percentage of influence and suitable weights as per the nature of classes. Percentage of influence and weights was selected as per the literature reviewed (Kumar *et al.* 2017; Lohar *et al*. 2018). The percentage of influence given for each layer is shown in Table 3.13. Then weighted overlay analysis was done to obtain the site suitability map. The sub basin was dived into three categories of suitability, namely highly suitable areas, moderately suitable areas and less suitable areas for implementing the water conservation measures. Based on the previous studies and IMSD guidelines the site suitability criteria were fixed and location and type of conservation measures like check dam, percolation pond, farm pond were identified for the watershed. The overall workflow is shown in Fig. 3.6.

Table 3.13 Percentage influence of raster layers

Raster layers	Percentage influence
Slope	25
LU/LC	25
Soil permeability	20
Drainage density	15
Runoff map	15

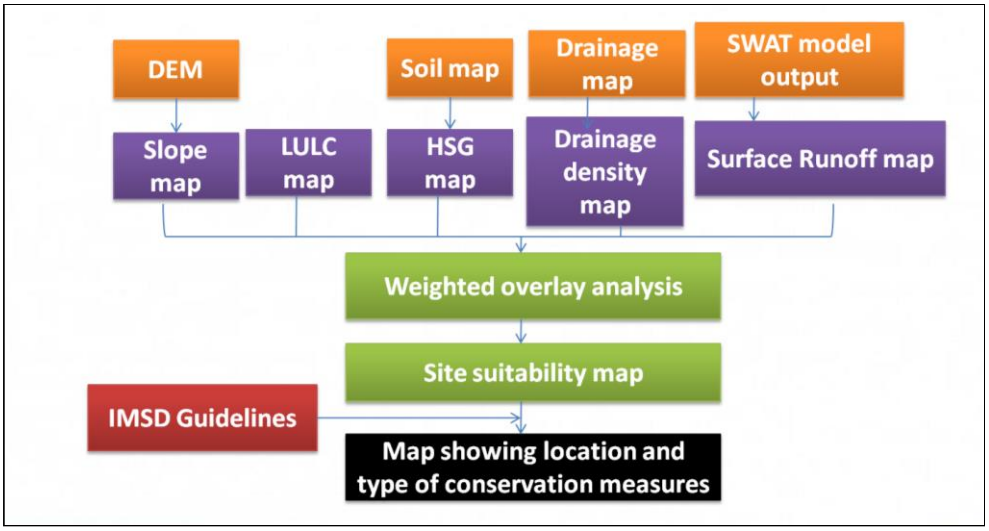

Fig. 3.6 Overall workflow for planning of conservation measures

A brief description of different conservation measures that can be adopted in the watershed are as follows.

3.11.7.1 *Check dam*

Check dams are very popular type of water harvesting structures and have greater importance since it has got a complimentary benefit of controlling soil erosion (IMSD, 1995). Check dams are structures constructed of rock, sediment retention fibre rolls, gravel bags, sandbags, or other proprietary product placed across a natural or manmade channel or drainage ditch.

3.11.7.2 ***Farm pond***

Farm ponds are made by either constructing an embankment across a water source or by excavating pits or the combination of both. These are the low-cost structures constructed in agricultural land located on higher reaches (IMSD, 1995). The farm ponds are used for protective irrigation in a prolonged dry spell in monsoon season.

3.11.7.3 ***Subsurface dyke***

Subsurface dyke is used to check the base flow in river and reduce evaporation losses. It is mainly used for domestic needs. Straight and wide river with 2 to 3 m thick sandy-gravely bed material are the required site condition for constructing subsurface dykes.

3.11.7.4 ***Nala bund/ Percolation pond***

Percolation ponds are the structures for recharging ground water. The required site conditions are high permeability and well-defined broad stream channel. These are generally constructed across streams and bigger gullies in order to impound a part of the run-off water (IMSD, 1995).

3.12 PLANNING OF CROPPING PATTERN FOR THE WATERSHED

Cropping pattern refers to yearly sequence or spatial arrangement of crops in field/watershed. It can be broadly divided as intercropping and sequential cropping. Intercropping is the pattern in which two or more crops are grown at the same time in same field. Sequential Cropping is the one in which growing two or more crops in sequence on the same field in a year. Planning of cropping pattern generally depends on soil type, physiography, seasonal water availability and existing crops. Existing crops were obtained from LU/LC map, soil type from soil map and physiography from DEM. Seasonal precipitation pattern and potential evapotranspiration variability is measured by an index called aridity index. Aridity index is the quantitative measure of the degree of water shortage and are usually related to distributions of natural vegetation and crops

(Stephen, 2005). It is the ratio of precipitation to potential evapotranspiration (UNESCO, 1979). Precipitation and potential evapotranspiration were obtained from SWAT model output. Hence the proposed cropping pattern in the watershed was done based on the four factors soil texture, physiography, aridity index and existing crops.

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The availability, sustainable use and optimal management of water resources in a watershed are the necessity of time in the wake of development and growing need of population. The lack of conservation measures in a watershed can contribute to increased runoff, soil loss and nutrient transport. In Manali watershed, there is always an increased chance of water level rise during monsoon season and scarcity of water during summer season. Hydrological modelling and geospatial techniques were found effective tools for planning watershed developmental activities. Hence an attempt was made in this study to plan water conservation measures and cropping pattern for Manali watershed in Karuvannur river basin of Thrissur district using geospatial techniques and SWAT modelling. The results pertaining to the preparation of various input data for SWAT model, calibration and validation of the model, estimation of monthly water balance of the watershed, estimation of water availability and water demand of the watershed, analysis of water availability and water demand and planning of conservation measures and cropping pattern were presented and discussed under the following subheads.

4.1 PREPARATION FOR VARIOUS INPUT DATA FOR SWAT MODEL

4.1.1 Digital Elevation Model

Manali watershed boundary was delineated from NASA DEM downloaded from USGS Earth Explorer using Soil and Water Assessment Tool (SWAT) model in ArcGIS workspace. The DEM used has a resolution of 30 m and WGS_1984_UTM_Zone_43N coordinate system. It facilitated for delineating watershed, creating reach networks, calculating sub-basin parameters and slope map creation which are necessary for HRU definition process. The DEM of Manali watershed is shown in Fig. 4.1 and its properties in Table 4.1.

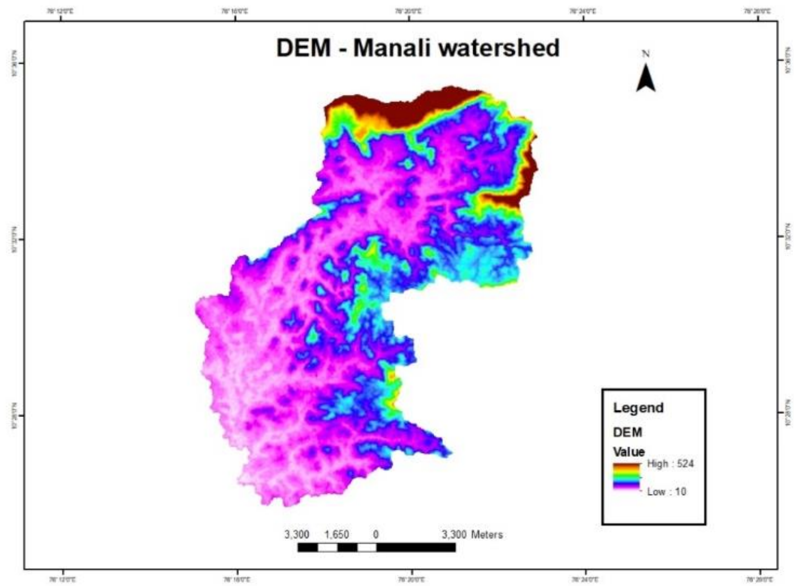

Fig. 4.1 Digital Elevation Model of Manali watershed

Table 4.1 Properties of DEM

DEM properties	
Metadata parameter	Value
Projection	Universal traverse mercator
False Northing	0
False Easting	500000
Central Meridian	75
Scale factor	0.9996
Reference latitude	0
Coordinate system	WGS 1984 UTM Zone 43N
Column/row count	468/575
Bits per pixel	16

4.1.2 Landuse/Land Cover Map (LU/LC Map)

Land use/land cover map (during the year 2016) purchased from State Land Use Board, zonal office, Thrissur district was digitized with the help of ArcGIS software. The spatial data then projected to the coordinate system, WGS_1984_UTM_Zone_43N for proper working in SWAT model. A land use look up table showing different land use/land cover categories present in the study area in dbase format was prepared for relating the default land use codes in SWAT model. Land use/land cover of study area was reclassified in SWAT model and is shown in Fig. 4.2. Fourteen land use /land cover classes were identified in the area and the details are presented in Table 4.2. The total drainage area of the watershed was found 140.94 $km^{2.}$ It was clear from the LU/LC that it is an agriculture dominated watershed as 33.65% of area comes under agricultural land followed by rubber plantation (23.72 %).

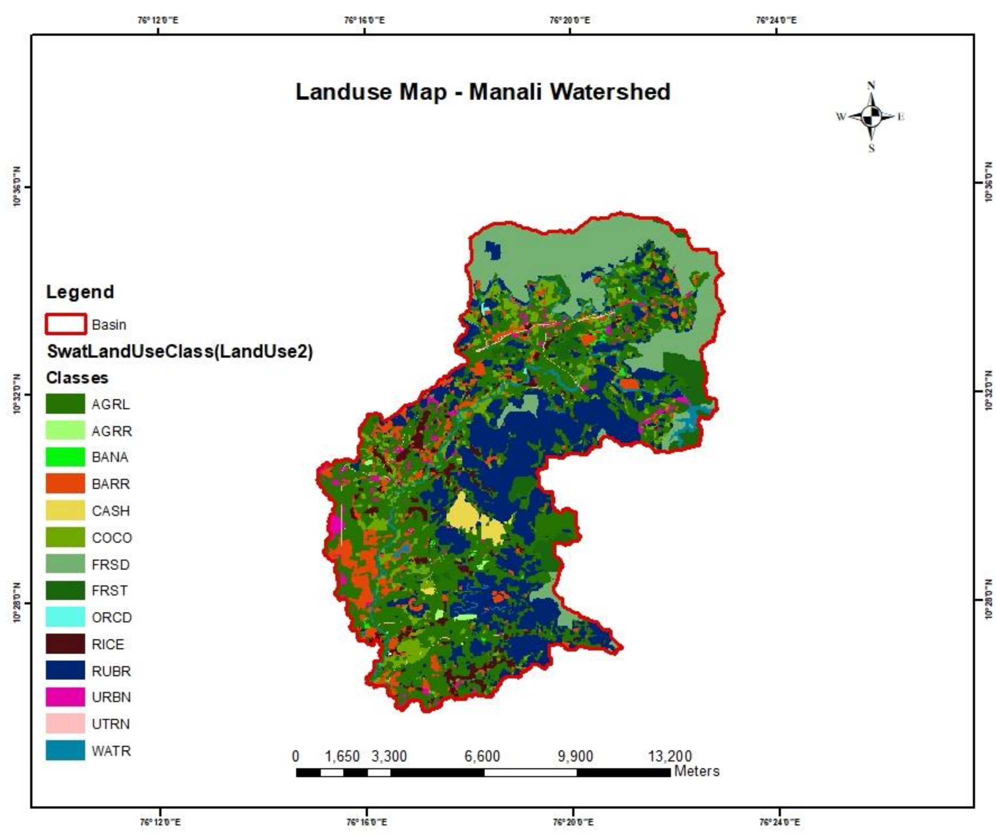

Fig. 4.2 SWAT defined land use/land cover classes in Manali watershed

Table 4.2 Areal statistics of Land use/land cover map of Manali watershed

Sl. No.	LU/LC	Area (ha)	%Watershed area
1	Agricultural (Land-Generic)	4743.51	33.65
2	Agricultural Land-Row	36.13	0.26
3	Bananas	41.12	0.29
4	Barren	853.84	6.06
5	Cashews	174.48	1.24
6	Coconut	880.91	6.25
7	Forest-Deciduous	2174.91	15.43
8	Forest-Mixed	739.06	5.24
9	Orchard	9.90	0.07
10	Rice	477.33	3.39
11	Rubber	3343.58	23.72
12	Residential	231.26	1.64
13	Transportation	60.08	0.43
14	Water	328.41	2.33
TOTAL		14094.5	100

4.1.3 Soil Map

Soil map purchased from Directorate of Soil Survey and Soil Conservation, Kerala State was digitized (polygon vector-based format) in ArcGIS and projected to WGS_1984_UTM_Zone_43N coordinate system. Kootala-Kozhkully, Kootala-Velappaya, Kulamavu, Maraickal, Mulayam-Madakkathara, Painkulam, Vaniampara, Velappaya-Anjur-Koratty, Ayyanthole-Kizhapallikara-Kolazhy were the soil series present in the watershed. A lookup table for soil map was prepared in dbase format. Soil characteristics such as hydraulic conductivity, available soil moisture etc. was calculated by using SPAW software and user soil database was then updated by feeding these characteristics of soil series present in this watershed. The digitized and reclassified soil map is shown in Fig. 4.3.

The areal statistics of soil series and its texture existing in Manali watershed is shown in Table 4.3.

Table 4.3 Areal statistics of soil series and its texture in Manali watershed

Sl. No.	Soil Series	Area (ha)	%Watershed area	Texture of soil
1	Ayyanthole-kizhpillykara	315.39	2.24	Clay loam
2	Kootala-kozhkully	6487.50	46.03	Clay loam
3	Kootala-velapaya	321.71	2.28	Sandy clay loam
4	Maraickal	440.83	3.13	Clay loam
5	Mulayam-madakkathara	393.11	2.79	Clay loam
6	Painkulam	267.01	1.89	Sandy clay loam
7	Vaniampara	2610.28	18.52	Sandy clay loam
8	Velappaya-anjur-koratty	3093.17	21.95	Clay loam
9	Water	165.52	1.17	Waterbody
TOTAL		14094.5	100	

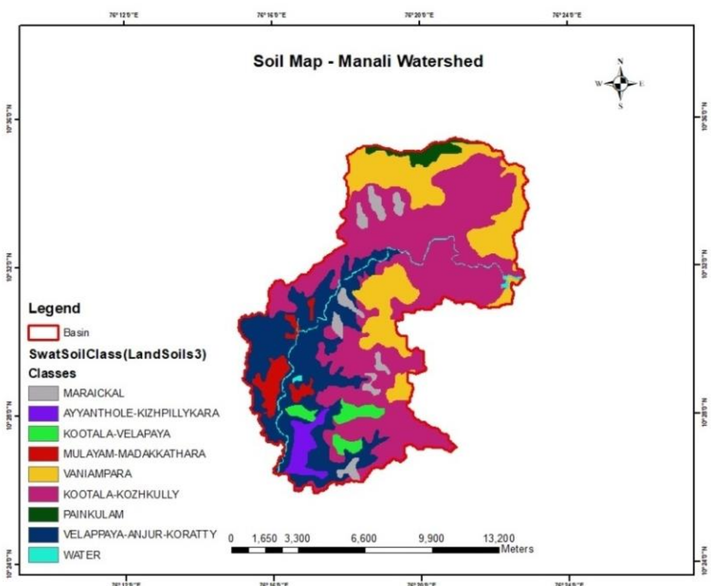

Fig. 4.3 SWAT defined soil map of Manali watershed

4.1.4 Slope Map

The slope map was prepared from DEM and classified into five slope groups and the reclassified slope map is shown in Fig.4.4. The different slope classes and its areal statistics are presented in Table 4.4. It was observed that majority of the area comes under the slope group 0-10 per cent (48%) followed by 10-30 per cent (41%) slope group.

