IMPACT OF CLIMATIC PARAMETERS ON WATERSHED MANAGEMENT PRACTICES USING GIS TECHNIQUES

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Impact of climatic parameters on watershed management practices using GIS techniques"** 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.

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Sandra George

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SYMBOLS & ABBREVIATONS

AGWA	Automated Geospatial Watershed Assessment
API	Application Programming Interface
ARS	Agricultural Research Service
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AWC	Available Water Content
CAD	Computer Aided Design
COD	Coefficient of Determination
DEM	Digital Elevtaion Model
DSSAT	Decision Support System for Agrotechnology Transfer
EE	Earth Explorer
ERDAS	Earth Resource Data Analysis System
ESRI	Environmental System Research Institute.
ET	Evapotranspiration
FCC	False Color Composite
GAI	Geostatistical Analyst Interface
GCMs	General Circulation Models
GES	Google Elevation Service
GHGs	Greenhouse Gases
GIS	Geographic Information System
GPS	Global Positioning System
HUMUS	Hydrologic Unit Model for the United States
HRUs	Hydrological Response Units
IPCC	Intergovernmental panel on climate change
IRS	Indian Remote Sensing
ISRO	Indian Space Research Organisation
KAU	Kerala Agricultural University
KFRI	Kerala Forest Research Institute
LULC	Land use/Land cover

NDVI	Normalised Difference Vegetation Index.
NRSA	National Remote Sensing Agency
NSE	Nash–Sutcliffe efficiency
OM	Organic Matter
PBDM	Physically Based Distributed Watershed Model.
PRMS	Precipitation Runoff Modeling system
RCP	Representative Concentration Pathway
R.F.	Radiative Forcing
RRA	Rapid Rural Appraisal
RS	Remote Sensing
SCS	Soil Conservation Services
SLTM	Soil Loss Tolerance Map
SLURP	Semi-distributed Land Use-based Runoff Processes
SOI	Survey of India
SPAW	Soil Plant Air Water
SRTM	Shuttle Radar Topographic Mission
SWAT	Soil and Water Assessment Tool
TMDL	Total Maximum Daily Load
TSVI	Topographical Sheet and Visual Interpretation
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
WGS	World Geodetic Survey
XB	Xebanghieng

Introduction

CHAPTER 1
INTRODUCTION

Climate change has been described as a change in the statistical distribution of weather parameters and their patterns when that change lasts for an extended period of time (i.e., decades to millions of years). Climate change includes major changes in temperature, precipitation, or wind patterns, and variation in other weather parameters that occur over several decades or longer. Changes in weather parameters will tend to have cascading effects on hydrology, biomass production and many other natural processes. The changes in precipitation pattern with increased intensity and higher frequency will lead to increased runoff and leaving less water available for ground water recharge. In addition, the extreme events have potential to cause localized flooding in urban centers, soil erosion, crop damage in rural areas and more frequent and prolonged periods of drought in the summer. The shift in rainfall pattern also affects the dissolved oxygen level in the waters which in turn affects the growth of flora and fauna and marine organisms. (Jack *et al.*, 2009)

Okorafor (2014) reported that a shift in the global air temperature has the potential to cause substantive impacts on all life forms on earth. Earlier warming in the spring would lead to a shift in the timing of the snowmelt, leading to rapid melt, and riverine flooding and leads to sea level rise and causes extinction of many species. In addition, warmer temperatures would increase the number of growing seasons per annum, potentially moving high value row crops to areas historically planted with forage crops. Increased temperature also leads to increased anthropogenic greenhouse gas concentration thereby resulting in global warming.

Natural resources are those elements of the nature such as land, water, air and vegetation. Proper management and utilization of nature and its resources is termed as natural resources conservation. International Union for conservation of Nature (IUCN) defined conservation as "rational use of environment to provide a high quality of living for the mankind''. The importance of natural resource management through adequate scientific interventions is increasing as the resources are subjected to quantity and quality erosion. Conservation is essential for life support system like air, water, land, flora & fauna, biodiversity and ecosystems.

A natural resource is often characterized by amounts of biodiversity and geodiversity existent in various ecosystems and these are the primary buffers for a stable national economy and social development (Gray *et al.,* 2013) The water and food security of the nation depends on the richness of the natural resources. Equitable and sustainable management of natural resources acts as a sound strategy to remove poverty and enhance means of livelihoods.

Land and water are the two important and indispensable natural resources, supporting all forms of life on earth. Water availability varies with time and space. As we all know that population is increasing rapidly and the demand for natural resources are also rising tremendously especially land, water and biomass resources. Due to overexploitation and deterioration, water has become more and more scarce resource. The imbalance between demand and supply is advocating to develop new approaches for water harvesting and management strategies. Biomass, the next important resource after land and water was considered as the source of food and fuel for the animal kingdom. Of late, it is also considered as a renewable source of energy and has the potential to supply the large quantum of 'green' energy. With effective forest management, advanced harvesting techniques and bio energy crops, together with new biomass plants, stoves, boilers and co-firing with coal powered power plants, biomass offers a sustainable opportunity to help meet the worlds growing energy demands. However, with industrialization and urbanization, mankinds great demand for natural resources and their large scale exploitation and consumption has resulted in the weakening, deterioration and exhaustion of these resources.

The watershed and drainage basins are synonymous terms indicating to an area, which is drained by a stream or system of connecting streams in such a way that all stream flow originated in the area is drained through a single outlet. Watersheds are the natural divides of the land masses and hence, the conservation of land, water and biomass resources have to be planned on watershed basis. Watershed management is the process of organizing the utilisation of natural resources on a watershed to provide necessary goods and services to people, while mitigating the detrimental impacts of land use activities on soil and water resources. This approach recognizes the intrinsic interrelationships among soil, water, and land use and the connections between upland watersheds and larger downstream river basins. It incorporates soil and water conservation and land use planning into a more holistic and logical framework.

The livelihoods of people are very much linked to the resources of the watershed. Inhabitants of watersheds manage their lands for the production, conservation, and sustainability of forage, food, and fiber for their survival and to generate income. Therefore, water, forage, wood, and other natural resources on the watersheds should be managed in the most economically efficient and environmentally sound combinations to obtain the products, commodities, and amenities. The consumption or otherwise the use of the natural resources on upland watersheds must also be balanced with the needs of people living downstream. Upland watersheds are the headwaters of many large rivers in dry land regions. As a consequence, the proper management of upland watersheds is a prerequisite to sustaining the flow of water that is necessary to maintain agricultural production within the river basins.

All climate change parameters, especially rainfall and temperature have great influence on the watershed processes such as ET, surface runoff, ground water recharge, baseflow and total river flow. Hence, quantifying these parameters in the context of climate change scenarios assumes great significance. Since the various watershed processes are interdependent and are highly variable with respect to time and space, prediction of watershed processes is not an easy task (Wagener *et al.*, 2003). Employing watershed models are the only practical solution in such cases. Among the watershed models, physically based watershed models will be yielding better results as they are designed to simulate the physical processes more close to reality. In this context, the study has been envisaged with the following objectives given below.

1. To identify the existing management practices of the selected watershed.
2. To study the effect of climatic parameters on important watershed processes.
3. To suggest modification of existing management practices using GIS techniques.

Review of Literature

CHAPTER 2

REVIEW OF LITERATURE

2.1 Climate change

Climate change is a change in the statistical distribution of weather patterns that lasts decades to millions of years. It is caused by factors such as biotic processes, variations in solar radiation received by Earth, plate tectonics, and volcanic eruptions. Certain human activities have also been identified as significant causes of recent climate change, often referred to as "global warming"(Sagan and Chyba, 1997).

Climatic changes inexorably affect the water cycle, the main reason stated was global warming. Along with trends in mean values in all aspects of the weather (precipitation, temperature, evaporation, *etc.*), one can expect variations in the frequency of exceptional events, and also in the hydrological regime. There may be major consequences in terms of economy and quality of life. This has often occurred in the past, and it would be strange if it does not happen again in the future. Besides the climate's natural variability, there are good reasons to think that man's activities that happened in the last two hundred years were leading towards a considerable rise in air temperature, the well-known anthropogenic greenhouse effect (Dragoni, 1998). The various climate models were in general agreement that annual average air temperatures in southern Ontario may rise by 2 to 5 °C by the end of 21st century.

Manifestation of global scale climate variations can be observed as fluctuations in the normal display of any local climatic features. Rainfall is considered as an important feature, understanding the trends and changes of which will help to resolve uncertainties (Singh, 1998) and it provides the knowledge base for decision making on a broad series of local issues related with agriculture, industry, irrigation, generation of hydroelectricity, and other human activities (Singh and Sontakke, 1999).

Another study also reported that since the beginning of industrial revolution, the influence of human activity has begun to extend to a global scale. Today, environmental issue has become the biggest concern on the mankind because of the increasing concentration of greenhouse gases in the atmosphere, the changing climate of the earth and the change of amount and distribution of rainfall. Sea level rise, change in precipitation pattern (up to ± 20%), and change in other local climate conditions are expected to occur as a cause and effects of rising global temperature (Cubasch *et al.*, 2001).

Climate change can also affect the freshwater availability for both human uses as well as ecosystems. The decline in river flows also affects the sustainability of water supplies and reduces the hydroelectric power potential. Climate change can have severe impact on sediment transport and erosion process with the highest soil loss rates occurring in regions that have high variability in precipitation and runoff. Change in temperature and precipitation components leads to changes in hydrological cycle, which can have direct impact on the spatial and temporal water resource availability and also it can affect water balance significantly (Hailemariam, 2001).

The rise in warming temperature is expected to drive possible decreases in soil moisture, surface water runoff, and lead to declines in water levels on the lower- and mid Great Lakes. Changes in atmospheric circulation patterns and storm tracks may also affect wind patterns, the frequency of storm surges, erosion, and the intensity of storm rainfalls. Increasing concentrations of CO_2 and other greenhouse gases from anthropogenic activities have caused warming of the global climate by modifying radiative forcings (Houghton et al., 2001).

Changes in the climate regime can affect natural processes of a watershed ecosystem and have long term implications on ecological processes. IPCC noted that climate change can influence key spatial patterns and fluxes of water in a landscape, particularly in areas where evapotranspiration and snowmelt are the primary components of water budget and could impact the hydrologic cycle and various processes of a watershed. The potential impacts include changes in runoff, nutrient enrichment, sediment loading and evapotranspiration rates in a watershed system. The changes in global climate appeared to severely affect the mid and high latitudes of the Northern Hemisphere, where temperatures have been noticeably getting warmer since 1970s. (IPCC, 2001)

Burgueno *et al.* (2004) reported that the relationship between climate change and water resources with special emphasis on ground water. It also aims to minimize the impact of climatic variations and to protect ground water resource. The climate has changed in the past, is changing in the present and will change in the future. The present climatic trend (i.e. a warming trend), which is not a hypothesis but a planet wide observation, may relate to a natural warming phase, probably at the scale of a few hundred years, which began in the nineteenth century; the warming is being accelerated and increased because of the anthropogenic activities such as greenhouse gases emission from fossil fuels during the last two centuries.

The study between groundwater resources and climate variation is based on a continuous, reliable and dense database of hydro meteorological data and soil moisture, covering a long time interval. These data must be coupled with a large amount of spatially distributed quantitative information such as hydraulic conductivity and porosity. Remote sensing provides a convenient and suitable way of assessing the temporal and spatial variations in water fluxes in different water cycle components. The ground water recharge is affected by any variation in the regime and quantity of precipitation along with variation in temperature and evapotranspiration (Labat *et àl.*, 2004).

Changes in global climate will have significant impact on local and regional hydrological regimes, which will in turn affect ecological, social and economical systems. Nevertheless, substantial differences are observed in regional changes in climate compared to the global mean change (Dibike and Coulibaly, 2005).

Huntington (2006) has reported that climate change can affect the spatial and temporal distribution of water resources as well as the intensities and frequencies of extreme biological events. The global average surface air temperature increased during the 20th century, and, although there is great uncertainty about the magnitude of future increases, most assessments indicate that future warming is 'very likely'. Increases in precipitation over land have been associated with corresponding increases in runoff in river basins in the conterminous USA. In contrast, in Canada, increasing temperature combined with almost no change in precipitation, resulted in no change in annual streamflow from 1947 to 1996 for most regions.

Climate change is a well discussed issue in recent times and possibly one of the gravest global challenges in the present century. It has been found that the Earth's climate has been changing notably, at a fast pace since the last century, and the changes that are expected to continue. Evidences of changes are prominent in the environment through the increase in global and regional temperatures and perceptible changes in the hydrologic cycles in many parts of the world including India (Goswami *et al.*, 2007).

Climate change is considered as one of the biggest challenges of 21st century to the whole world. It is now widely accepted that climate change has already happened and further change is inevitable. Over the last century (between 1906 and 2005), the average global temperature rose by about 0.74 °C. This has occurred in two phases, from 1910s to 1940s and more severely from the 1970s to the present (IPCC, 2007).

In order to overcome the present and future water and environmental problems it is necessary to try to predetermine the problems through focused research, based on a good set of meteorological and hydrological data, which at present are far from satisfactory. The protection and restoration of ecosystems that provide critical water resources, such as those protecting recharge areas, wetlands and mountain forests is critical. There is a need to reduce the gap between the water supply and demand with more efficient irrigation systems, training of farmers, recycling of waste water, water conservation through public awareness and groundwater legislation for better groundwater management (Dragoni and Sukhija, 2008).

Gardener (2009) proposed that any decrease in runoff will then threaten surface water supplies and riparian habitats and may also alter fluvial geomorphic processes. Accordingly, there is great interest in developing methods for predicting the effect of climate change on river discharge. At present, most forecasts for the effect of climate change on runoff are largely based on regionalized global circulation models (GCMs). Attempts have also been made to forecast the effects of climate change on streamflow based solely on historical records of discharge and climatic conditions in specific river basins. The historical data are used either to develop multivariate regressions between runoff and climate parameters or to identify and quantify indices for the sensitivity of streamflow to change in climate. In any case to assess the effect of climate change on runoff over a large area, the hydrologic or empirical models must be applied to sufficiently large number of watersheds representative of the area.

The changes in flow characteristics resulting from climate change depend on individual catchment characteristics. In particular, basin geology and elevation are first order controls on the timing and magnitude of basin runoff to climate change. If a drainage basin is located in a low elevation and is dominated by rainfall, runoff change is more controlled by changes in precipitation than temperature, while basins located in high elevations with snow melt dominated regimes are highly sensitive to temperature changes (Heejun and Won, 2010).

According to Sverdlik (2011), the Philippines cannot escape the negative impacts of climate change. The country was tagged as a climate hotspot and vulnerable to some of the worst manifestations of climate change. As with other developing countries in Asia, the Philippines is highly subjected to natural hazards as exemplified by the 2006 landslide and the havoc wreaked by typhoons. The country is also prone to various hydro-meteorological and geological hazards because of its geographic and geologic setting, threatening the country by the passage of tropical cyclones and occurrences of extreme or prolonged rainfall, strong earthquakes, volcanic eruptions and tsunamis and these hazards will be aggravated and the impact of geological events can be worsened by global warming (Principie, 2012).