Table 4.4 Areal statistics of slope in Manali watershed

Sl. No.	Slope	Area (ha)	%Watershed area
1	0-10	6771.77	48.05
2	10-30	5746.46	40.77
3	30-50	1348.71	9.57
4	50-70	211.74	1.50
5	70-9999	15.84	0.11
Total		14094.5	100

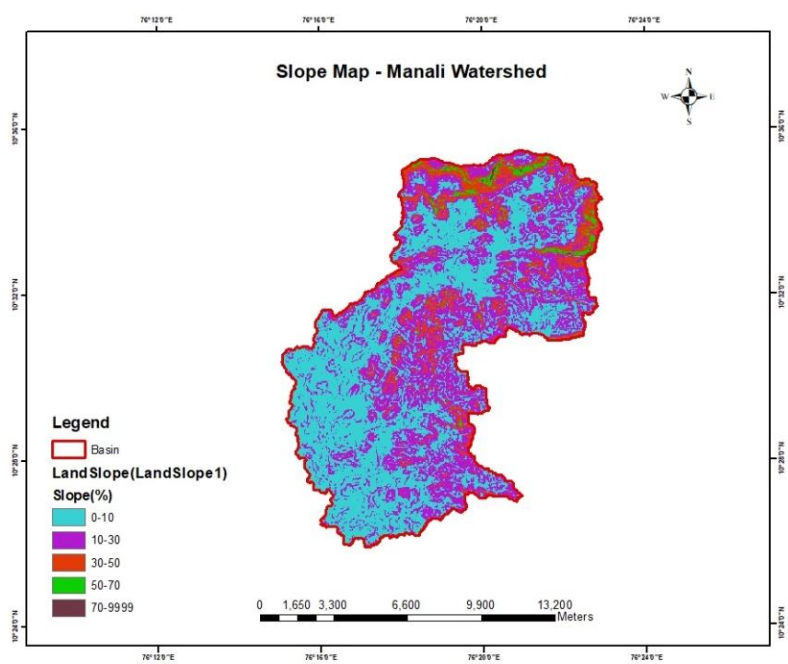

Fig. 4.4 Slope map of Manali Watershed

4.2 DEVELOPMENT OF SWAT MODEL OF THE WATERSHED

4.2.1 SWAT Model Setup

The SWAT model setup consists of preparation of input data, watershed delineation, HRU analysis, weather data definition and test run of the model. This includes writing input table, editing input and SWAT model simulation run. The results of these steps are described as follows.

4.2.2 Watershed Delineation

Watershed delineation was done by using automatic watershed delineator in SWAT model. The entire catchment was delineated into 39 sub-basins with the help of DEM and automatic watershed delineation option. The delineated watershed has a drainage area of 140.94 km^2.The delineated watershed and its sub-basins are shown in Fig. 4.5. The outlet of the watershed was found in sub-basin number 39 of the watershed. The sub-basin area of each watershed is shown in Appendix I.

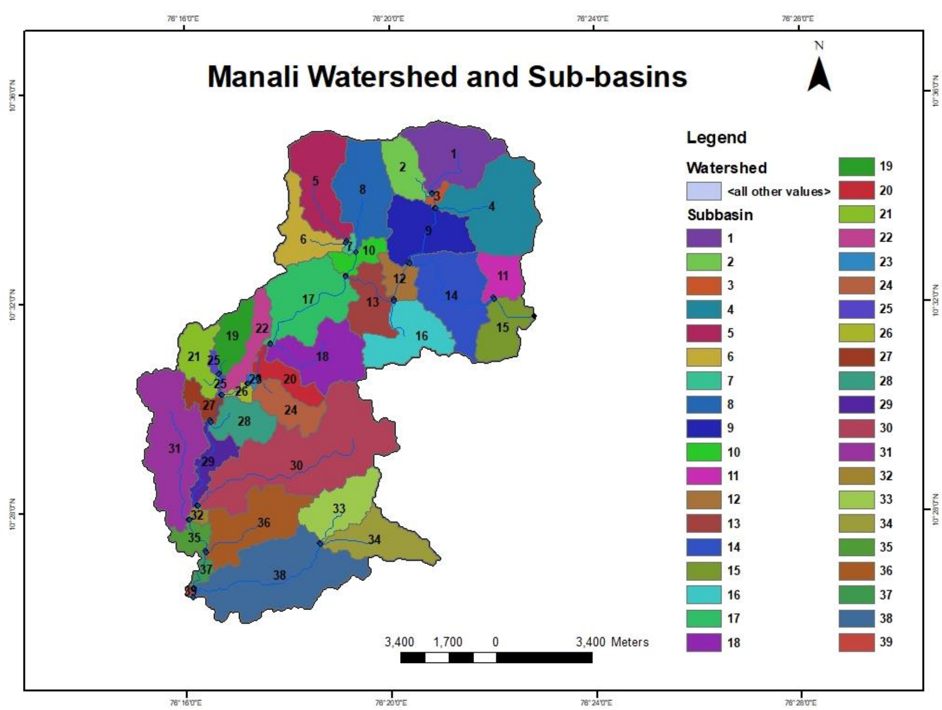

Fig. 4.5 Sub-basin delineation and outlet of watershed

4.2.3 Hydrologic Response Unit (HRU) Analysis

Hydrologic Response Unit (HRU) analysis is the process of dividing the watershed into different hydrologic response unit. For this, maps and user tables of land use, soil and slope are loaded into the model. Then reclassification and overlay analysis was done to obtain the different HRUs.

The sub basins of watershed were divided into different HRUs by assigning an HRU definition of 5, 5, and 10 percent to land use, soil and slope respectively. This combination resulted in 683 HRUs in the whole watershed. The maximum number of HRUs (34 numbers) were found in the sub-basin number 38 followed by sub-basin number 20 (32 numbers).The minimum number of HRUs were in the sub-basin number 3 and 7 (6 numbers) followed by sub-basin number 16 and 27 (8 numbers).

4.2.4 Write Input Tables and SWAT Model Run

Meteorological data loading, writing SWAT input tables and model run were performed here after the HRU analysis.

4.3 SENSITIVITY ANALYSIS, CALIBRATION, VALIDATION AND UNCERTAINTY ANALYSIS OF SWAT MODEL

4.3.1 Sensitivity Analysis

All files in TxtInOut of SWAT model output was fed into SWAT-CUP project directory after the model run. SUFI-2 algorithm of SWAT-CUP was used for performing sensitivity analysis. Among the different parameters, 12 parameters related to flow were selected for sensitivity analysis. Global sensitivity analysis method was used to perform the sensitivity analysis and the parameters were ranked as per the sensitivity ranges. The indicators t-stat and p-value were used to rank the flow parameters. The measure of sensitivity is shown by t-stat value and the significance of sensitivity is shown by p-value. Parameter having largest absolute value of t-stat value is the most sensitive parameter. In the case of p-value, the parameters having value close to zero is most significant. Base flow alpha factor (ALPHA_BF) which is the direct index of ground water flow response to changes in recharge was found to be the most sensitive parameter followed by Mannings ‘n’ value for the main channel (CH_N2). The sensitive parameters selected and their rankings are shown in Table 4.5.

Table 4.5 The selected sensitive parameters and their ranking

Sl. No.	Parameter	Description	t stat-value	p-value	Sensitivity Rank
1	ALPHA_BF.gw	Base flow alpha factor	-14.33	0.00	1
2	CH_N2.rte	Manning’s n value for main channel	8.20	0.00	2
3	CN2.mgt	SCS runoff curve number	-4.39	0.00	3
4	SOL_K (..).sol	Soil hydraulic conductivity	-3.69	0.00	4
5	CH_K2.rte	Effective hydraulic conductivity of main channel	2.72	0.01	5
6	SOL_AWC (..).sol	Available water holding capacity of soil	2.26	0.02	6
7	GW_DELAY.gw	Groundwater delay time (days)	-1.56	0.12	7
8	SURLAG.bsn	Surface lag coefficient	0.69	0.49	8
9	GW_REVAP.gw	Ground water revap coefficient	0.65	0.52	9
10	EPCO.hru	Plant uptake compensation factor	-0.30	0.76	10
11	ESCO	Soil evaporation compensation factor	-0.23	0.81	11
12	GWQMN	Threshold depth of water in shallow aquifer required to return flow to occur	0.21	0.83	12

4.3.2 Calibration and Validation of the Model

Physically based distributed watershed models should be calibrated before they are put in use in the simulation of hydrologic processes. This is to reduce the uncertainty associated with the model prediction. Calibration and validation were done with the help of SWAT-CUP software, by adopting SUFI-2 algorithm. In this study total available datasets of discharge and rainfall were divided into two sets. Calibration of the model was done using 11 years of data from first January 1997 to 31 December 2007. In calibration process the selected parameters where adjusted based on their sensitivity ranges by SWAT-CUP and 500 iterations were performed for getting observed and simulated values of river flow in satisfactory goodness of fit statistically. Among the 12 parameters selected for sensitivity analysis, 10 parameters were selected for calibration. Validation was done for a period of ten years data starting from first January 2008 to 31 December 2017. During validation, the same fitted parameters as that of calibration were inputted and the same number of iterations as that of calibration were performed to get satisfactory results. The default range of parameter values and the fitted values after calibration are shown in Table 4.6. The observed and simulated river flow during calibration and validation is presented in Fig. 4.6 and Fig. 4.7.

Table 4.6 Default ranges of parameters and fitted values after calibration

Parameters	**SWAT-CUP default range**	**Fitted value after calibration**
r__CN2.mgt	-0.2 to 0.2	-0.03
v__ALPHA_BF.gw	0.0 to1.0	0.06
r__EPCO.hru	0 to 1	0.79
a__SURLAG.bsn	0.05 to 24	5.76
v__CH_N2.rte	-0.01 to 0.3	0.032
r__SOL_K().sol	0 to 100	58.22
v__CH_K2.rte	5 to 130	126.83
r__SOL_AWC().sol	-0.2 to 0.4	0.14
v__GW_DELAY.gw	30 to 450	149.16
v__GW_REVAP.gw	0.02 to 0.2	0.19

(v, r and a prefixed before the sensitive parameters in Table represents, the default value is replaced by the parameter, existing value is multiplied by a value (got by adding one to the given value) and added to existing parameter respectively.)

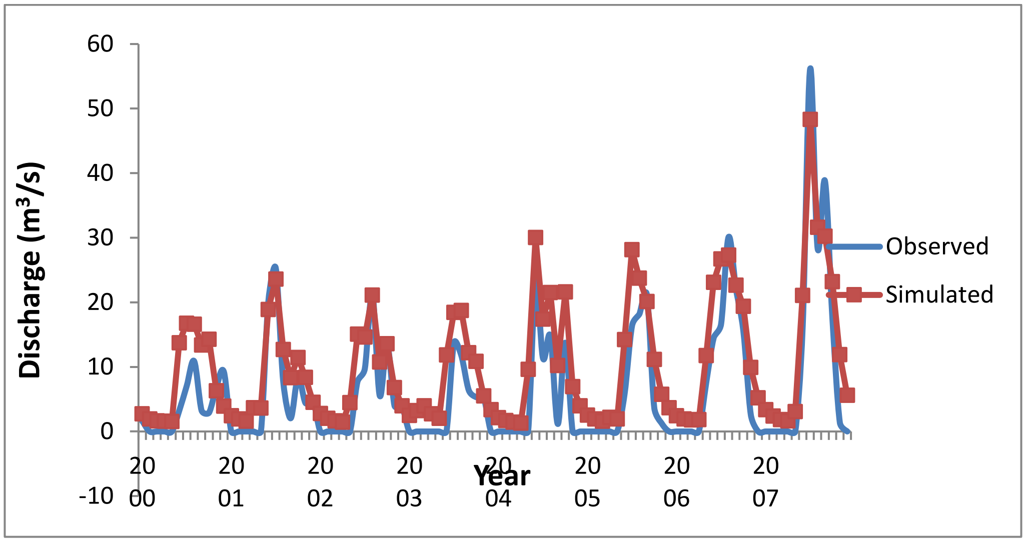

Fig. 4.6 Observed versus simulated monthly streamflow during calibration

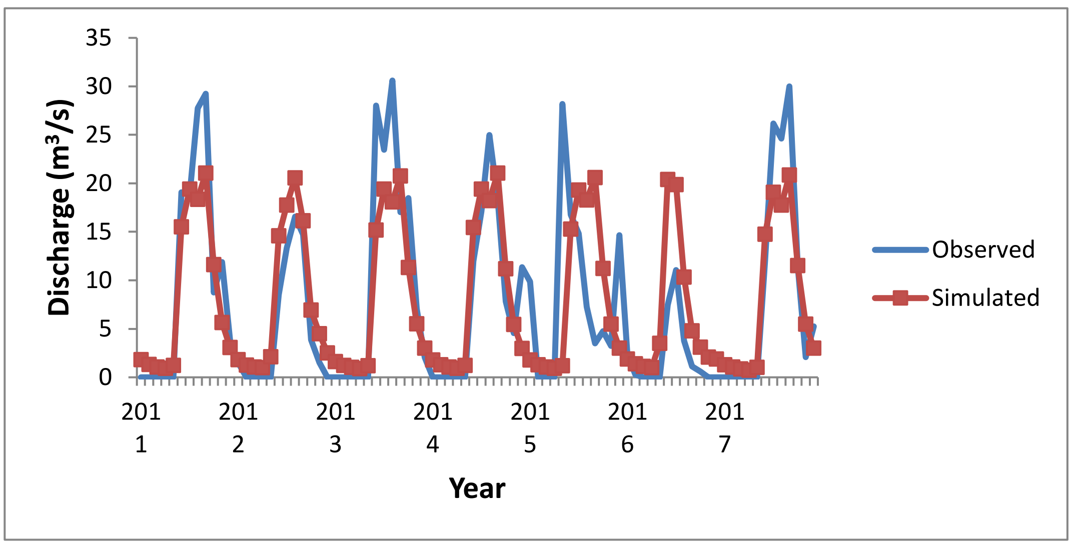

Fig. 4.7 Observed versus simulated monthly streamflow during validation

During calibration period (2000-2007), a good correlation between observed and simulated streamflow was obtained. In most of the years, observed and simulated streamflow values were in best fit and in the case of peak flow, the simulated values are slightly over estimated than observed flow during calibration. During validation period (2011-2017) simulated and observed streamflow were correlated satisfactorily. In most of the months simulated and observed values were in best fit and in the case of peak flow, the simulated values were slightly under estimated by the model.