IPCC (2013) has reported that a general consensus is that the average global temperature has risen by about 4.6 °C under high emission scenario by the end of 21st century with the doubling of the CO_2 concentration in the atmosphere.

Knez *et al.* (2013) stated that climate change is a challenging present day issue now. The report about heat waves, floods and storms and their impact on society and environment reach us almost every day. These are threat to our present way of living, urging for responsibility, environmental behavior and ecologically sustainable progress. There is an increasing awareness that climate change is not only an economic and ecological dilemma, but also a physiological and social one , meaning that drastic policies are necessary to prevent a serious adverse impact on natural resources by promoting a sustainable behavior.

Rao *et al.* (2014) reported that global climate changes can also affects long term rainfall patterns which impacts the water availability, along with the increasing occurrences of floods and droughts. A study suggested that in many parts of Asia, the frequency of more intense rainfall has increased, whereas the numbers of rainy days and total annual precipitation have decreased. Impacts of climate change and climate variability on the water resources affect the stream hydrology. Stream flows may rise drastically in the monsoon season, but will decrease in the non monsoon season due to the projected future climate change.

2.2 Watershed and watershed processes

The science community now generally agrees that the earth's climate is undergoing changes in response to natural variability, including solar variability, and increasing concentrations of greenhouse gases and aerosols. Furthermore, agreement is widespread that these changes may profoundly affect atmospheric water vapor concentrations, clouds, precipitation patterns, and runoff and stream flow patterns (IPCC, 2001).

The factors for development of watershed are related to the drainage basin and also it relates to the extent to which the development activities are organized in a delineated boundary. The specialty of watershed is that all the resources can be controlled and conserved from a highest ridge to lowest point without taking the interference of the ecological balance to achieve the sustainable development (Kumar, 2002).

According to Karegoudar *et al.* (2006), the Singnodi sub watershed which is considered as one of the high priority watersheds in the Krishna river basin in Raichur taluk, was studied during the years 1998-2000 and was found to be fourth order watershed having a dendritic drainage network. The information they derived from the study includes bifurcation ratio Rb (3.01 to 3.5), stream length ratio R.L (1.22 to 1.36) and stream area ratio Rb (2.43 to 2.62) of the watershed which revealed that the watershed has developed over a uniform geologic structure and shows that the size of a drainage area is directly proportional to the highest order of its stream network.

Water is one of the vital resources that are sensitive to climatic changes. The projected changes in climate will have direct and indirect impacts on natural environment as well as on human societies. Hydrology and water resources will be affected, since they are closely linked to climate (Barnett, *et al.,* 2005). Therefore, climate change may induce major changes in hydrological conditions. The most serious earth science and environmental policy issues facing society is the potential changes in the earth's water cycle due to climate change . Studies carried out on Lake Ziway watershed, Ethiopia showed that the impact of temperature on the hydrological process by increasing evapotranspiration seems to improve (Zeray *et al.*, 2006).

Terrestrial vegetation influences water balance through the interception of rain and snow and the removal of water from the root zone as a result of plant transpiration and evaporation from the soil surface. As vegetation composition responds to climate change, so that will affect the amounts of water intercepted, evaporated, and transpired, thus altering snow accumulation and melt processes, water balance, groundwater recharge, and ultimately stream flow and mass wasting processes (IPCC, 2007). A change in catchment vegetation as a result of climate change directly or indirectly may affect the catchment water balance. Several studies have assessed changes in biome type under climate change (Kim *et al.*, 2008).

The hydrology process in a watershed relates to the physical characteristic of the watershed, like morphometry (area, slope, flow pattern density, elevation difference, river span, etc), vegetation cover, land usage and soil (Anwar, 2011).

According to Sarala (2013), morphometric analysis is considered as an important factor in any hydrological studies and it is inevitable in development and management practices of drainage basin. The connection of geomorphological parameters with hydrological characteristics of the basin procures a simplest way in understanding the hydrologic behavior of the different basins especially in ungauged basins because the hydrologic and geomorphic effects of natural and human process within a catchment are focused at its outlet. The development of morphometric techniques provides the quantitative description of the geometry of the drainage basins and its network helps in characterizing the drainage network. The geomorphological properties including the linear, areal and relief aspects of the watersheds are important in hydrologic point of view.

Quantitative morphometric analysis of watershed can give information on the hydrological nature of the rocks that are exposed within the watershed. A drainage map of the watershed provides details about reliable index of permeability of rocks and their relationship between rock type, structures and their hydrological status. Watershed management and characterization requires detailed information about topography, channel length, drainage network, water divide and geomorphologic and geological set up of the area for proper watershed implementation and management for water conservation techniques (Sreedevi *et al.*, 2013).

2.3 Physical characteristics of watershed

Bharathamala-Vattakotta watershed, which is located in the central eastern region of Thrissur districut, and it, is a micro watershed of Karuvannur river basin and drains to tributary of Kurumali river basin was chosen to study the micro level planning for sustainable land and water management carried out by Kumar, (2002). The major source of runoff is from the streams, which is originated from the Bharathamala and Vattakotta. He has conducted micro level studies on soil and water resources with people's participation in a micro watershed of Karuvannur river basin. The entire area of the watershed is well drained except the valley portions, where drainage is impeded during the monsoon season. The area is drained to a number of small streams originating from the side slopes of the surrounding hills and developing into Bharathmala Vattanathra stream, which finally empties into Manali river. Four types of soil series viz., mariakkal, koottala,kozhukkully and painkulam were identified.

An attempt has been made by Das and Mukherjee (2005) to analyze the drainage characteristics of some of the watersheds of Raigad district, Maharashtra, especially the morphology and related parameters. The results suggested that the ratio between cumulative stream length and stream order is constant throughout the successive orders of the drainage basins. The low values of drainage density and bifurcation ratio indicate that drainage in the study area has not been affected by structural disturbances and also the area is mostly underlain by resistant and permeable rocks with a dense vegetative cover. The higher groundwater levels in some of the watersheds showing low values of drainage density, stream frequency and infiltration number. The detailed morphometric analysis also led to the conclusion that those watersheds with low infiltration numbers have high infiltration capacity and thus better scope for artificial recharge

Anwar (2011) aimed to determine what all are the parameters of physical characteristics of the watershed that affected the surface runoff coefficient. He also developed the correlation between physical characteristics of the watershed with the surface runoff coefficient. The analysis package used for determining the parameter of physical characteristics of the watershed is geographical information system (GIS) and the development of surface runoff coefficient model by using multiple linear correlation regression. His findings depicted that the mean slope of watershed, the main river length factor, land use factor, topography factor and land type factor influenced the surface runoff coefficient. He further added that the relationship between rainfall and runoff characteristics in a watershed which is influenced by the physical characteristics of a watershed such as area, length, slope, shape, land use, relief, vegetation cover and flow pattern density.

Another study carried out by Ansari *et al.* (2012) suggested that the drainage pattern of main river Yamuna and its tributaries shows a dendritic pattern indicating homogenously underlain material whereas the mean bifurcation ratio values suggested that the geological structures were not disturbing the drainage pattern. The form factor value of sub basins showed that the basin was more or less elongated. Circularity ratio values of the sub basins fall within range of elongated basin and low discharge. The areas that are having low density indicate that the region has high permeable sub-soil material and dense vegetation.

In addition, Palaka and Sankar (2014) reported that the watershed characteristics such as size, slope, shape, drainage density, land use/land cover (LULC), geology and soils, and vegetation were important factors affecting various aspects of runoff. His study dealt with the general watershed or morphometric characteristics associated with the watershed which is located near Kosigi village in Kurnool district, Andhra Pradesh, India. For the analysis, they have downloaded the input data from Open Data Archive (CartoDEM) of Indian Space Research Organisation (ISRO's) Bhuvan website. They also noted that the thematic maps such as watershed boundary, drainage network, and contour maps were prepared from the Digital Elevation Model (DEM) data using Arc GIS 10

Hydrology tools. They have developed an online tool for studying the watershed characteristics using Google Maps Application Programming Interface (API) and Google Elevation Service (GES). The GES provides elevation data for locations on the surface of the earth which is useful to find the gross slope of the terrain which is considered as one of the important factor affecting runoff. Other watershed characteristics such as size, shape, drainage density of watershed can be analysed using Google Maps API. They also explained the morphometric analysis as the quantitative evaluation of form characteristics of the earth surface and any landform unit. It incorporates quantitative study of the various components such as, stream segments, basin length, basin parameters, basin area, altitude, slope, profiles of the land which indicated the nature of development of the basin.

2.4 GIS in watershed analysis

Geographic Information System (GIS) manage geographically referenced information by integrating a database and mapping software tools to analyse spatial relationships between events or phenomena. So, GIS can be described as an organized collection of computer software, hardware, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced information (ESRI, 1995). According to Dunn *et al.* (1997), GIS is a means of evaluating geographical relationships through spatial analyses, database management and geographical display. Using GIS software, geomorphology, soils, landuse, land cover maps were combined to generate action plans in a watershed (Sidhu *et al.,* 2000).

Amatya *et al.* (2011) suggested that Soil and Water Assessment Tool (SWAT) is a GIS based basin scale model widely used for characterization of hydrology and water quality of large, complex watersheds.

Chang (2002) defined GIS is a computer system for capturing, storing, quering, analyzing and displaying geographic data. GIS has four components namely computer system (hardware), GIS software, brain ware and infrastructure.

Tong and Chen (2002) used GIS spatial analyses to examine the general association of land use, flow and water quality, and locate the watersheds that are enriched with contaminants and with strong relationships with land use. GIS is a powerful data integration and spatial analysis tool. Their research on modeling the relationship between landuse and surface quality, they relied on ArcView GIS to aggregate, synthesize and analyze large databases, and to identify spatial relationships.

Giridhar and Viswanadh (2002) used GIS and Remote Sensing (RS) to estimate the runoff in an ungauged watershed. Since, ungauged watershed lacks data, GIS and RS technology can augment the conventional methods to a great extent in rainfall runoff studies. They have prepared the landuse from Indian Remote Sensing (IRS) LISS-III imageries for Palleru sub basin (K-11) using Earth Resource Data Analysis System (ERDAS). They also used Arc GIS 9.1 software for data generation, storage, manipulation and integration to estimate the daily runoff.

Rao and Fizee (2004) prepared detailed thematic maps of soil, land use, land cover, hydro morphological maps using satellite data of Katepurasa watershed in Maharashtra. The critical areas for land treatment in selected microwatershed were identified using GIS environment.

According to Guobin *et al.* (2007), the Arc GIS Geostatistical Analyst Interface (GAI) provides a comprehensive set of tools for creating surfaces from measured sample points compared with the previous method of using adjustable tension continuous curvature surface gridding. As a result, users can rapidly compare different interpolation techniques in order to obtain the best solution. Model results can subsequently be used in GIS models for visualization and analyses.

A study conducted by Hlaing *et al.* (2008) in Bago watershed by integrating remote sensing and GIS to determine soil conservation prioritization of watershed based on soil loss due to erosion and morphometric analysis. Soil erosion of the

Bago watershed was determined using the Universal Soil Loss Equation (USLE). Factors such as rainfall, soil erodibility, slope length gradient, and crop management were compiled as input parameters for modeling. They also developed the soil erosion maps of the Bago watershed from the available data. Later on, the resulting Soil Loss Tolerance Map (SLTM) could be utilized to develop watershed management planning, forestry management planning, etc.

A study on watershed ecological factors and lake ecology in Northern New York depended on the availability of high quality spatial data, GIS, and water ecology data, a more comprehensive approach is now possible to study the watershed-water quality. The purpose of the study was to analyze natural and anthropogenic factors of lake watersheds and compare corresponding water quality in order to better understand the relationships influencing lake health (Gemesi *et al.*, 2011).

Recent studies in large watersheds have reported about taking advantage of RS data and GIS, have been oriented toward quantifying the combined influence of watershed characteristics, landuse changes, and social and economic factors on nutrient discharges into rivers (Lu *et al.*,2011; Wise and Johnson, 2011).

Ajeeth and Thomas (2013) suggested that there are new developments and improvements in the modeling systems that increasingly depended on GIS techniques. GIS has made large area simulation feasible and Microsoft Access to support modeling and analysis.

Sarala (2013) reported that morphometric analysis of Halia drainage area, Nalgonda district, Andhra Pradesh, India has been carried out using geoprocessing techniques in GIS. They found that GIS techniques proved to be a competent tool in morphometric analysis.

The study carried out by Singh *et al.* (2014) highlighted the importance of satellite images and DEM for assessment of drainage and extraction of relative parameters for the Orr watershed Ashok Nagar district, Madhya Pradesh, India. Hydrological parameters include drainage analysis, topographic parameters and land use pattern. These parameters were evaluated and interpreted for the watershed management of the area. Arc GIS software was used for calculation and delineation of the watershed. The morphometric analysis of the watershed was carried out with the help of Shuttle Radar Topography Mission (SRTM) DEM. The stream order of watershed was in between first and sixth order which represents dendritic type drainage network. This type of network was considered as a sign of homogeneity in texture and lack of structural control of watershed. The drainage density of this area was found to be low to medium range which indicates that the area possesses highly permeable soils and low relief. In the case of bifurcation ratio, ranges between 4.74 and 5 and the elongation ratio was 0.58 which denoted that the basin belongs to the elongated shaped basin category. The mean R_b value of the entire basin is 4.62 which indicate that the drainage pattern is not much influenced by geological structures. Land use map of the watershed was taken from the latest available multispectral satellite data and whole watershed includes settlement, agricultural land, forest, mining areas, fallow land and water body. This study also revealed that SRTM DEM based hydrological evaluation was more realistic and precise compared to all other available techniques.

Saklani *et al.* (2015) have studied about GIS application for integrated watershed management of sub catchment Beas in Mandi, Himachal Pradesh, India. The integrated watershed development depends on the physical characteristics of this area. They have taken effort to identify the physical characteristics of watershed using GIS and RS techniques. Cartosat II, Survey of Indian (SOI) toposheets, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM 30 were the inputs for their study. The study also showed that GIS and RS are time consuming and precise application in order to give reliable and rapid data within a given framework of time. They have found out that there was no need to focus on check dam and soil conservation techniques and the physical characteristics indicated that the watershed are most vulnerable to flash floods, landslides and deforestation.

2.5 Remote sensing in watershed analysis

According to Engman (1995), RS offered watershed researchers a very different type of data form that than they have traditionally worked with. The spatial nature of remote sensing data has its most unique characteristic, especially when considering that all other hydrologic data are from point measurements. RS data give the researcher a new tool to use in scaling and in extrapolating point measurements to represent areas. In addition, remote sensing offers entirely new measurements, such as surface soil moisture, snow water content, and surface temperature, which have not been traditionally available to hydrologists.