4.3.3 Evaluation of Model Performance Indices

The statistical comparison parameters Nash-Sutcliffe Coefficient (NSE) and Coefficient of determination (R^2) were used for the statistical evaluation of model simulation. The coefficient of determination indicates the strength of the relationship between the simulated and observed values, whereas, the NSE indicates how well the observed versus simulated values fit in 1:1 line (Santhi *et al*., 2001). Nash-Sutcliffe efficiency (NSE) was found 0.71 during calibration and 0.61 during validation. Santhi *et al*. (2001) reported that NSE greater than 0.5 is considered as adequate for SWAT model application. Narasimhan *et al*. (2007) reported that NSE greater than 0.65 is satisfactory for calibration and validation of SWAT model. The coefficient of determination (R^2) during calibration and validation were found 0.85 and 0.61 respectively. The model performance was considered acceptable when R^2 is greater than 0.6 (Santhi *et al.* 2001; Kang *et al.* 2006). The statistical parameters showed that the model is calibrated and validated well for the watershed. Similar results were also reported by Moraisi *et al.* (2007).

The scatter plot of monthly streamflow during calibration and validation periods are shown in Fig. 4.8 and Fig. 4.9 respectively, which shows a good relationship between the observed and simulated values with good likelihood measures of R^2 as 0.85 and 0.61 during calibration and validation period respectively in this study. The best fit simulation was found during the years 2007 (calibration) and 2015 (validation). The monthly values of observed and predicted stream flow showed good match between them in all the years. All the parameters indicated satisfactory goodness of fit of the model for Manali watershed and hence water balance components can be estimated satisfactorily with SWAT model developed.

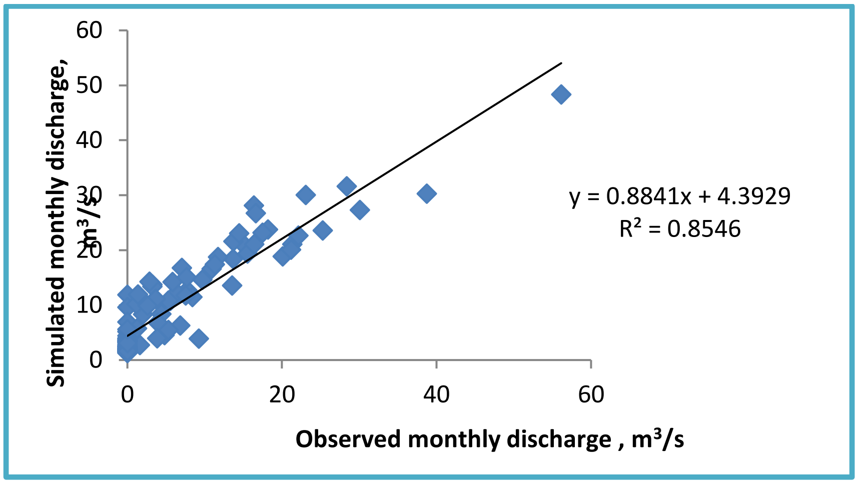

Fig. 4.8 Scatter plot of observed and simulated monthly streamflow during calibration

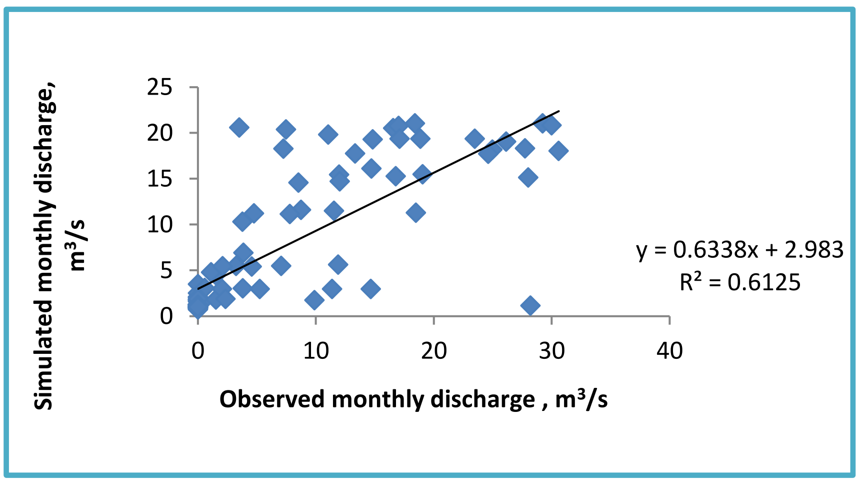

Fig. 4.9 Scatter plot of observed and simulated monthly streamflow during validation

4.3.4 Uncertainty Analysis of Model

The strength of the model calibration and uncertainty was analyzed using the p-factor and r-factor. The p-factor in this study was found 0.34 and 0.35 during calibration and validation while r-factor was found 0.70 and 0.75 during calibration and validation respectively. These results were in conformity with the findings as reported by Varughese (2016) and Deshmukh (2018). The results of uncertainty analysis showed that the SWAT model can be used as a promising tool for water management studies. Table 4.7 shows the values of NSE, R^2, p-factor and r-factor during calibration and validation. It can be inferred from Table 3.3 that, the values of performance indicators in Table 4.7 is in satisfactory range.

Table 4.7 Performance indices of the model during calibration and validation

Monthly discharge		
Statistical indices	**Calibration**	**Validation**
R^2	0.85	0.61
NSE	0.71	0.61
r-factor	0.70	0.75
p-factor	0.34	0.35

4.4 ESTIMATED WATER BALANCE COMPONENTS FROM SWAT MODEL

The water balance components of Manali watershed were estimated with the help of calibrated SWAT model to assess the water availability. The fitted parameter values after calibration and validation were fed into the SWAT model with the help of manual calibration helper and SWAT model run was performed to obtain the water balance components. The monthly average basin values of hydrologic water balance components of Manali watershed obtained from SWAT model output is shown in Table 4.8. The maximum monthly average rainfall of 643.40 mm and surface runoff of 246.64 mm was found in the month of June. The minimum monthly average rainfall of 2.18 mm and runoff of 0.13 mm surface runoff was found in the month of January.

It was observed that the average annual precipitation received in Manali watershed amounts to 2501.2 mm. Out of the total precipitation received, surface runoff component was found 861.06 mm, lateral flow component 978.20 mm, groundwater flow 101.68 mm, actual evapotranspiration 434.07 mm, percolation 213.96 mm, and recharge to deep aquifer 10.54 mm.

Table 4.8 Monthly average water balance components of Manali watershed

Month	Rainfall (mm)	SURFQ (mm)	LATQ (mm)	GWQ (mm)	ET (mm)	Water yield (mm)
Jan	2.18	0.13	0.72	8.24	7.53	9.09
Feb	11.89	3.50	3.62	4.83	18.66	11.95
Mar	18.74	1.68	6.14	2.54	32.07	10.35
Apr	63.72	5.48	23.63	1.12	33.39	30.22
May	227.60	45.99	87.48	0.72	47.59	134.18
June	643.40	246.64	257.33	3.87	56.49	507.84
July	469.22	160.64	199.87	10.10	60.43	370.60
Aug	453.20	178.85	168.86	13.63	55.59	361.33
Sep	321.72	125.08	120.16	14.78	45.77	260.02
Oct	231.86	84.63	87.99	16.07	38.93	188.68
Nov	47.01	7.95	18.81	13.92	25.19	40.68
Dec	10.56	0.51	3.62	11.87	12.46	16.00
Total	2501.08	861.06	978.20	101.68	434.07	1940.94

4.5 ESTIMATION OF WATER AVAILABILITY OF MANALI WATERSHED

Water yield of the watershed was obtained by adding water balance components, surface runoff, lateral flow and groundwater flow contributing to the streamflow. Water yield multiplied by the area of the basin estimated the water availability of the basin. Area of basin was 140.94 km^2. Table 4.9 shows the monthly values of water yield and water availability of Manali watershed. Water yield was found highest (507.84 mm) in the month of June and lowest (9.09 mm) in the month of January. Water availability was found highest in the month of June (71.57 Mm^3) and lowest in the month of January (1.28 Mm^3). Water availability was found good in almost all the months of the year except January, February, March, November and December.

Table 4.9 Monthly water yield and average water availability of the basin

Month	**Water yield (mm)**	**Water availability (Mm^3)**
Jan	9.09	1.28
Feb	11.95	1.68
Mar	10.35	1.46
Apr	30.22	4.26
May	134.18	18.91
Jun	507.84	71.57
Jul	370.60	52.23
Aug	361.33	50.93
Sep	260.02	36.65
Oct	188.68	26.59
Nov	40.68	5.73
Dec	16.00	2.26
TOTAL	1940.94	273.56

4.6 ESTIMATION OF WATER DEMAND IN MANALI WATERSHED

Agriculture water demand, domestic water demand and livestock water demand were calculated separately and added together to get the total water demand of the watershed. The results of various calculations of water demand estimation are explained in the subsequent sections.

4.6.1 Agricultural Water Demand Estimation

The major crops cultivated in Manali watershed are rice, rubber, coconut, banana and cashew which were identified from LU/LC map and their irrigation requirement was estimated using CROPWAT 8 model. The agricultural water demand was then obtained by multiplying the irrigation water requirement (depth in mm) with the area of each crop in the watershed and summed together to get the total agriculture water demand. The various steps and results involved in the determination of irrigation requirement are as follows.

4.6.1.1 Estimation of ET_0 by CROPWAT 8 model

The Penman-Monteith equation was used to estimate the reference crop evapotranspiration in CROPWAT model. The average meteorological data of thirty years (1988-2017) collected from KAU, Vellanikkara were fed into climate module of CROPWAT. The monthly ET_0 values calculated by the model are shown in Table 4.10. The increase in temperature caused an increase in radiation and ET_0 values. But humidity showed an inverse relationship with ET_0. Monthly values of ET_0 showed that ET_0 values were high during January, February and March and it was lowest during July.

Table 4.10 Monthly average values of climatic parameters and ET_0 during 1988-2017

Month	Min. temp (°C)	Max. temp (°C)	Humidity (%)	Wind-velocity (km/day)	Sunshine (hours)	Radiation (MJ/m^2 /day)	ET_0 (mm/day)
Jan	22.2	32.9	56	188	8.9	20.3	5.28
Feb	22.7	34.7	57	146	9.2	22.1	5.46
Mar	24.1	35.8	65	98	8.6	22.4	5.27
Apr	25	34.9	71	84	7.6	21.2	4.89
May	24.8	33.2	76	82	6.2	18.8	4.26
Jun	23.4	30	86	79	3.1	13.9	3.06
Jul	22.9	29.2	87	74	2.4	12.9	2.82
Aug	23.2	29.6	85	73	3.7	15.1	3.24
Sep	23.2	30.5	82	67	5.3	17.4	3.68
Oct	23.1	31.3	81	65	5.6	16.9	3.6
Nov	23.1	31.7	71	111	6.5	17.2	3.91
Dec	22.6	31.8	62	186	7.3	18.4	4.7
Avg	23.4	32.1	73	104	6.3	18	4.18

4.6.1.2 Estimation of crop water requirement (ET_C)

Crop water requirement refers to the amount of water required to compensate for evapotranspiration losses from the cropped field during its specific growth period. It is obtained by multiplying ET_0 with crop coefficient (Kc).

4.6.1.3 Estimation of effective rainfall (P_{eff})

Effective rainfall was estimated based on USDA-SCS method which is embedded in CROPWAT 8 model. Effective rainfall is required to estimate the irrigation requirement of crops.

4.6.1.4 Estimation of irrigation requirement (IR)

Irrigation requirement was obtained by subtracting effective rainfall from crop water requirement (ET_c). Table 4.11, Table 4.12, Table 4.13, Table 4.14, Table 4.15 shows the values of ET_0, K_c, ET_c, P_{eff} and IR of major crops in 10 days interval (decade) obtained from CROPWAT 8 model for Manali watershed.

Table 4.11 ET_0, K_C, ET_C, P_{eff} and IR values of Banana

Month	**Decade**	**Stage**	**ET_0**	**Kc coeff**	**ETc mm/dec**	**P_{eff} mm/dec**	**IR mm/dec**
Aug	1	Init	21.3	1	21.3	40.7	0
Aug	2	Init	32.2	1	32.2	54.3	0
Aug	3	Init	38.0	1	38	54.6	0
Sep	1	Init	35.0	1	35	52.9	0
Sep	2	Init	37.7	1	37.7	51	0
Sep	3	Init	37.7	1	37.7	48.7	0
Oct	1	Deve	36.6	1.01	37	53	0
Oct	2	Deve	35.5	1.04	36.9	52.3	0
Oct	3	Deve	39.5	1.06	41.9	49.8	0
Nov	1	Deve	36.5	1.09	39.8	39	0.9
Nov	2	Deve	39.3	1.12	44	22.7	21.3
Nov	3	Deve	41.4	1.15	47.6	11.8	35.7
Dec	1	Mid	44.6	1.16	51.7	9	42.8
Dec	2	Mid	46.7	1.16	54.2	4.3	49.9
Dec	3	Mid	54.4	1.16	63.1	2.4	60.7
Jan	1	Mid	51.8	1.16	60.1	0.1	60
Jan	2	Mid	52.6	1.16	61	1.5	59.5
Jan	3	Mid	59.5	1.16	69	0.3	68.7
Feb	1	Mid	55.3	1.16	64.1	1.9	62.3
Feb	2	Late	54.9	1.15	63.1	4.4	58.7
Feb	3	Late	42.8	1.1	47.1	7.7	39.4
Mar	1	Late	53.8	1.05	56.5	4.2	52.3
Mar	2	Late	53.0	1	53	13	40.1
Mar	3	Late	55.9	0.94	52.5	4.6	47.9
Total irrigation requirement of Banana							700.1

Table 4.12 ET_0, K_C, ET_C, P_{eff} and IR values of Cashew

Month	Decade	Stage	ET_0	Kc coeff	ETc mm/dec	P_{eff} mm/dec	IR mm/dec
Oct	2	Init	3.57	0.84	3	5.2	0
Oct	3	Init	39.29	0.84	33	49.8	0
Nov	1	Init	36.43	0.84	30.6	39	0
Nov	2	Init	39.29	0.84	33	22.7	10.3
Nov	3	Init	41.43	0.84	34.8	11.8	23
Dec	1	Init	44.52	0.84	37.4	9	28.4
Dec	2	Init	46.67	0.84	39.2	4.3	34.9
Dec	3	Init	54.29	0.84	45.6	2.4	43.2
Jan	1	Init	51.67	0.84	43.4	0.1	43.3
Jan	2	Deve	52.50	0.84	44.1	1.5	42.6
Jan	3	Deve	59.29	0.84	49.8	0.3	49.5
Feb	1	Deve	55.24	0.84	46.4	1.9	44.5
Feb	2	Deve	54.88	0.84	46.1	4.4	41.7
Feb	3	Deve	42.74	0.84	35.9	7.7	28.2
Mar	1	Deve	53.69	0.84	45.1	4.2	40.9
Mar	2	Deve	53.33	0.84	44.8	13	31.8
Mar	3	Deve	56.19	0.84	47.2	4.6	42.6
Apr	1	Deve	49.76	0.84	41.8	17.4	24.4
Apr	2	Mid	48.69	0.84	40.9	27.6	13.4
Apr	3	Mid	48.21	0.84	40.5	24.5	16
May	1	Mid	45.71	0.84	38.4	42.9	0
May	2	Mid	42.74	0.84	35.9	43.8	0
May	3	Mid	43.69	0.84	36.7	51.3	0
Jun	1	Mid	33.21	0.84	27.9	60.9	0
Jun	2	Mid	29.29	0.84	24.6	65.8	0
Jun	3	Mid	29.52	0.84	24.8	65.4	0
Jul	1	Mid	29.29	0.84	24.6	62.3	0
Jul	2	Late	27.38	0.84	23	64.9	0
Jul	3	Late	30.83	0.84	25.9	62.4	0