Sekhar and Rao (2002) identified the soil erosion areas and suggested appropriate measures for controlling soil erosion with the help of RS and GIS techniques in the Phulang Vagu watershed in the Sriramsagar catchment area of Andhra Pradesh. They have used digital imagery data and satellite images for their study. They interpreted the satellite images for preparing land use/ land cover maps using ERDAS imagine processing system. Toposheets were used for developing drainage and slope maps. The imagery data obtained from National Remote Sensing Agency (NRSA) is used to prepare land use/land cover and the imagery was interpreted by using ERDAS image processing software. The process included the six basic photo elements, namely color/tone, texture, shape, size, pattern and association. Along with this ground truth observations and collateral data in the toposheets were used .A total number of five distinct land use/land cover types, namely forest cover, crop-land, water bodies, waste-land and built-up land were identified and modeled.

In addition, Das and Mukherjee (2005) also reported that RS and GIS techniques were effectively used in morphometric analysis of watersheds.

Yarrakula *et al.* (2010) used RS and GIS tools for data transforming from CARTOSAT-1stereo images to inundation and damage areas.

Further, Ansari *et al.* (2012) suggested that RS and GIS techniques have been proved to be efficient tools in the delineation, updating and morphometric analysis of drainage basin.

RS data along with increased resolution of satellite platform makes the watershed management studies appeared to be more appealing accurate and precise works. It also provides better impact on land resource management initiatives involved in monitoring LULC mapping and change detection at varying spatial scales in semi-arid regions undergoing stresses due to the combined effects of growing population and climate change (Singh *et al.,* 2012).

Bastawesy *et al.*(2013) utilized RS data and DEMs to obtain hydrological parameters of watershed for delineating storage areas of Uganda Equatorial Lakes region. They also concluded that DEMs were fast, accurate and precise tool for calculating morphometrical parameters and watershed delineation for watershed management.

2.6 Data sources for GIS

Lawas and Luning (1996) employed different data acquisition techniques like Rapid Rural Appraisal (RRA), farmer based interview schedule, field visit and observation, checklist of questions, analog maps, aerial photographs, published and unpublished reports and documents for primary as well as secondary data collection for integrating into a GIS for further analysis.

Rao (2000) had suggested geographic data base requirement for GIS application in different scales. He opined that the geographical data play a key role in deriving information on natural resources and environment and in the interpretation of spatial and attribute data in a GIS environment for decision making. Though topographical maps provide some spatial information about spatial and cultural features of the terrain, it is not enough for development planning. Timely and reliable information on natural resources with respect to their potentials and limitations is a pre-requisite for sustainable development.

Timely and reliable information on natural resources with respect to their potentials and limitations was considered as a pre-requisite for sustainable development. Data sources for creating new data include remotely sensed data, *Global Positioning System* (GPS) data and paper maps (Chang, 2002).

The information derived from various sources can be stored as a database in a GIS and enables future use of stored data for an effective and efficient manipulation of spatial and non-spatial data. In the context of GIS, data means representation that can be manipulated using a computer. It can be obtained from various sources and are stored as a database in a GIS and enables future use of stored data for an effective and efficient manipulation of spatial and non-spatial data (Aravind and Rakesh, 2004).

2.7 Watershed management and GIS

GIS has been used in various aspects of watershed management. The use of GIS in watershed related studies and decision support systems for management has been documented by Angermeier and Bailey (1992); James and Hewitt (1992); Pickus and Hewitt (1992) and Frye and Denning (1995).

Increasing number of indigenous remote sensing satellites, reasonable pricing of indigenous satellite data and increasing trained manpower have further facilitated use of remote sensing for watershed management (Saxena *et al.* 2000). In India, integration of RS and GIS for prioritizing watershed has been done by several researchers (He *et al.*, 2000; Johnson *et al.*, 2001).

Sarkar *et al.*, (2001) reported that GIS is a potential tool for facilitating the generation and use of thematic information, has been applied to groundwater potentiality of the Shamri micro-watershed in Shimla Taluk. The role of various parameters, namely, drainage. lineament. lithology . slope and landuse have been emphasised for delineation of groundwater potential zones. IRS-I C IAN and LISS Ill False Color Composite (FCC) merged satellite images on 1:25000 scale and Topographic map no. 53L/4 SI together with field traverses have been used as the data source.

Application of spatial data in watershed management has been evaluated and remote sensing has been described as an effective tool for the treatment and conservation of watersheds (Biswas, 2002).

According to Khan and Mohrana (2002), GIS provides tool to delineate watersheds and in tandem with RS data, delineation of watershed had become easier. Tomar *et al.* (2002) used integrated approach through RS and GIS for generating site specific action plan for watershed management of Shipra watershed, Meghalaya. Satellite data was visually interpreted for land use, soil drainage, and aspect and hydro geomorphological information of the watershed. These informations were integrated with socio- economic characteristics of generation of action plan. The action plan package consisted of plantations, silvipasture, agro-horticulture, agroforestry, double cropping, grazing lands, aquaculture etc.

Sekhar and Rao (2002) identified soil erosion zones to suggest measures for control of soil erosion using remote sensing, GIS and conventional techniques in the PhulangVagu watershed in Sriramsagar catchment area of Andhrapradesh.

The landuse and anthropogenic impacts on water quality are more complicated at large scale watersheds than small scale watersheds. Investigating the spatial and temporal variation of surface water quality at the large watershed is particularly useful in the development of an effective watershed management system (Baker, 2003; Gosain and Rao, 2004).

Effective watershed management requires the integration of knowledge, data, simulation models, and expert judgment to solve practical problems and provide a scientific basis for decision making at the watershed scale. For watershed management practices, GIS technologies nowadays occupy a prominent place among the modern computer tools and constitute an invaluable support in the decision making problems with a spatial dimension (Rivas and Lizama, 2005).

Dineshkumar *et al.* (2007) utilized the GIS applications to delineate the ground water potential zones of Muvattupuzha river basin, Kerala along the South-West coast of India.

Chowdary *et al.* (2009) prepared detailed thematic maps of soils, land use and hydro-geomorphology of Mayurakshi watershed, India.

Another study by Kashiwar *et al.* (2009) made detailed thematic maps of soil, landuse/ land cover of Salai watershed in Maharashtra. Further, Wani, *et al.* (2010) identified that cartosat DEM can be used as an input for planning the development of watershed.

A study by Bisht and Kothyari (2001) stated that Land-use change and Land-cover classes in Garur Ganga watershed of Bageshwar district in Uttranchal State during the periods 1963–1996 and 1986–1996 were analyzed through SOI Topographical Sheet and Visual Interpretation (TSVI) of LANDSAT 5 TM image bands 2, 3 and 4 using GIS. The detailed analyses have revealed that the area under agriculture and settlement increased from 34.98 to 42.34%, whereas the forest and barren land show a declining trend. Expansions of agriculture land and buildup areas have been found to be maximum in the 1200–1600 m elevation zone with 7–14° slope class. The loss of vegetation cover has been estimated to be 5.07% between 1963-1996 and 0.81% between 1986–1996.

Sreenivasulu *et al.* (2014), studied on landuse and land cover analysis using RS and GIS in and around Rajampet, Kadapa district , Andhra pradesh. For their study, they used high resolution IRS LISS III satellite imagery for identifying the LULC classes. ERDAS and ArcGIS software were used to demarcate the land use/land cover features of study area. RS and GIS provide consistent and accurate base line information than many of the conventional surveys employed for such a task. The land use and land cover analysis in and around Rajampet area has been attempted based on thematic mapping of the area consisting of built-up land, agriculture land, water bodies, forest and waste land using the satellite image. The research concludes that there is a rapid expansion of built-up area. In the study area the major part is occupied by the cultivated land. Land use and land cover information, when used along with information on other natural resources, like water, soil, hydro-geomorphology, etc. will help in the optimal land use planning at the macro and micro level.

Kumar *et al.* (2014) studied on watershed impact evaluation using RS. For their experiment they have taken four clusters of watershed in Vidarbha region, Maharashtra. They explained watershed management as a way for sustainable rural development and thus impact evaluation as must. The common approach of post classification comparison of pre and post implementation satellite imageries for watershed impact evaluation suffers from serious limitations, mainly ignoring the changes which are not due to watershed interventions. To minimize such limitations, control area approach is proposed and relative change in watershed compared to control area is attributed to watershed management. They have used Indian IRS P-6 LISS III data for the study. They relied on ERDAS IMAGINE 9.3 for computing Normalised Difference Vegetation Index (NDVI). They had performed watershed delineation in ARC GIS 9.3. Boundary reported (provided by the project implementing agency) and boundary delineated using SRTM data were compared. They concluded that there is need of improvement in delineation of micro watershed for proper implementation of soil and water conservation measures in watershed management. A synergic use of microwave and optical remote sensing has the potential to be utilized for proper watershed planning, hydrological monitoring, hydrological modeling and impact evaluation.

The common guidelines have also emphasized the use of advanced tools like remote sensing, GIS and GPS. The use of remote sensing has already begun in prioritizing developing area specific watershed development plan as well as impact evaluation (Chowdary *et al.*, 2009).

2.8 Watershed models

As quoted by Dawdy and O'Donnell (1965); Mandeville *et al.* (1970), the first ideas regarding watershed modeling were associated with the development of civil engineering in the nineteenth century and the watershed model has gained a well acceptance all around the world now, it has become possible only after the advent of computers. Since then, a number of more or less complex models have been proposed. The first ones were essentially lumped models considering the catchment as an undivided whole. Though more lumped models were developed later on, they were challenged by various types of distributed models more able to account for the spatial variability of processes within watersheds (Morin *et al.*, 1975, Blaikie and Eeles 1985; Deschenes *et al.*, 1985 a, b). Also, more physically based models like System Hydrologic European (SHE) (Abbott *et al.* 1986 a, b) and TOPMODEL (Beven and Kirkby, 1979) were developed. TOPMODEL requires only less data than SHE and developed specifically for unforested watersheds in humid and temperate climates (Beven et al., 1984). The development of a new generation of distributed hydrological models compatible with remotely sensed and GIS data was to be very useful if not imperative, as most of the existing models had a spatial structure that was not easily compatible with this new type of data (Rango,1985). More recently, hydrological models with a spatial structure based on DEMs have been developed (Palacios-Velez and Cuevas-Renaud 1992; Vieux and Gaur 1994), whereas models like SHE and TOPMODEL were adapted to that new type of data (Quinn *et al.*, 1991; Robson *et al.*, 1993). At the same time, new models compatible with remotely sensed and GIS data have been developed (Leavesley and Stannard, 1990; Wigmosta *et al.*, 1994; Julien *et al.*, 1995; Desconnets *et al.*, 1996; Olivera and Maidment, 1999).

DEMs such as from the SRTM, or the ASTER GDEM product (USGS, Denver, Colorado, USA), have been used for extracting different geomorphological parameters of drainage basins such as drainage networks, slope gradient and aspect catchment divides the upstream flow contributing areas (Mark, 1984; Tarboton, 1997).

Precipitation Runoff Modeling system (PRMS) developed by the USGS and used for long term runoff analysis, is a physically based, deterministic, semi-distributed modeling system (Leavesley *et al.*, 1983). SWAT, developed by the

USDA, is a semi distributed continuous simulation model. This model has been widely applied to predict the effects of climate and vegetative changes, groundwater withdrawals and reservoir management (Arnold *et al.*, 1993). Semi-distributed Land Use-based Runoff Processes (SLURP) is a conceptual model that can be fully distributed hydrological model, although it is normally used in a semi distributed form (Kite and Haberlant, 1999).

Fortin *et al.* (2001) reported that the distributed hydrological model compatible with GIS and remote sensing has been developed over the past years. They have developed a model called HYDROTEL which was programmed on a microcomputer with a user friendly interface. It had the possibility of displaying and/or storing a number of input, state, and output variables during a simulation run. Also, a modular approach was decided, allowing easy addition, modification, or dropping of algorithms, as well as the translation of the interface, including on-line help, into various languages. In their study, they have chosen a small sub watershed for the vertical water budget and flow toward the outlet of the unit and river reaches for channel flow.

The study by Fu *et al.* (2005) used RUSLE and GIS for assessing soil loss in the Yanhe watershed, China. RUSLE factor maps were made with the help of local data in the watershed.

The Automated Geospatial Watershed Assessment (AGWA) is a GIS interface tool. It is developed jointly by the USDA-Agricultural Research Service (ARS), the U.S. Environmental Protection Agency, the University of Arizona, and the University of Wyoming. It is used to automate the execution and parameterization of SWAT and KINEmatic Runoff and EROSion (KINEROS2) hydrologic models. By integrating these two models, AGWA can direct hydrologic modeling and watershed assessments at multiple time and space scales. AGWA uses commonly available GIS data layers to fully parameterize, execute, and visualize results from both the SWAT and KINEROS2. Then the user selects an outlet, from which AGWA delineates and discretizes the watershed using a DEM. The watershed model elements are then employed with soils and land cover data layers to obtain the requisite model input parameters. Then the selected model is set for running, and the results obtained are imported back into AGWA for visual display. This will allow users to identify the problem areas and also those areas which require additional monitoring. It helps in providing suitable mitigation activities to enhance the result or output of the model. After this, the AGWA tool is further developed for online decision support to provide ready access to environmental decision makers, resource managers, researchers, and user groups. In addition, a variety of new capabilities have been incorporated into AGWA (Goodrich *et al.*, 2006).

Drainage parameters extracted since last two decades was more popular from digital topographical information, called as DEM. It is considered as more fast, precise, updated and expressive way for analyzing watershed (Maathuis, 2006).

Yarrakula *et al.* (2010), have used high resolution CARTOSAT-1 sterero data procured from NRSA for development of DEM. Refinements of imageries were carried out using control points collected from SOI. They have assigned Universal Transverse Mercator (UTM) projection and the datum used is World Geodetic Survey (WGS) 84. Then they extracted the river cross sectional nodes from DEM.

Principe and Blanco (2012) reported that the river discharge in the Cagayan river basin and land cover based adaptation measures was achieved by an integration of watershed models, and GIS. They have used GIS, platform for the Arc SWAT interface of SWAT model to assess the effect of climate change on river discharges from the Cagayan River basin. The inputs used for the SWAT model includes landuse/land cover maps from RS data (Landsat TM and ETM+ images), SRTM DEM (SRTM-DEM), soil map and hydrologic data. They also carried out the automatic watershed delineation via the Arc SWAT interface using the input DEM while subbasins and finer subdivisions in the basin called the hydrologic response units (HRU). They also noted that the values of the Nash-Sutcliffe Efficiency (NSE) > 0.6 and coefficient of determination (R^2) > 0.7 for both model calibration and validation of mean daily river discharges showed that SWAT can realistically model flow dynamics in the study area.