Aug	1	Late	30.24	0.84	25.4	58.2	0
Aug	2	Late	32.26	0.84	27.1	54.3	0
Aug	3	Late	37.98	0.84	31.9	54.6	0
Sep	1	Late	35.00	0.84	29.4	52.9	0
Sep	2	Late	37.74	0.84	31.7	51	0
Sep	3	Late	37.62	0.84	31.6	48.7	0
Oct	1	Late	36.67	0.84	30.8	53	0
Oct	2	Late	32.14	0.84	27	47.1	0
Total irrigation requirement of Cashew							**558.7**

Table 4.13 ET_0, K_C, ET_C, P_{eff} and IR values of Coconut

Month	Decade	Stage	ET_0	Kc coeff	ETc mm/dec	P_{eff} mm/dec	IR mm/dec
May	1	Init	45.79	0.95	43.5	42.9	0.5
May	2	Init	42.74	0.95	40.6	43.8	0
May	3	Init	43.68	0.95	41.5	51.3	0
Jun	1	Init	33.16	0.95	31.5	60.9	0
Jun	2	Init	29.26	0.95	27.8	65.8	0
Jun	3	Init	29.58	0.95	28.1	65.4	0
Jul	1	Init	29.26	0.95	27.8	62.3	0
Jul	2	Init	27.37	0.95	26	64.9	0
Jul	3	Deve	30.84	0.95	29.3	62.4	0
Aug	1	Deve	30.21	0.95	28.7	58.2	0
Aug	2	Deve	32.11	0.95	30.5	54.3	0
Aug	3	Deve	38.09	0.94	35.8	54.6	0
Sep	1	Deve	35.00	0.94	32.9	52.9	0
Sep	2	Deve	37.66	0.94	35.4	51	0
Sep	3	Deve	37.45	0.94	35.2	48.7	0
Oct	1	Deve	36.77	0.93	34.2	53	0

Oct	2	Deve	35.59	0.93	33.1	52.3	0
Oct	3	Mid	39.25	0.93	36.5	49.8	0
Nov	1	Mid	36.34	0.93	33.8	39	0
Nov	2	Mid	39.14	0.93	36.4	22.7	13.7
Nov	3	Mid	41.29	0.93	38.4	11.8	26.6
Dec	1	Mid	44.41	0.93	41.3	9	32.3
Dec	2	Mid	46.56	0.93	43.3	4.3	39
Dec	3	Mid	54.19	0.93	50.4	2.4	48
Jan	1	Mid	51.61	0.93	48	0.1	47.9
Jan	2	Mid	52.37	0.93	48.7	1.5	47.2
Jan	3	Late	59.03	0.93	54.9	0.3	54.6
Feb	1	Late	55.00	0.92	50.6	1.9	48.8
Feb	2	Late	54.84	0.91	49.9	4.4	45.5
Feb	3	Late	42.78	0.9	38.5	7.7	30.8
Mar	1	Late	53.93	0.89	48	4.2	43.8
Mar	2	Late	53.64	0.88	47.2	13	34.2
Mar	3	Late	55.91	0.88	49.2	4.6	44.6
Apr	1	Late	49.66	0.87	43.2	17.4	25.7
Apr	2	Late	48.60	0.86	41.8	27.6	14.2
Apr	3	Late	48.24	0.85	41	24.5	16.5
Total irrigation requirement of Coconut							**613.8**

Table 4.14 ET_0, K_C, ET_C, P_{eff} and IR values of Rubber

Month	**Decade**	**Stage**	**ET_0**	**Kc coeff**	**ETc mm/dec**	**P_{eff} mm/dec**	**IR mm/dec**
Jun	1	Init	33.16	0.95	31.5	60.9	0
Jun	2	Init	29.26	0.95	27.8	65.8	0
Jun	3	Init	29.58	0.95	28.1	65.4	0

Jul	1	Init	29.26	0.95	27.8	62.3	0
Jul	2	Init	27.37	0.95	26	64.9	0
Jul	3	Init	30.84	0.95	29.3	62.4	0
Aug	1	Init	30.32	0.95	28.8	58.2	0
Aug	2	Init	32.21	0.95	30.6	54.3	0
Aug	3	Deve	38.00	0.95	36.1	54.6	0
Sep	1	Deve	34.95	0.95	33.2	52.9	0
Sep	2	Deve	37.68	0.95	35.8	51	0
Sep	3	Deve	37.68	0.95	35.8	48.7	0
Oct	1	Deve	36.63	0.95	34.8	53	0
Oct	2	Deve	35.58	0.95	33.8	52.3	0
Oct	3	Deve	39.37	0.95	37.4	49.8	0
Nov	1	Deve	36.42	0.95	34.6	39	0
Nov	2	Deve	39.26	0.95	37.3	22.7	14.6
Nov	3	Mid	41.47	0.95	39.4	11.8	27.5
Dec	1	Mid	44.53	0.95	42.3	9	33.3
Dec	2	Mid	46.63	0.95	44.3	4.3	40
Dec	3	Mid	54.32	0.95	51.6	2.4	49.2
Jan	1	Mid	51.68	0.95	49.1	0.1	49
Jan	2	Mid	52.42	0.95	49.8	1.5	48.3
Jan	3	Mid	59.37	0.95	56.4	0.3	56.1
Feb	1	Mid	55.16	0.95	52.4	1.9	50.6
Feb	2	Mid	54.84	0.95	52.1	4.4	47.7
Feb	3	Late	42.74	0.95	40.6	7.7	32.9
Mar	1	Late	53.68	0.95	51	4.2	46.8
Mar	2	Late	53.26	0.95	50.6	13	37.7
Mar	3	Late	56.11	0.95	53.3	4.6	48.8
Apr	1	Late	49.79	0.95	47.3	17.4	29.9
Apr	2	Late	48.74	0.95	46.3	27.6	18.7
Apr	3	Late	48.21	0.95	45.8	24.5	21.3
May	1	Late	45.79	0.95	43.5	42.9	0.5
May	2	Late	42.74	0.95	40.6	43.8	0
May	3	Late	43.68	0.95	41.5	51.3	0

Total irrigation requirement of Rubber	653

Table 4.15 ET_0, K_C, ET_C, P_{eff} and IR values of Rice

Month	Decade	Stage	ET_0	Kc coeff	ETc mm/dec	P_{eff} mm/dec	IR mm/dec
Sep	1	Nurs	1.75	1.2	2.1	26.4	0
Sep	2	Nurs/LPr	19.82	1.13	22.4	51	22.9
Sep	3	Nurs/LPr	37.83	1.06	40.1	48.7	0
Oct	1	Init	36.76	1.08	39.7	53	71.7
Oct	2	Init	35.64	1.1	39.2	52.3	0
Oct	3	Init	39.36	1.1	43.3	49.8	0
Nov	1	Deve	36.64	1.1	40.3	39	1.3
Nov	2	Deve	39.20	1.13	44.3	22.7	21.6
Nov	3	Deve	41.48	1.15	47.7	11.8	35.9
Dec	1	Mid	44.53	1.17	52.1	9	43.1
Dec	2	Mid	46.75	1.17	54.7	4.3	50.4
Dec	3	Mid	54.36	1.17	63.6	2.4	61.2
Jan	1	Mid	51.79	1.17	60.6	0.1	60.5
Jan	2	Late	52.41	1.16	60.8	1.5	59.3
Jan	3	Late	59.37	1.11	65.9	0.3	65.6
Feb	1	Late	55.28	1.06	58.6	1.9	56.7
Feb	2	Late	10.97	1.03	11.3	0.9	11.3
Total irrigation requirement of Rice							**561.4**

4.6.1.5 Monthly agriculture water demand

The monthly agriculture water demand from cropped area was obtained by multiplying the individual crop irrigation requirement with their corresponding cropped area. The monthly agriculture water demand of the major crops in the watershed is shown in Table 4.16.

The highest monthly agriculture water demand was observed in the month of January (7.65 Mm^3) followed by December (6.13 Mm^3) and February (6.08 Mm^3). It was found that irrigation was not needed during May, June, July, August, September and October because the available rainwater was sufficient to meet the crop water requirement.

Table 4.16 Monthly agriculture water demand of major crops in Manali watershed

Month	Agriculture water demand (Mm^3)					
	Banana	Cashew	Coconut	Rubber	Rice	Agriculture water demand
January	0.08	0.24	1.32	5.13	0.88	7.65
February	0.07	0.20	1.10	4.39	0.32	6.08
March	0.06	0.20	1.08	4.46	0.00	5.80
April	0.00	0.09	0.50	2.34	0.00	2.93
May	0.00	0.00	0.00	0.02	0.00	0.02
June	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00
September	0.00	0.00	0.00	0.00	0.11	0.11
October	0.00	0.00	0.00	0.00	0.34	0.34
November	0.02	0.06	0.36	1.41	0.28	2.13
December	0.06	0.19	1.05	4.10	0.74	6.13
Total	0.29	0.97	5.41	21.83	2.68	31.18

4.6.1.6 Crop wise agriculture water demand in Manali watershed

Table 4.17 shows total crop wise agriculture water demand in the watershed. In the case of seasonal crops, the irrigation requirement of Banana was found highest (700.1 mm) followed by Rice (561.4 mm). In the case of perennials crops, it was highest (653 mm) for rubber and lowest (558.7 mm) for cashew. In Manali watershed comparatively larger area was utilized for cultivating rubber. Hence agriculture water demand was highest for rubber followed by rice and coconut. If rubber and cashew are treating as rainfed crops, that irrigation requirement forms the surplus water in the watershed. Many researchers have proved that irrigation in rubber and cashew has increased the yield (Vijayakumar *et al*., 1998; Mangalassery *et al*., 2019). Hence irrigation requirement of these crops were considered in this study.

Table 4.17 Crop wise water demand in Manali watershed

Crop	Area (ha)	IR (mm)	Total agriculture demand (Mm^3)
Rice	477.33	561.4	2.68
Cashew	174.48	558.7	0.97
Coconut	880.91	613.8	5.41
Rubber	3343.58	653	21.83
Banana	41.12	700.1	0.29
Total	4917.43	3087	31.18

4.7 ESTIMATION OF NON-AGRICULTURAL WATER DEMAND

Non-agriculture water demand includes human water demand and livestock water demand.

4.7.1 Estimation of Human Water Demand

The human population water demand was obtained by multiplying per capita water requirement with population data.

4.7.1.1 Determination of population of Manali watershed

Population of Manali watershed obtained by population density concept is shown in Table 4.18.

Table 4.18 Population of Manali watershed by population density concept

YEAR	Population of Thrissur	Population density of Thrissur	Population of Manali watershed
2011	3121200	1031.12	145326
2001	2974232	982.57	138483
1991	2737311	904.30	127452
1981	2439633	805.96	113592
1971	2128877	703.30	99123

4.7.1.2 Estimation of forecasted population for the year 2021

Decrease rate of growth or decreasing rate method was then used for population forecasting for the year 2021. In this method, the average decrease in the percentage increase was worked out and then subtracted from the latest percentage increase of last known decade. Table 4.19 shows estimation of average decrease in percentage increase of population.

Table 4.19 Estimation of average decrease in percentage increase of population

Year	Population of Manali watershed	Increase in population	Percentage increase in population	Decrease in percentage increase
1971	99123			
1981	113592	14469	14.59	
1991	127452	13860	12.02	2.39
2001	138483	11031	8.65	3.55
2011	145326	6843	4.94	3.71
Total				9.65
Average				3.22

Estimation of net percentage increase in population was calculated by subtracting average decrease in percentage increase from percentage increase in population of the year 2011. Then forecasted population of 2021 was estimated by adding the product of net percentage increase in population and population of 2011 to the population of 2011. Thus the forecasted population in the year of 2021 was obtained as 147830. Calculation procedure for population forecasting is appended in Appendix II and III.

4.7.1.3 Population interpolation and estimation of average population

Population data of the recent 6 years from 2012 to 2017 were obtained by interpolation of population of the year 2011 and the forecasted population 2021. Population obtained by interpolation is presented in Table 4.20. The average population of these six years was taken as the population of Manali watershed and is obtained as 146077. Total population demand of water was obtained by multiplying this average population of 146077 with per capita water demand of 270 litres per capita per day.

Table 4.20 Population of 2012 to 2017 using interpolation method

Year	Population by interpolation
2012	145576
2013	145827
2014	146077
2015	146328
2016	146576
2017	146828
AVERAGE	146077

4.7.2 Estimation of Monthly Livestock Water Demand

Livestock water demand was obtained by multiplying livestock population with per capita water requirement of livestock.

4.7.3 Monthly Water Demand of the Watershed

Total monthly water demand is the sum of agricultural and non-agricultural water demand and is presented in Table 4.21. Water demand was highest in the month of January (8.91 Mm^3) followed by December (7.40 Mm^3). Water demand was lowest in the month of June (1.23 Mm^3) followed by July and August (1.27 Mm^3). Out of the various water demands, agricultural water demand has taken the major share.

Table 4.21 Total monthly water demand

Month	Agriculture demand (Mm^3)	Livestock demand (Mm^3)	Population demand (Mm^3)	Total demand (Mm^3)
Jan	7.65	0.043	1.22	8.91
Feb	6.08	0.041	1.14	7.26
Mar	5.80	0.043	1.22	7.06
Apr	2.93	0.042	1.18	4.15
May	0.02	0.043	1.22	1.29
June	0.00	0.042	1.18	1.23
July	0.00	0.043	1.22	1.27
Aug	0.00	0.043	1.22	1.27
Sep	0.11	0.042	1.18	1.33
Oct	0.34	0.043	1.22	1.61
Nov	2.13	0.042	1.18	3.35
Dec	6.13	0.043	1.22	7.40
Total	31.18	0.51	14.44	46.13

4.8 ANALYSIS OF WATER DEMAND AND WATER AVAILABILITY IN THE WATERSHED

The analysis of monthly water availability and water demand in Manali watershed was carried out to get an idea of current water status in the watershed. The monthly water availability, demand and surplus/deficit is shown in Table 4.22 and its variation is shown in Fig. 4.10

Table 4.22 Monthly water availability, water demand and surplus/deficit in Manali watershed

Month	Total availability (Mm^3)	Total demand (Mm^3)	Surplus/Deficit (Mm^3)	
Jan	1.28	8.91	-7.63	Deficit
Feb	1.68	7.26	-5.58	Deficit
Mar	1.46	7.06	-5.60	Deficit
Apr	4.26	4.15	0.11	Sufficient
May	18.91	1.29	17.62	Surplus
Jun	71.57	1.23	70.35	Surplus
Jul	52.23	1.27	50.97	Surplus
Aug	50.93	1.27	49.66	Surplus
Sep	36.65	1.33	35.31	Surplus
Oct	26.59	1.61	24.98	Surplus
Nov	5.73	3.35	2.38	Sufficient
Dec	2.26	7.40	-5.15	Deficit
Total	273.56	46.13	227.43	Surplus

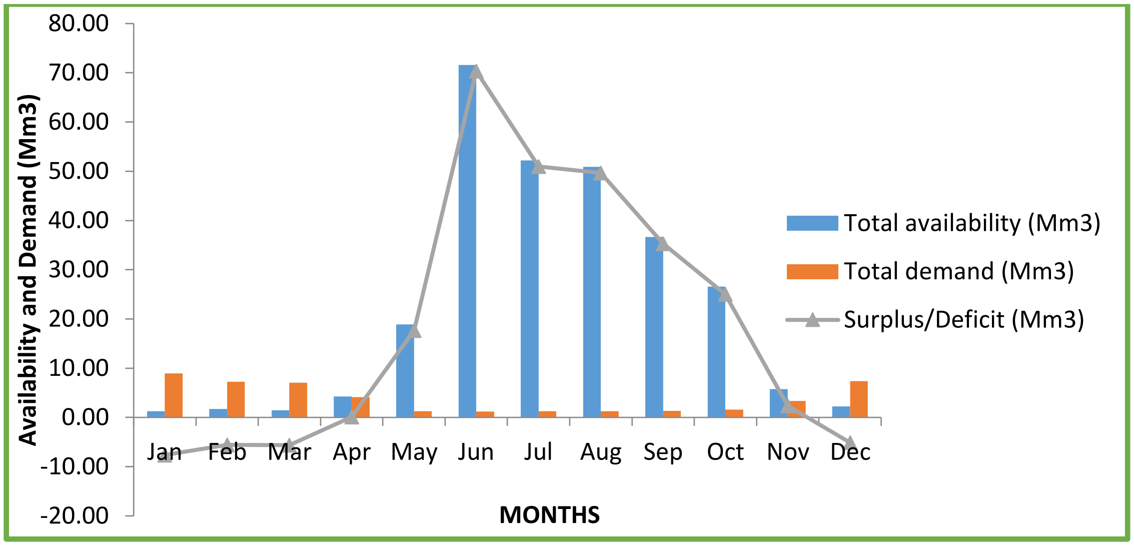

Fig. 4.10 Monthly variation of water availability, demand and surplus/deficit in Manali watershed

The analysis of monthly water availability and water demand in the watershed (Table 4.22) revealed that there is surplus amount of water in the Manali watershed in all the months except January, February, March and December. Even though surplus water is available in almost all the months, water scarcity, shortage of irrigation water and low productivity are experienced in the watershed. The lack of land use planning and absence of conservation measures in the watershed may be the reason for the increased runoff, soil loss and nutrient loss in the watershed. This may affect the sustainable socioeconomic development of the watershed. Hence it is of prime importance to adopt suitable soil and water conservation measures in the watershed.

4.9 PLANNING CONSERVATION MEASURES IN MANALI WATERSHED

The average annual basin value of rainfall in Manali watershed was found 2501.08 mm. Out of which the surface runoff (861.06mm), lateral and groundwater flow together (1089.45 mm) forms about 78 per cent of rainfall and contributes to runoff process as stream flow and reach the outlet and it is lost if it is not properly conserved.

In order to identify the suitable sites for water conservation measures the weighted overlay analysis of various thematic maps were carried out in GIS for site suitability modelling. Land use/land cover map, soil permeability map, slope map, surface runoff map and drainage density map were the different thematic layers used for site suitability modelling. Weighted overlay analysis was performed to form an integrated map which shows suitable sites for suggesting water conservation measures. The selection of the type of conservation measures were done as per IMSD guidelines. The various thematic maps prepared were prepared for planning water conservation measures are as follows.

4.9.1 Landuse/ Land Cover (LU/LC) Map

Information about the purpose of land is obtained from land use land cover map. Land use/land cover classes of Manali watershed were found as agriculture land (mixed crop and row crops), banana, barren land, cashew, deciduous and mixed forest, orchard, rice, rubber, urban area (residential and transportation) and water body. The reclassified LU/LC map is shown in Fig 4.11. Usually water demand is high in agricultural lands. So water conservation measures are necessary in agricultural lands. Barren lands are more prone to runoff. So the conservation measures are required in barren lands. Hence high weights were given for agricultural lands and barren lands for site suitability modelling.

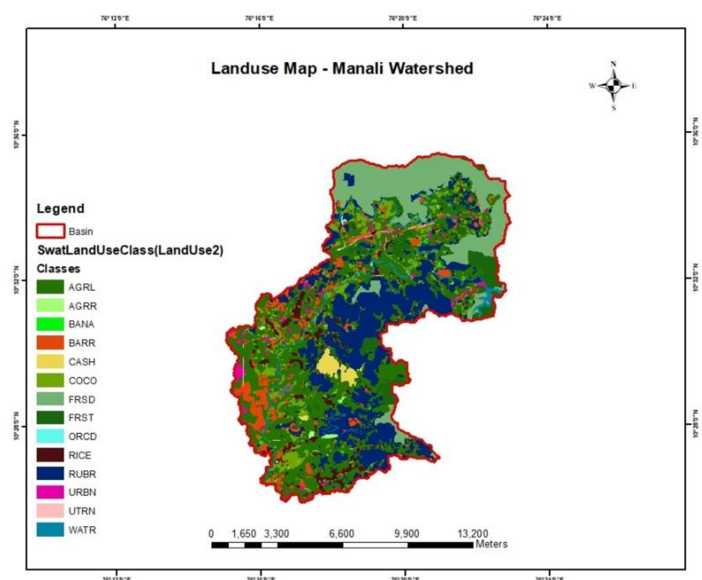

Fig. 4.11 Land use/Land cover map for planning conservation measures

4.9.2 Soil Permeability Map

Permeability of soil is an important parameter which determines the rate of infiltration. The soil permeability map was prepared based on the hydrological soil groups. The watershed identified only two permeability groups namely C and D. The soil permeability map generated is shown in Fig 4.12. High/moderate runoff potential and slow infiltration rates are the characteristics of soil group C and high runoff potential with very low infiltration is the characteristics of soil group D. The spatial variation of soil infiltration and permeability were shown by this map. Hence water conservation measures can be planned in areas with Hydrologic Soil Group D for reducing the runoff and storing more water.

4.9.3 Slope Map

Slope is an important parameter for site selection of water harvesting structures. The runoff and movement of surface water depends on the slope of the area. As the steepness increases the speed of runoff process also increases. Steep slopes are not much recommended for planning conservation measures. The western and southern portion having lower slope is suitable for planning conservation measures and hence high weights were given for less slope areas. The reclassified slope map is shown in Fig. 4.13.

4.9.4 Drainage Density Map and Stream Order Map

Drainage density is the length of the stream per unit area and it plays a significant role in surface-runoff processes. Dendritic drainage pattern was identified in Manali watershed. Stream ordering based on Strahler method was done. Watershed consisted of 1^{st}, 2^{nd} and 3^{rd} order streams only. Higher order stream has high drainage density which implies high runoff. The drainage density map and stream order map are shown in Fig. 4.14 and Fig. 4.15 respectively.

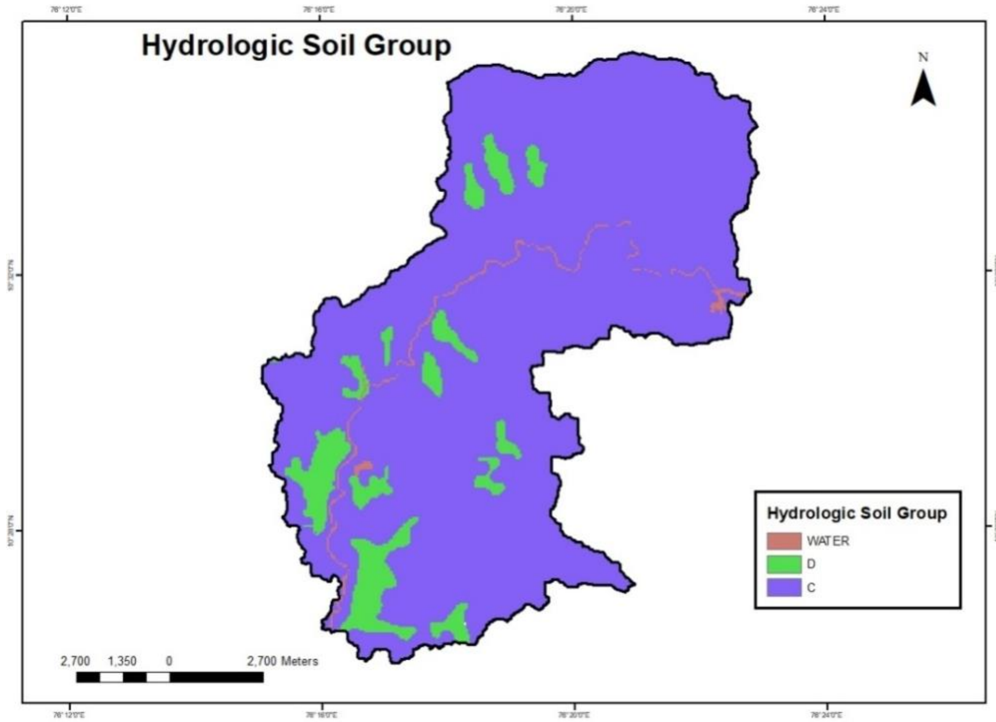

Fig. 4.12 Soil permeability map of Manali watershed

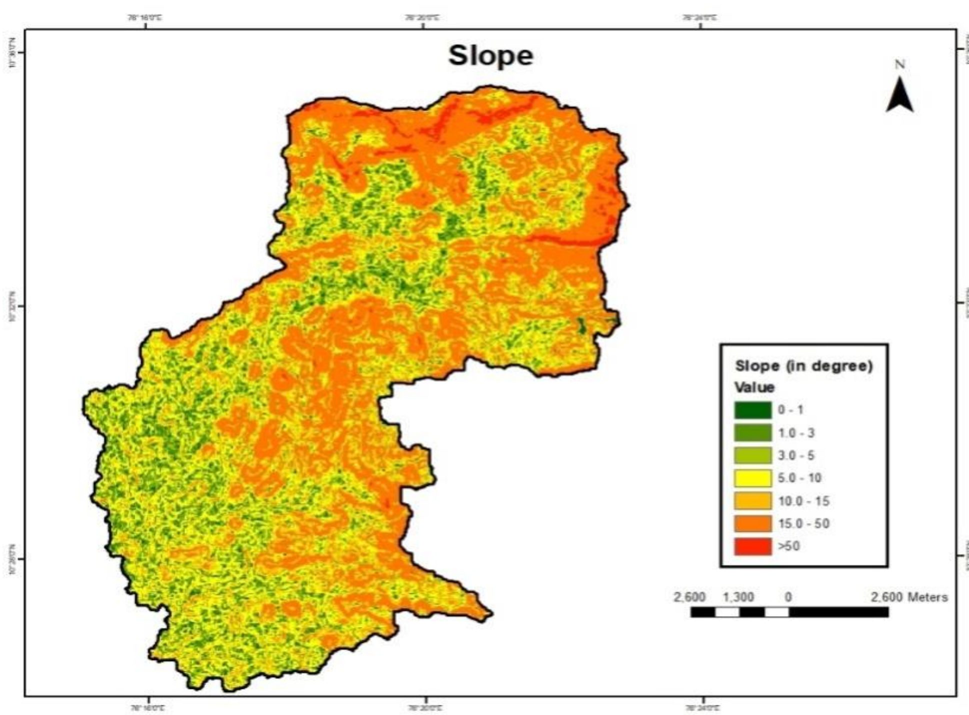

Fig. 4.13 Reclassified slope map of Manali watershed

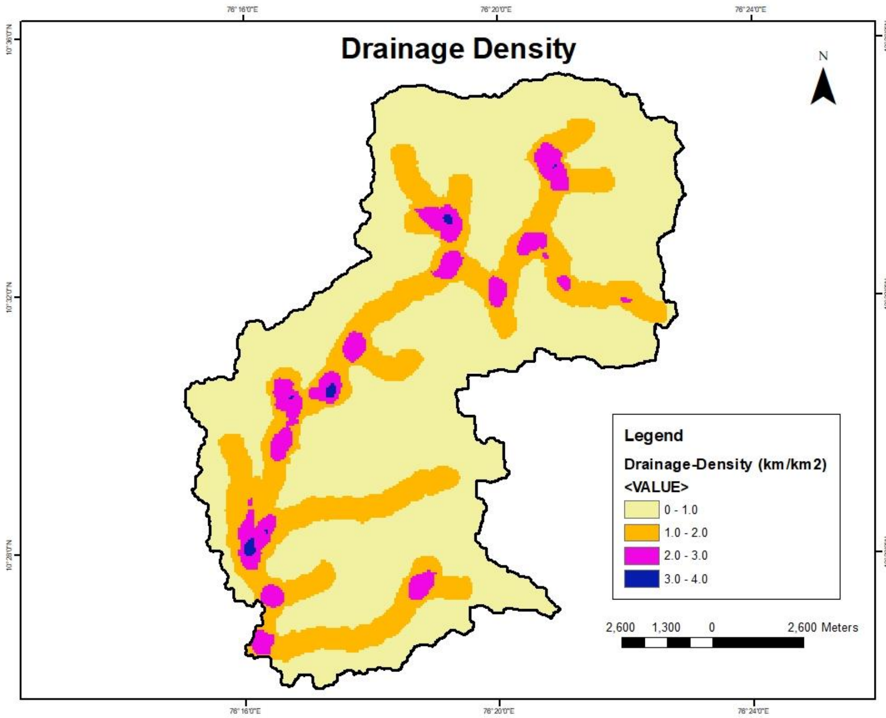

Fig. 4.14 Drainage density map of Manali watershed

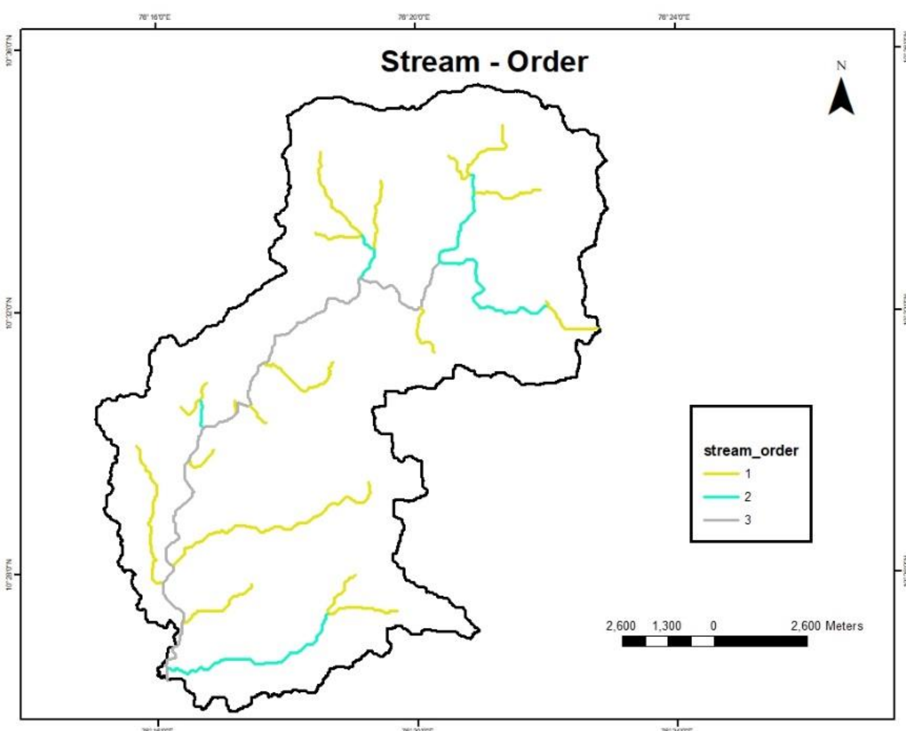

Fig. 4.15 Stream order map of Manali watershed

4.9.5 Surface Runoff Map

Runoff map was prepared by calculating the runoff contribution of each sub basin from SWAT model output. The surface runoff was found to be more in south and south-western portion of the watershed. So it is necessary to plan conservation measures in these portions of watershed. Hence based on the surface runoff, sub-basins were divided into five classes of runoff classes and shown in Fig. 4.16.