According to Chitra and Sumam (2013), watershed modeling is the use of mathematical or physical techniques to simulate hydraulic behavior of water systems and make projections relating to water levels, flows and velocities. Hydraulic models are available in many types, from simple 1D model to complex 3D models. Common 1D models used in practical river engineering problems are, MIKE 11, ISIS and HEC RAS. HEC HMS is the hydrological model used for forecasting flood in a river basin. The calibration and validation of model is carried out with the help of observed discharge data. The inputs for the HEC HMS model is extracted using HEC-geo HMS software which is compatible with ArcGIS.

Watershed evaluation based on GIS with the help of SRTM have given a fast, precise and an inexpensive way for examining hydrological systems (Panhalkar, 2014).

2.7 Soil and Water Assessment Tool (SWAT)

Arnold *et al.* (1998) ; Arnold and Fohrer, (2005) has mentioned that SWAT as an effective tool for assessing water resource and non point source pollution problems for a wide range of scales and environmental conditions across the globe.

The SWAT is a river basin, daily time step operated, continuous time simulated model that was developed by the USDA ARS. The SWAT has been used in many land and water resource management studies (Pikounis *et al.,* 2003; Sun and Cornish, 2005.) to simulate the effects of different management strategies (landuse/ land cover and reservoir, groundwater, and fertilizer management) have on local hydrology (Neitsch *et al.,*2005).

Jayakrishnan *et al.* (2005) studied about some recent advances in the application of SWAT and the SWAT GIS interface for water resources management. They have presented four case studies. The Hydrologic Unit Model for the United States (HUMUS) project used SWAT to conduct a national scale analysis of the effect of management scenarios on water quantity and quality. Incorporation of the SWAT model with rainfall data available from the WSR 88D radar network helps user to integrate the spatial variability of rainfall into the modeling process. Their study revealed the usefulness of radar rainfall data in distributed hydrologic studies and the potential of SWAT for application in flood analysis and prediction. A hydrologic modeling study of the Sondu river basin in Kenya using SWAT indicates the potential for application of the model in African watersheds and development of better model input data sets in Africa. The application of SWAT for water quality analysis in the Bosque river basin, Texas demonstrates the strength of the model for analysing different management scenarios to minimize point and non point pollution, and its potential for application in total maximum daily load (TMDL) studies

SWAT model is a "river basin, or watershed, scale model which is developed to predict the effect of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time" (Neitsch *et al.*,2005).

Another study by Gassman *et al.* (2007) also described that SWAT is a basin scale, continuous time model that operates on a daily time step. It was designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. The model was physically based, computationally efficient, and capable of continuous simulation over long period of time. The major components of model included weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In SWAT, a watershed is divided into multiple subwatersheds, which were further subdivided into hydrologic response units

(HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs denotes percentages of the subwatershed area and were not identified spatially within a SWAT simulation.

Another study by Githui *et al.* (2009) also explained the impacts of land cover change on runoff using SWAT in the Nzoia catchment, Kenya. The model was calibrated and validated against measured daily discharge and land cover changes were examined through satellite image classification.

Sathian, (2009) has carried out a work on solving the issues related to the setting up and calibration of a Physically Based Distributed Watershed Model (PBDM). He mentioned that setting up and calibration of a PBDM is extremely challenging, especially in a highly complicated data limited scenario. The present technique is mostly linear, equifinality problems worsen the regression equations, data requirement form large number of gauged catchments takes the problem to practically impossible levels. For solving the above mentioned issues he relied on the most widely accepted PBDM, SWAT for his study. He has studied on the feasible use of a PBDM in a data limited scenario and demonstrated a method for simplifying the effort involved in calibrating a complex PBDM.

Arnold *et al.* (2012) stated that SWAT is a kind of water resources professional model which make use of model GIS interface, aids the efficient creation of input data files. It is a distributed parameter model developed by the United States Department of Agriculture in 1990s.

Principe and Blanco (2012) noted that watershed delineation via the SWAT model interface in ArcGIS™ (ArcSWAT) using the input DEM (90-m SRTM-DEM) while subbasins and finer subdivisions in the basin called the hydrologic response units (HRUs) are defined by setting threshold limits for land use/land cover, soil type and slope class. River discharge data were divided into two sets, one used for model calibration while the other for validation. A sensitivity analysis was also done to identify and rank parameters that have significant impact on stream flow. The model was then set for run in three scenarios: base, with climate change, and with adaptation measures.

The impact of climate change in the Philippines was examined in the country's largest basin the Cagayan River Basin by predicting its sediment yield for a long period of time. The prediction was done by integrating the SWAT model, RS and GIS. SRTM-DEM was used for DEM requirement of the model whereas ArcGIS™ provided the platform for the Arc SWAT extension, for storing data and displaying spatial data. He also explained about the calibration of the model. A Nash-Sutcliff efficiency (NSE) > 0.4 and coefficient of determination (R^2) > 0.5 for both the calibration and validation of the model depicted that SWAT model can realistically simulate the hydrological processes in the study area (Principie, 2012).

Another water balance study on Karuvannur river basin by Ajeeth and Thomas (2013) reported that SWAT is a physically integrated distributed watershed model developed by USDA. The suitability and acceptance of this model has been well established all over the world. The inputs of the model includes DEM, land use, soil and climate data. After this, the model is calibrated using observed river flow data. Before calibration, they have carried out a sensitivity analysis of the model in order to obtain the most sensitive parameters. By doing this it is possible to minimize the parameter reduction at the calibration stage. They have performed a manual calibration.

Memarian *et al.* (2013) developed the application of SWAT for impact assessment of landuse/ land cover change and best management practices. They also integrated SWAT and GIS in current estimation, future prediction and proper decision making in terrestrial ecosystems. The results of their work includes deployment of SWAT and landuse/ land cover simulation models for impact assessment improves accuracy, reduces costs and allows the simulation of a wide variety of conservation practices at watershed scale. They concluded the synergistic role of SWAT and GIS technologies in improving watershed management.

Fukunga *et al.* (2014) presents the evaluation and ability of the SWAT hydrological model in estimating daily streamflows of the Upper Itapemirim River basin (Brazil). The model parameters were calibrated and validated with the daily climate, streamflow data, precipitation, solar radiation, wind speed, temperature and relative humidity starting from 1993 to 2000. The model was found to be highly sensitive to baseflow and they showed a satisfactory performance of SWAT model in this study.

Rivaz and Lizama (2014) observed that GIS is the framework within which spatially distributed data were collected and used to prepare model input files and evaluate model results. GIS based tools, such as the Automated Geospatial Watershed Assessment (AGWA) SWAT, can be used to illustrate the effects of landuse practices on runoff, and to support watershed-wide land use management decisions.

Boupha and Sourinphomy (2015) have studied on rainfall runoff simulation using remote sensing and GIS Tool (SWAT Model). The Arc SWAT model was applied to the Xebanghieng (XB) river Basin for modeling of the hydrological water balance. The primary objective of this study was to assess the water availability in the basin and feasibility of the SWAT model for prediction of main stream flow which is available for gauging site and which is not available so far for gauging site in the Basin. The water balance modeling was performed on annual, monthly and daily basis using spatial and temporal data of surface runoff. The model was calibrated and validated in main stream in lower part of XB River using SUFI-2. The sensitive analysis of the model to sub basin delineation and HRU definition thresholds showed that the flow is more sensitive to the HRU definition thresholds than sub basin discretization effect. SUFI-2 gave good result during calibration period. Coefficient of determination (R^2) criterion, Nash and Sutcliffe efficiency (NSE) were adopted to see performance of the model during calibration and validation period. Study indicated that due to high intensity of precipitation and good water retention capacity, the study area has high potential for agricultural activities.