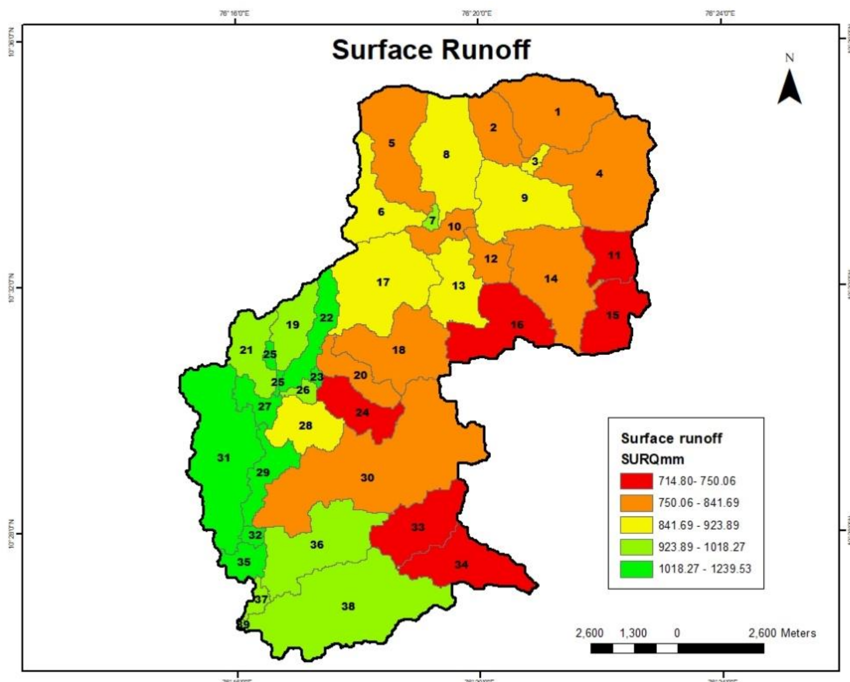

Fig. 4.16 Surface runoff map of Manali watershed

4.9.6 Site Suitability Modelling for Identifying the Site for Conservation Measures

Suitability modelling was done by multi criteria weighted overlay analysis of the various thematic. Thus watershed was divided into three categories namely highly suitable areas, moderately suitable areas and less suitable areas. The site suitability map is shown in Fig. 4.17. It was found that 15 % of total area highly suitable, 84.8% of total area moderately suitable and 0.2 % of the area less suitable for planning conservation measures.

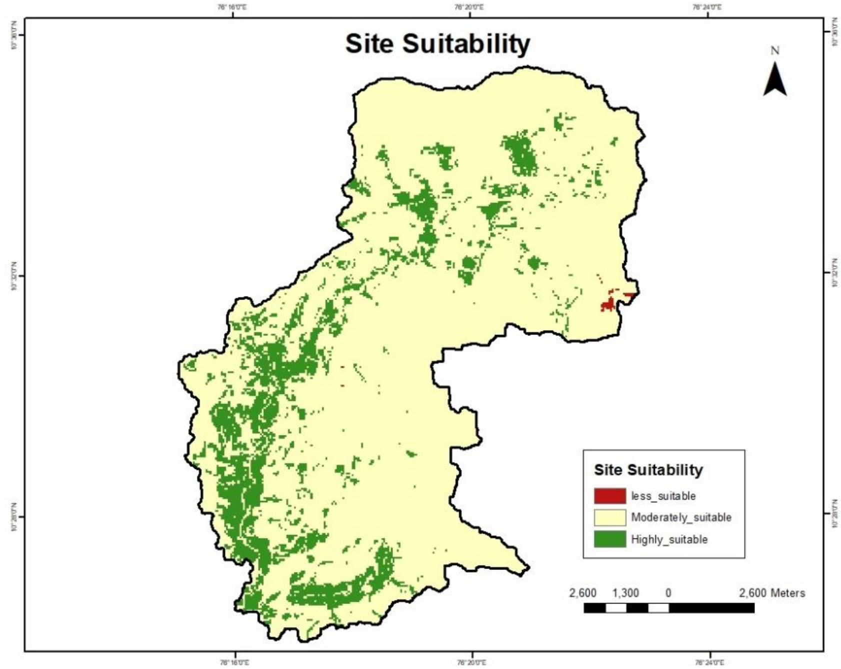

Fig. 4.17 Site suitability map of Manali watershed

4.9.7 Identification of Location and Type of Water Conservation Measures

For identification of suitable site and type of conservation measures, the multi-layer integrated maps and technical guidelines suggested by IMSD (1995) were used.

Farm ponds can be made by either constructing an embankment across a water source or by excavating pits. Normally low-cost structures are used for storage of water. Gentle slope and small catchment area are the required site condition for the farm ponds. Farm ponds were found more suitable in the area. 32 number of farm ponds were identified and they were mainly proposed in southern and north western portion of Manali watershed.

Percolation ponds are normally suggested for recharging aquifer and are used where surface storage is available for restricted period. Required site conditions are moderate to high permeability area. Percolation ponds were found suitable in seven sites and they are located in the southern region of Manali watershed which helps to improve the ground water recharge.

Check dam are the water harvesting structure for surface storage and its use restricted to domestic and irrigation needs and the site conditions for check dam are across well-defined straight stream channel. Hence check dams were proposed across the streams which reduce the velocity of stream flow and thus reduce erosion. Totally four check dams were proposed in Manali watershed.

Sub-surface dykes are used to check the base flow in river and reduce evaporation losses and can be located nearby valley and streams of order above four. Straight and wide river with 2 to 3 m thick sandy-gravely bed material and stream order greater than four are the required condition for constructing subsurface dykes. As there is no stream of order greater than four, subsurface dykes were not proposed in this study area.

The proposed sites for check dams, percolation tank and farm ponds identified in the watershed are shown in Fig. 4.18. Though the sites for water conservation measures were suggested by conducting hydrological modelling and GIS, the practical implementation of these measures, depends on other factors like economy, site conditions and social implications of the area.

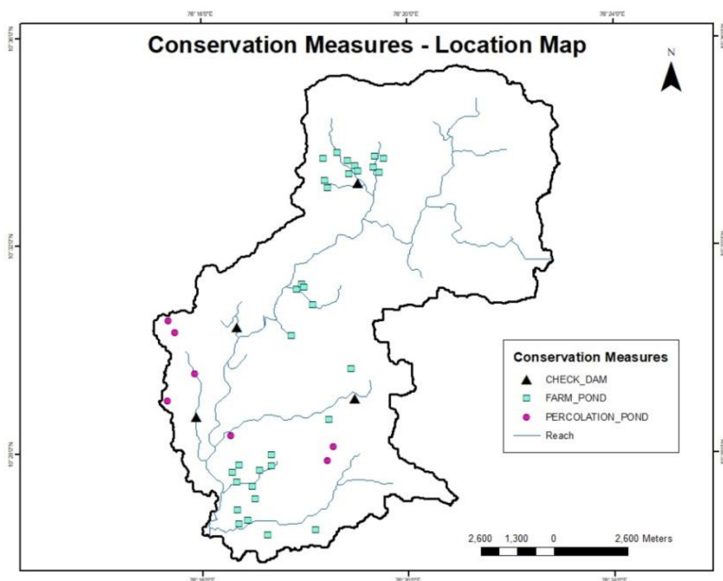

Fig. 4.18 Map showing proposed location and type of water conservation measures in Manali watershed

4.10 PLANNING OF CROPPING PATTERN IN MANALI WATERSHED

Cropping pattern was suggested based on soil, topography, existing crops and aridity index. Crops suitable for Manali watershed based on soil textures such as sandy clay loam and clay loam are paddy, coconut, arecanut, banana, tapioca, vegetables, yam, pepper and pineapple. Based on physiography, forest vegetation and rubber are suitable in mid-upland region, coconut, arecanut, banana, cashew, rubber, nutmeg and rice are suitable for midland region. Rice, coconut, banana are preferred in lowland region. Fig. 4.19 shows the physiographic map of Manali watershed.

Major crops existing in watershed were arecanut, banana, coconut, paddy, nutmeg, cashew and rubber. Spatial representation of these crops in Manali watershed is shown in Fig. 4.20.

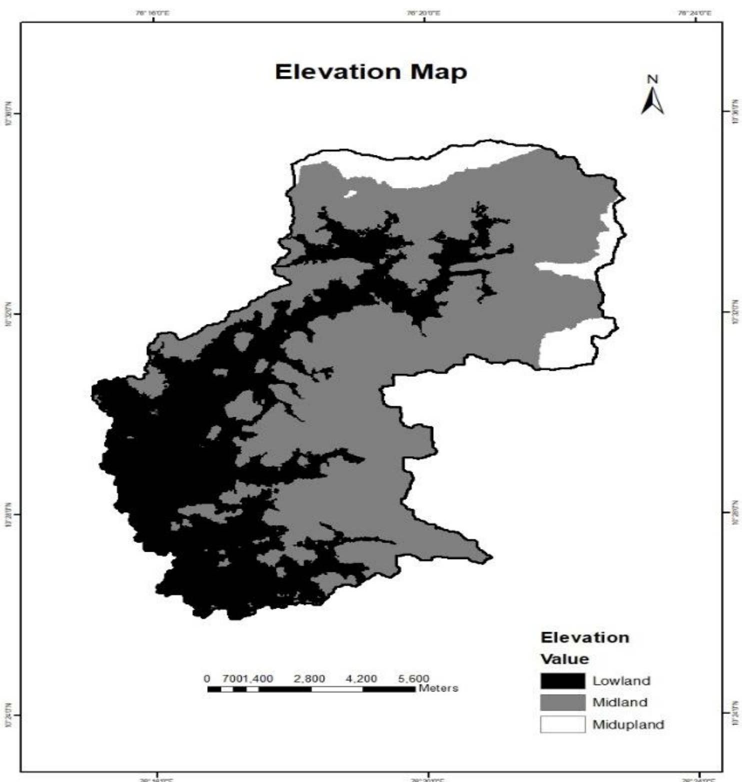

Fig. 4.19 Physiography of Manali watershed

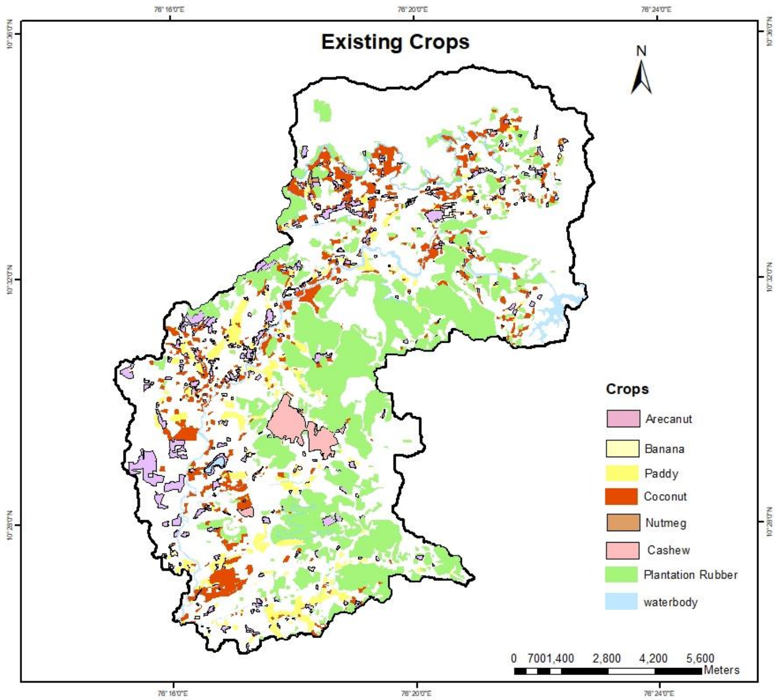

Fig. 4.20 Major crops existing in Manali watershed

Seasonal precipitation and potential evapotranspiration was analyzed based on aridity index. Monthly aridity index values are presented in Table 4.23. Monthly aridity values were found low in January, February, March and December which indicates dry condition and lacks soil moisture for proper growth of crops. Monthly and seasonal wise aridity index are given in Table 4.23. Mean aridity index was highest in Kharif season followed by Rabi season and Zaid season. The high values of aridity index indicated humid condition and high soil moisture and hence rice cultivation is suitable in this season. The moderate aridity index in Rabi season is due to low evapotranspiration hence cool season vegetables and rice may be proposed in Rabi. The low aridity index values during the Zaid season may be due to high potential evapotranspiration and low precipitation. Hence pulses may be suggested in Zaid season. Intercropping and sequential cropping may also be proposed in Manali watershed based on existing crops, soil, physiography and aridity.

Table 4.23 Monthly rainfall, potential evapotranspiration and aridity index of Manali watershed

Months	Rainfall	PET	RF/PET	Season
Jan	2.17	55.42	0.04	Rabi
Feb	11.88	68.39	0.17	Zaid
Mar	18.74	104.21	0.18	Zaid
April	63.72	112.98	0.56	Zaid
May	227.59	114.85	1.98	Kharif
June	643.4	77.43	8.31	Kharif
July	469.22	80.49	5.83	Kharif
Aug	453.19	90.39	5.01	Kharif
Sep	321.72	80.6	3.99	Kharif
Oct	231.86	68.88	3.37	Rabi
Nov	47.00	61.09	0.77	Rabi
Dec	10.56	50.10	0.21	Rabi

The variation of aridity index in sub-basins of Manali watershed for different season such as kharif, rabi and zaid is shown in Fig. 4.21, Fig. 4.22 and Fig. 4.23 respectively. Aridity index was found to change with respect to season in Manali watershed. But within a particular season, the values were almost same in sub-basins. Hence cropping pattern may be planned in this watershed based on seasonal variation and hence it was found that there is not much significance for planning of cropping pattern based on sub-basins. But cropping pattern is also influenced by many other external factors such as:

- Traditional social practices in the area.
- Practicable pest and disease control method.
- Adoption of profitable (or high-yielding) variety crops.
- Profit maximization and cost minimization.

Hence these factors are also to be considered while implementing the actual cropping pattern in Manali watershed. Table 4.24 shows the existing crops and suggested cropping pattern for Manali watershed.

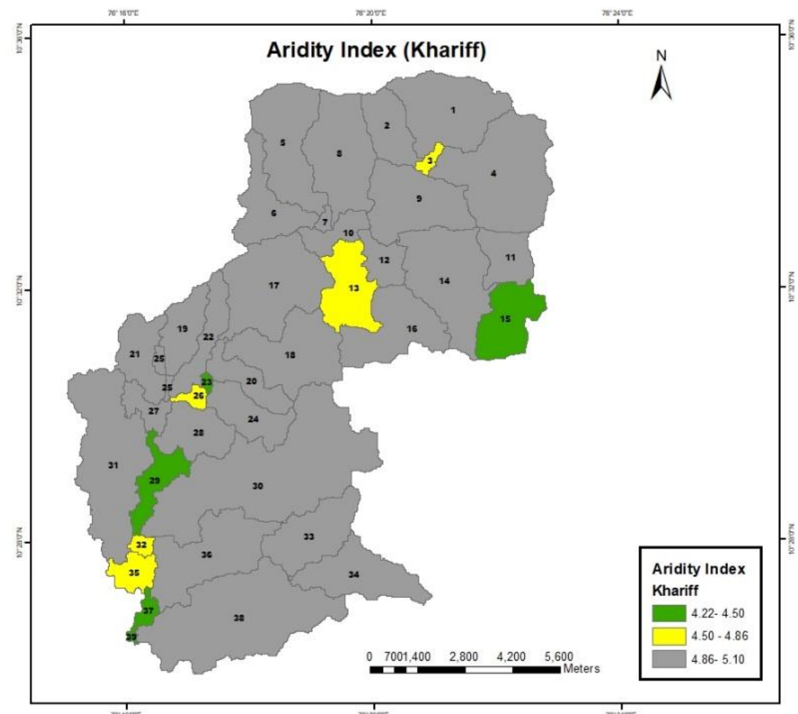

Fig. 4.21 Aridity index of Kharif season

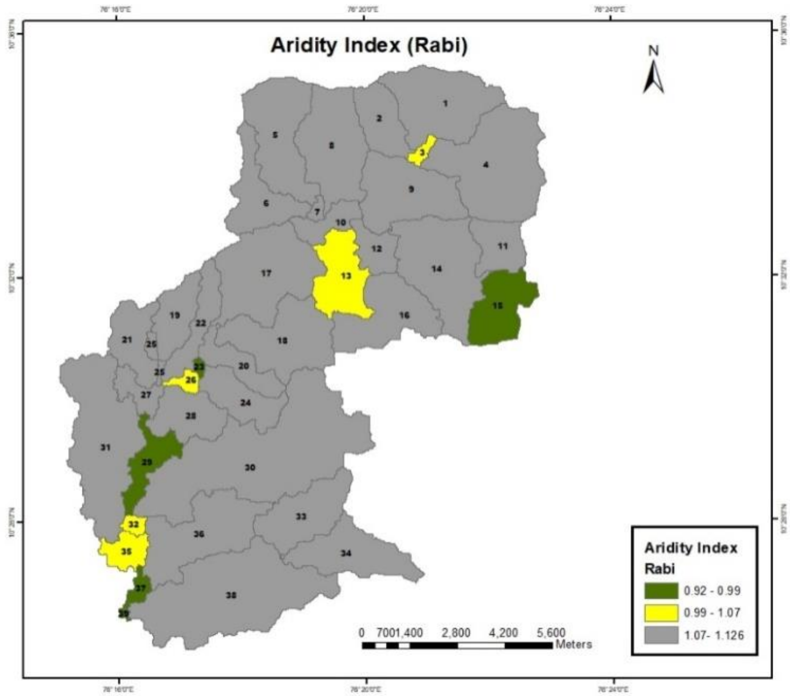

Fig. 4.22 Aridity index of Rabi season

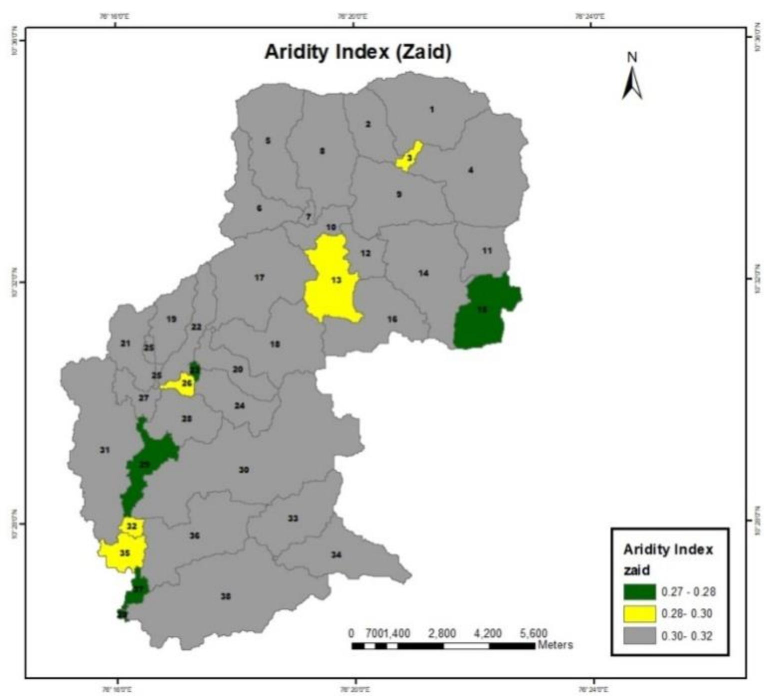

Fig. 4.23 Aridity index of Zaid season

Table 4.24 Existing crops and suggested cropping pattern for Manali watershed

Sl. No.	Existing crops	Physiography	Soil	Cropping pattern
1	Paddy	Lowland areas	Sandy clay loam and clay loam soil	Sequential cropping Paddy (First season) Vegetables (second season) Paddy (First season) Paddy (second season)
2	Paddy	Midland	Sandy clay loam soil	Sequential cropping Paddy (First season) Fodder grass (second season) Paddy (First season) Coleus (second season) Paddy (First season) Tapioca (second season)
3	Arecanut	Lowland and midland,	Sandy clay loam soil	Intercropping Arecanut and amaranthus (arecanut in initial stage) Arecanut and banana (arecanut two year old) Arecanut - pineapple, pepper or legumes (matured arecanut)
4	Coconut	Lowland	Sandy clay loam	Intercropping Coconut and Ginger/turmeric/nutmeg and pepper
5	Nutmeg	Midland and lowland	Sandy clay loam soil	Intercropping Nutmeg and cocoa/pineapple
6	Rubber	Midland	Sandy clay loam soil	Intercropping Rubber and cocoa
7	Cashew	Midland	Sandy clay loam soil	Intercropping Cashew and pineapple / bush pepper
8	Banana	Midland	Sandy clay loam soil	Intercropping Banana and amaranthus

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

The Manali watershed in Thrissur district consists of a drainage area of 140.94 km^2 was selected for the study. In Manali watershed there is always an increased chance of water level rise during monsoon season and scarcity of water during summer season. Hence a prudent management and conservation of available water is essential for sustainable development of the watershed. An integrated watershed concept using easy and affordable technologies like geospatial techniques and hydrologic modelling is very powerful for planning water conservation measures and cropping pattern in the watershed. Hence a study entitled 'Water conservation measures and cropping pattern for a watershed using geospatial techniques and SWAT modelling' was taken up. The monthly water availability and demand analysis of Manali watershed was conducted to know the surplus/deficit of water in the watershed. Suitable conservation measures and cropping pattern were proposed for the watershed based on the study.

Water availability was found using SWAT water balance modelling. The required thematic maps in ArcGIS 10.3 interface and meteorological data in Microsoft excel and notepad files were prepared and fed into the SWAT model. The calibration and validation of SWAT model was done using SWAT-CUP with SUFI-2 algorithm. The water demand of the watershed consists of agriculture water demand, domestic water demand and livestock water demand. The agricultural water demand was estimated by CROPWAT 8 model. The irrigation requirement of the major crops cultivated in the watershed was taken as the agriculture water demand. Rice, banana, rubber, coconut and cashew were the major crops cultivated in the watershed. The water availability and demand analysis of the watershed showed that there is surplus of water in almost all the months of the year. Still the watershed experience acute water scarcity and shortage of water in the non-monsoon months. The steep and undulating topography permits high runoff in the watershed. Hence there is an urgent need to implement water conservation measures in the watershed as watershed is the natural divide for efficient water resource management. Hence this study identified suitable locations and type of conservation measures for the watershed based on the hydrology of watershed. Cropping pattern was proposed based on the existing crops, soil, physiography and seasonal aridity index. The major conclusions drawn out from the study are as follows.

- SWAT model was calibrated and validated for Manali watershed

- The performance indices of the model R^2 and NSE during calibration period (1997-2007) were found 0.85 and 0.71 while the same for validation period (2008-2017), were found 0.61 and 0.61 respectively. The r-factor and p-factor during calibration were found 0.70 and 0.34 respectively, while the same during validation were found 0.75 and 0.35 respectively.

- The most sensitive parameters of the watershed were identified as base flow alpha factor (ALPHA_BF) followed by Mannings 'n' value for main channel (CH_N2).

- The annual water balance estimation showed that, out of the total precipitation received (2501.2 mm) in Manali watershed, the surface runoff, lateral flow, evapotranspiration and groundwater flow components were found to be 861.06 mm, 978.20 mm, 434.25 mm and 101.68 mm respectively.
- The total water yield which was taken as the sum of surface runoff, lateral flow and groundwater flow contribution to stream flow was obtained as 1940.94 mm.

- The monthly water availability from SWAT water balance showed that water availability was highest (71.57 Mm^3) during June and lowest (1.28 Mm^3) during January.

- The monthly water demand estimation of the watershed showed that water demand was highest in the month of January (8.91 Mm^3) and lowest in the month of June (1.23 Mm^3).

- Water availability and demand analysis indicated that Manali watershed have surplus yield of water in all the months of year except in December, January, February and March.
- The annual total surplus of water in the watershed was found 227.43 Mm^3
- Suitable locations and type of conservation measures viz. farm ponds, check dams and percolation ponds were identified for the watershed.
- 32 farm ponds, 7 percolation ponds and 4 check dams were proposed to be constructed in the watershed.
- Farm ponds were found to be the most suitable conservation measure in the area and they were mainly proposed in southern and north western portion of the watershed.
- Percolation ponds were proposed to locate in the southern region of the watershed.
- Based on the existing crops, soil, physiography and seasonal aridity index values, cropping pattern such as sequential cropping and intercropping were proposed for the watershed.
- It was found that plenty of water is available in the basin, but it is lost mainly due to surface runoff. Hence adoption of proper conservation measures and cropping pattern may improve the overall productivity and economic status of the watershed.

Suggestions for Future Research

1. Optimization of water conservation strategies by SWAT modelling
2. Optimization of suggested cropping pattern by linear programming model

REFERENCES

REFERENCES

Abineh, T. and Teferie, B. 2015. A GIS based slope analysis for recommended soil and water conservation techniques in Sekela District, Amhara State, Ethiopia. *Int. J. Adv. Agric. Res.* 3:45-54.

Abrahim, M. and Mathew, R.A., A.M. 2018. Assessment of surface runoff for Tank watershed in Tamil Nadu using hydrologic modeling. *Int. J. of Geophysics.* Available: http://doi.org/10.1155/2018/2498648 [5june 2018]

Ahamad, F. and Goparaju, L. 2019. Analysis of seasonal precipitation, potential evapotranspiration, aridity, future precipitation anomaly and major crops at district level of India. *J. of Cartography and Geogr. Inf.* 69:143–154.

Allen, R.G. and Pereira, L.S. 1998. FAO Irrigation and Drainage paper No. 56:87-134.

Anoh, K.A., Koua, T.J., Eblin, S.G., Kouame, K.J., and Jourda, J.P. 2017. Modelling freshwater availability using SWAT model at a catchment-scale in Ivory coast. *J. of Geoscience and Environ. Prot*. 5:70-83.

Arai, F.K., Pereira, S.B., and Goncalves, G.G. 2012. Characterization of water availability in a hydrographic basin. *Engenharia Agrícola*. 32(3):591-601.

Arnold, J.G., Allen, P. M., and Bernhardt, G. 1993. A comprehensive surface-groundwater flow model. *J. Hydrol.* 142(1):47–69.

Ayivi, F. and Jha, M.K. 2018. Estimation of water balance and water yield in the Reedy Fork-Buffalo Creek watershed in North Carolina using SWAT Frederick. *Int. Soil and Water Conserv. Res.* 6(3):203–213.

Bhat, S.A., Pandit, B.A., Khan, J.N., Kumar, R., and Rehana, J. 2017. Water Requirements and Irrigation Scheduling of Maize Crop using CROPWAT Model. *Int. J. Curr. Microbiol. App. Sci.* 6(11):1-9.

Bhatu, H. and Rank, H. 2017. Estimating the water balance component in Rangmati river basin using SWAT model. *IJASR.* 7(4):547-554.

Brooks K.N., Ffolliott, P.F., and Magner, J.A. 2013. Hydrology and the management of watersheds, 4th edn. *Wily-Blackwell, Ames*, 552p.

Byakode, K., Shivapur, A.V., and Venktesh, B. 2017. Application of SWAT model for generating surface runoff and estimation of water availability for Balehonnuru catchment area for Badhra river basin. *IRJET*. 4(8):1143-1148.

Chowdary, V.M., Ramakrishnan, D., Srivastava, Y.K., Vinu C., and Jeyaram, A. 2009. Integrated water resource development plan for sustainable management of Mayurakshi watershed, India using remote sensing and GIS. *Water resour. Manag*. 23:1581–1602.

Department of Town & Country Planning, Kerala. 2015. *DSP [District Spatial Plan] Thrissur* [Online]. Available: http://townplanning.kerala.gov.in/town/wpcontent/uploads/2019/04/dsp_thrissur.pdf[January 2011].

Deshmukh, P. 2018. Optimization of water conservation strategies using SWAT. PhD Thesis, KrishiVidyapeeth, Akola, Maharashtra. 137p.

Doorenbos, J and Pruitt, W.O. 1977. Guidelines for predicting crop water requirements. Irrigation and Drainage paper 24(revised) Food and Agricultural Organisation of the United Nations, Rome.144p.

Ewaid, S.H., Salwan, A.A. and Nadhir Al-Ansari. 2019. Crop Water Requirements and Irrigation Schedules for Some Major Crops in Southern Iraq. *Water 2019*, 11(756):1-12.

Farsana, Z.S., Zafor, M.A., and Shahariar, J.A. 2019. Application of SWAT model for assessing water availability in Surma river basin. *J. of the Civil Eng. Forum*. 5(1):29-32.

Ganiyu, H.O., Adeogun, A.G., and Ahmed, I.A. 2019. Assessment of water resources availability and demand in Malete watershed, North Central Nigeria. *Nigerian Research J. of Engg. and Environ. Sciences.* 4(2):667-674.

George, S. and Sathian, K.K. 2016. Assessment of water balance of a watershed using SWAT model for water resources management. *Int. J. of Engg. Sci and Res. Technol.* 5(4):177-184.

Griensven and Meixner. 2006. To quantify and identify the sources of uncertainty for river basin water quality models. *Water Sci. and Tech*. 53(1):51-59.

Gupta A., Himanshu S.K., Gupta S., and Singh R. 2020. Evaluation of the SWAT model for analysing the water balance components for the upper Sabarmati basin. *Ad. in water Resour. Engg. and Manag.* 39:141-151.

Gupta, C.D. and Gupta, V.K. 2012. Total annual average daily per capita demand. *Water supply handbook.* Jain Brothers, New Delhi, pp. 19-25.

He, C. 2003. Integration of geographic information systems and simulation model for watershed management. *Environ. Modelling and Software.* 18:809-813.

IMSD. 1995. Integrated Mission for Sustainable Development (IMSD) Technical guidelines. National Remote Sensing Agency(NRSA), Hyderabad, Department of Space, Govt. of India

Jha, M.K., Chowdhury A., Chowdary V.M., and Peiffer, S. 2007. Groundwater management and development by integrated RS and GIS: prospects and constraints. *Water Resour. Manag.* 21(2):427–467.

Kang, H., Hahn, M., Fortin, D., and Hyun, Y.J. 2006. Effects of perceived behavioral control on the consumer usage intention of e-coupons. *Psychology and Marketing*. 23(10):841-864.

KAU (Kerala Agriculture University). 2016. Package of practices recommendations: crops (14^{th} Ed.) Kerala agriculture University Thrissur.

Kolekar, S., Chauhan, S., Raavi, H., Gupta, D. and Chauhan, V. 2017. Site selection of water conservation measures by using RS and GIS: A review. *Adv. in Computational Sci. and Tech.* 10(5):805-813.

Krishna, V., Jhansi Lakshmi, S., and Ramana, M.V. 2018. Estimation of soil and water conservation measures in micro-watershed. *J. of Pharmacognosy and Phytochemistry*. 7(5): 2600-2604.

Kumar , L., Khalkho, D., Pandey, V. K., Nigam G.K., and Bisen, Y. 2017. Site suitability analysis of water storage structures using remote sensing & GIS for a small watershed of Lormi block in Mungeli district, Chhattisgarh state. *IJABR*. 7(3):495-503.

Lee, V., Yoon, T., and Shah, F.A. 2013. Optimal watershed management for reservoir sustainability: Economic appraisal. *J. Water Resour. Plan. Manag.* 139(2):129-138.

Lohar, T., Balasubramani, K., and Bhatt, B. 2018. Site suitability analysis for establishing soil and water conservation structures using Geoinformatics - A case study of Chinnar watershed, Tamil Nadu, India. *J. of Geomatics*. 12(2):146-157.

Mangalassery, S., Rejani, R., and Philip, P.S. 2019. Impact of different irrigation regimes under varied planting density on growth, yield and economic return of cashew (Anacardium *occidentale* L). *Irrigation science*. 37:483-494.

Mangrule, V.N., and Kahalekar, U.J. 2013.Watershed Planning and Development Plan by Using Rs and GIS of KhultabadTaluka of Aurangabad District. *Int. J. of Inf. and Computation Technol*. 3(10):1093-1100.

Mengistu, A.G., Rensburg, L.D., and Woyessa, Y.E. 2019. Techniques for calibration and validation of SWAT model in data scare arid and semi-arid catchments in South Africa. *J. of Hydrol.* 25:1-18.

Mirrah, A. and Kusratmoko, E. 2018. Application of GIS for assessment of water availability in the Cianten watershed, West Java. *Earth Environ. Sci*. 98(1):1-10.

Moriasi D. N., Arnold J. G., VanLiewVeith, T. L ., and Bingner,R. L . 2017. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Am. Soc. of Agric. and Biol. Engg*. 50(3):885−900.

Moriasi, D.N., Arnold, J.G., Van Liew M.W., Bingner, R.L., Harmel, R.D., and Veith, T,L. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE* 50(3):885–900.

Narasimhan, B, Allen, P.M., Srinivasan, R., Bednarz, S.T., Arnold, J.G. and Dunbar, J.A. 2007. Streambank erosion and best management practice simulation using SWAT. *In: Proceedings of 4th conference on 'Watershed management to meet water quality standards and TMDLs'*, March10–14 ,2007 San Antonio, Texas.

Narmada, K., Gobinath, K., and Bhaskarana, G. 2015. An assessment of resource potentials for sustainable development of micro-watershed in Tirunelveli district using geoinformatics– A case of Nambiyar micro-watershed in Tirunelveli district, Tamil Nadu, India. *Aqua.Proc.* 4:1299-1306.

Nash, J.E. and Sutcliffe, J.V. 1970. River flow forecasting through conceptual model part 1-A discussion of principles. *J. of Hydrol.* 10:282-290.

Nivesh, S., Kashyap P.S., and Saran, B. 2019. Irrigation water requirement modelling using CROPWAT model: Balangir district, Odisha. Pharma Innovation. 8(12):185-188.

Pantoja, H.M. and Hiscock, K.M. 2015. Projected impacts of climate change on water availability indicators in a semi-arid region of central Mexico. *Environ. Sci. Policy*. 54:81-89.

Patode, R.S., Pande, C.B., Nageve, M.B., K. Moharir, K.N. and Wankhade, R.M. 2017. Planning of Conservation Measures for Watershed Management and Development by using Geospatial Technology – A Case study of Patur Watershed in Akola District of Maharashtra. *Curr. World Environ.* 12 (3):708-716.

Poojari, M. and Jayaraj, G.K. 2017. Comparison of Runoff Estimation Using ArcSWAT and Conventional Method for Different Catchment Scales. *IJRASET*. 5(10):103-107.

Ramachandra, T. V., Nagar, N., Vinay, S., and Aitha, B.H . 2014. Modelling Hydrologic regime of Lakshmanatirtha watershed, Cauvery river. *IEEE Global Humanitarian Technology Conference - South Asia Satellite (GHTC-SAS)* September 26-27, 2014,Trivandrum,pp 64-71

Regulwar, D.G. and Ambhore, R.M. 2017. Site suitability analysis of soil and water conservation structures in watershed using GIS. European water. 57:187-192.

Sabeena, S., Rema, K.P. and Shyla J. 2016.Irrigation Scheduling Of Salad Cucumber inside a Polyhouse Using CropwatModel. *Int. J. of Eng. Sci. and Computing*. 6 (12): 3545-3548.

Santhi, C., Arnold, J.G., Williams, J.R., Dugas, W.A., and Hauck, L. 2001. Validation of the SWAT model on a large river basin with point and nonpoint sources. *J. of the Am. Water Resour. Assoc.* 37(5): 1169–1188.

Shahul, S., Rema, K.P., and Joseph, S. 2016. Irrigation scheduling of Salad cucumber inside a polyhouse using CROPWAT model. *IJESC*. 6(12):3545-3548.

Shawul, A.A., Alamirew, T., and Dinka. 2013 Calibration and validation of SWAT model and estimation of water balance components of Shaya mountainous watershed, Southeastern Ethiopia. *Hydrol. Earth Syst. Sci. Discuss*. 10: 13955–13978.

Sloboda, M. and Swayne, D. 2011. Auto calibration of environmental process models using a PAC learning hypothesis. *9^{th} IFIP WG 5.11 International Symposium, ISESS 2011*, June27-29, 2011, Brno, Czech Republic. pp. 528-534.

Soil Conservation Service (SCS). 1972. National Engineering Handbook, Section 4: Hydrology. Department of Agriculture, Washington DC, 762 p.

Stephen, J. 2005. Aridity Indexes. In: Oliver, J. E. (eds). Encyclopedia of World Climatology. Encyclopedia of Earth Sciences Series. Dordrecht: Springer, available at: https://doi.org/10.1007/1-4020-3266-8_17.

Surendran, U., Sushanth, C.M., George, M., and Joseph, E.J. 2015. Modelling the crop water requirement using FAO-CROPWAT and assessment of water resources for sustainable water resource management: A case study in Palakkad district of humid tropical Kerala, India. *Aquatic Procedia* 4:1211 – 1219.

Surendran, U., Sushanth. C.M., Joseph, E.J., Ansari, N.A., and Zaher, M.Y. 2019. FAO CROPWAT model-based irrigation requirements for coconut to improve crop and water productivity in Kerala, India. *Sustainability*. 11:1-15.

Suryavanshi, S., Pandey, A., and Chaube, U.C. 2017. Hydrological simulation of the Betwa River basin (India) using the SWAT model. *Hydrol. Sci. J*. 62(6):1-10

Tabares, D. R., Tarquis, A.M., Willaarts B. and Miguel, A.D. 2019. An accurate evaluation of water availability in sub-arid Mediterranean watersheds through SWAT: Cega-Eresma-Adaja. *Agric. Water Manag.* 212 : 211-225.

United Nations Educational, Scientific and Cultural Organization (UNESCO). 1979. Map of the World Distribution of Arid Regions: Explanatory Note. Paris, France: UNESCO.

UNWWDR (United Nations World Water Development Report).2019. Leaving no one behind.11p.

USDA (United States Department of Agriculture), Soil Conservation Service. 1986. Technical release 55, Urban hydrology for small watersheds. pp. 14-23.

Varughese, A. 2016. Impact of climate change and watershed development on river basin hydrology using SWAT – A case study. PhD Thesis, Kerala Agriculture University Thrissur. 117p.

Vijayakumar, K.R., Dey, S.K., Chandrasekhar, T.R., Devakumar, A.S., Mohankrishna, T., Rao, P.S., and Sethuraj, M.R. 1997. Irrigation requirement of rubber trees (*Hevea brasiliensis*) in the subhumid tropics. *Agric. Water Manag.*35:245-259.

Vyshak, A., Ajithkumar, B., and Sathish J.V. 2016.Effect of dates of planting on crop water requirement of rice in Kerala. *J. of Agrometeorol. Agmet Special Issue*: 51-54.

Yin, J., Zhan, C., and Ye, W. 2016. An experimental study on evapotranspiration data assimilation based on the hydrological model. *Water Resour. Manag.*, 30(14): 5263–5279.

APPENDICES

Appendix I The sub-basin area of each watershed

Sub-basin	Area (ha)	Sub-basin	Area (ha)
1	577.0	21	260.2
2	254.5	22	220.8
3	34.0	23	16.6
4	821.9	24	262.6
5	541.6	25	37.0
6	329.2	26	44.3
7	25.3	27	117.4
8	566.0	28	277.7
9	521.0	29	195.6
10	142.7	30	1474.2
11	213.7	31	850.1
12	154.5	32	36.5
13	328.6	33	394.2
14	668.5	34	415.4
15	315.7	35	122.4
16	464.0	36	587.6
17	679.5	37	51.0
18	538.2	38	1109.4
19	234.5	39	9.0
20	202.0		
Total area (ha)			14094.5

Appendix II Calculation procedure of decrease in percentage increase

Year	Population of Manali watershed	Increase in population	Percentage increase in population	Decrease in percentage increase
1971	99123			
1981	113592	113592-99123=14469	(14469/99123)*100=14.59	
1991	127452	127452-113592=13860	(13860/113592)*100=12.02	14.5970-12.0215=2.3954
2001	138483	138483-127452=11031	(11031/127452)*100=8.65	12.0215-8.6550=3.5465
2011	145326	145326-138483=6843	(6843/138483)*100=4.94	8.6502-4.9414=3.7136
TOTAL		46203	TOTAL	9.6556
AVERAGE		(46203/4)=11550.75	AVERAGE	(9.6556/3)=3.2185

Appendix III Calculation procedure of population forecasting of 2021

YEAR	NET PERCENTAGE INCREASE IN POPULATION	POPULATION
2021	4.9414-3.2185=1.7229	145326+(1.7229/100)*145326 = 147830

WATER CONSERVATION MEASURES AND CROPPING PATTERN FOR A WATERSHED USING GEOSPATIAL TECHNIQUES AND SWAT MODELLING

By

PANCHAMY BALAN

(2018-18-003)

ABSTRACT OF THESIS

Submitted in partial fulfilment of the requirements for the degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Soil and Water Engineering)

Faculty of Agricultural Engineering &Technology

Kerala Agricultural University

Department of Irrigation and Drainage Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR, MALAPPURAM-679573

KERALA, INDIA

2020

ABSTRACT

The Manali watershed located in Thrissur district of Kerala with a drainage area of 140.94 km^2 receives an average annual rainfall of 2501.08 mm. But the watershed experiences increased water level rise during monsoon and scarcity of water during non-monsoon season. In order to address the problem of water scarcity in the watershed, an attempt was made to plan conservation measures and cropping pattern using geospatial techniques and SWAT modelling. SWAT model was used effectively for the hydrologic water balance assessment and water availability in the watershed. Water demand was estimated as the sum of agricultural and non-agricultural water demand. Agricultural water demand was estimated using CROPWAT 8 model. An analysis of monthly water availability and water demand was carried out to know the status of water in the watershed. Site suitability modelling was done using GIS to locate water conservation measures and IMSD guidelines were applied to select the type of water conservation measures. Cropping pattern was proposed based on existing crops, soil type, physiography and aridity index.

The model was calibrated and validated satisfactorily for the watershed with NSE values 0.71 and 0.61 and R^2 values 0.81 and 0.61 during calibration and validation respectively. The highest water availability (71.57 Mm^3) was found in the month of June and lowest (1.28 Mm^3) in the month of January. Water demand was highest in the month of January (8.91 Mm^3) and lowest in the month of June (1.23 Mm^3). Water surplus was observed in almost all the months of the year except January, February, March and December. The annual total water surplus in the watershed was obtained as 227.43 Mm^3. Hence conservation measures were proposed for the watershed. Thus 32 farm ponds, 7 percolation ponds and 4 check dams were suggested to construct in the watershed area. Farm ponds were found to be the most suitable conservation measure in the area. Suitable cropping pattern like sequential cropping and intercropping were also suggested to improve the productivity and economic status of the watershed.