Pervez and Henebry (2015) mentioned that SWAT allowed users to adjust CO_2 concentration, weather parameters (e.g., temperature, precipitation, radiation and humidity), and land use, and includes approaches describing how those parameters affect plant growth, ET, snow, and runoff generation. SWAT has been found to be suitable for large basins such as the Brahmaputra, and has often been used as a tool to investigate climate and land use change effects on freshwater availability around the world (Abbaspour *et al.*, 2009; Gosain *et al.*, 2006; Jha *et al.*, 2006; Montenegro and Ragab, 2010; Rossi *et al.*, 2009; Schuol *et al.*, 2008; Siderius *et al.*, 2013).

Malunjkar *et al.* (2015) estimated the surface runoff using SWAT model. SWAT is a physically based distributed parameter model which has been developed to predict runoff, erosion, sediment and nutrient transport from agricultural watersheds under different management practices. For the present study, a small agricultural watershed has been selected for runoff assessment. Geoinformatic techniques such as ERDAS software and SRTM data are used for execution of the model. Calibration of the model is done with the help of observed data and then it is validated on selected study area. For calibration and validation, daily observed runoff data of 1997 and 1998 were used. It is found from the results that, Nash and Sutcliffe efficiency was 0.62 and 0.74 respectively and coefficient of determination was 0.98 and 0.95 respectively for calibration and validation period.

Materials & Methods

CHAPTER 3
MATERIALS AND METHODS

3.1 Study area

Kurumali sub basin of Karuvannur river in Thrissur district, Kerala was selected as the study area. The Kurumali river or Kurumali Puzha is one of the two important tributaries of Karuvannur river. It originates from the Pumalai hills in Chimmony wildlife sanctuary in the Western Ghats of Kerala and flows westwards through the Thrissur district to join with the Arabian Sea. The Karuvannur river lies in the latitude longitude range of 10°15' N to 10° 40'N and 76°00' E to 76° 35' E. Total catchment area of the river is 1054 km^2. The Mupli stream coming from Pundimudi region at an elevation of +1116 m and joins the Chimmony river, forming the Kurumali river in Elikode near Karikulam. Further downstream, Kurumali river joins with Manali river at Palakkadavu and forms Karuvannur river.

Karuvannur is the most important river basin of Thrissur district with a utilizable water resources of 623 million cubic metre per annum of which the net utilizable surface and ground water resources are 519.8 million cubic metre and 103.2 million cubic metre respectively (Ajeeth and Thomas, 2013). The average rainfall in the low land of the Karuvannur basin was estimated to be 2858 mm, the midland receiving 3011mm and the highland 2851 mm. About 60 per cent of the annual precipitation is received during South West monsoon period, 30 per cent from North East monsoon and 10 per cent as the summer and pre monsoon period. The outlet selected for the study is at Kurumali in Muriyad Grama panchayath with a latitude and longitude of 10°24'4" North and 76°16'56" East respectively. A river gauging station managed by the Water Resources Department of Kerala is situated in that location.

3.2. Source of data used

3.2.1 Rainfall data

Daily rainfall for a period of 20 years (1993 to 2012) has been collected from Echipara and Muply raingauge station. Geographic location of these stations are 10°26'27"N, 76°27'00" E and 10° 25'00" N and 76°23'44" E respectively. These raingauges are managed by Water Resource Department of Kerala.

3.2.2 Runoff data

The daily river flow of Kurumali basin has been collected for the period starting from 1993 to 2012 from Data Dissemination Centre, Jalavijnana Bhavan Ambalamukku, Trivandrum .Gauging station employs stage level method to compute the discharge. Flow measurements are made two times a day and the average value of daily river flow is used in the study.

3.2.3 Other climatic data

The weather data other than rainfall viz., temperature, wind speed, relative humidity, sunshine hours and evaporation were collected from Meteorological Observatory, Kerala Agricultural University (KAU), Vellanikkara for the same time period starting from 1993 to 2012. This observatory is located at an aerial distance of 19.7 km from the centroid of the study area.

3.2.4 Digital Elevation Model (DEM)

DEM with 30 m resolution of Shuttle Radar Topography Mission (SRTM) was obtained from Earthexplorer.usgs.gov. The U.S. Geological Survey (USGS) Earth Explorer (EE) tool provides users the ability to query, search, and order satellite images, aerial photographs and cartographic products from several sources. The data can be freely downloadable from this site.

3.2.5 Soil data

Soil data of Kurumali sub basin comprising of soil texture and organic carbon has been collected from Department of Soil Survey and Soil Conservation, Kerala (Table 1) and Kerala Forest Research Institue (KFRI), Peechi. Soil Plant Atmosphere Water (SPAW) hydrologic budget model developed by Keith Saxton, United States Department of Agriculture (USDA) Agricultural Research Service (ARS) is used in this study for finding out Soil hydraulic conductivity, electrical conductivity and bulk density.

Table 1. Physical properties of soil collected from Department of Soil Survey and Soil Conservation, Kerala

Soil Code	Soil Series	Sand (%)	Silt (%)	Clay (%)	O.C (%)	O.M (%)	Rock Wt (%)	E.C (ds/m)
AYYAN	Ayyanthole	42.24	27.26	30.5	1.02	1.82	0	0
MULAY	Mulayam	58.39	5.15	36.46	0.26	0.50	0	0.01
MARAI	Maraickal	40.13	24.30	35.51	0.90	1.60	0	5
VELLA	Vellapaya	43.67	35.86	20.47	0.61	1.08	35.94	0
KOTTA	Koottala	52.28	12.15	35.57	0.83	1.47	0.58	5.7
VANIA	Vaniampara	78.81	13.77	7.42	2.4	4.27	41.03	0
PAINK	Painkulam	71.23	7.44	21.33	4.08	7.26	18.52	5.5
KULAM	Kulamavu	68.64	2.76	24.83	2.54	4.52	13.33	0

3.2.6 Landuse

Landuse map has been prepared by the supervised classification of the multispectral LISS III imagery of IRS P6 procured from National Remote Sensing Agency (NRSA), Hyderabad. The spatial resolution of the imagery was 23.5m.

Spectral bands used in the colour composite preparation and the classification were

Band 1 : 0.52-0.59 micrometer (μ)

Band 2 : 0.62-0.68 micrometer (μ)

Band 3 : 0.77-0.87 micrometer (μ)

3.2.7 Topographic map

Topographic map prepared in 1:50,000 scale was collected from Survey of India (SOI) bearing numbers 58B03, 58B06, 58B07 and 58B11 for the study area. An overall idea about the terrain, drainage network, landuse, land cover were obtained from the toposheets. Also, it was used as a reference material in the image classification and in the drainage analysis.

3.2.8 Climate change data

Climate change data for the time period starting from 2021 to 2030 is obtained from Marksim DSSAT weather generator developed in the 1980s and 1990s to simulate weather from known sources of monthly climate data from around the world. The data is used for predicting the future watershed processes using SWAT model.

3.3 Software packages and techniques used in the study

3.3.1 Arc GIS 10.3

Arc GIS is a Geographic Information System (GIS) for working with maps and geographic information. It is mainly used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, in a range of applications and managing geographic information in a database. The developer of Arc GIS is ESRI initially released on December27, 1999 at Newyork. Arc GIS 10.3, which was released in December 10, 2014, is used for this study. The system provides an infrastructure for making maps and geographic information, available in an organization, across a community, and openly on the Web.

Arc GIS for Desktop consists of several integrated applications, including Arc Catalog, Arc Map, Arc Toolbox, and Arc Globe. Arc Catalog is the data management application, used to browse datasets and files on the computer, database, or other sources. In addition to showing what data is available, Arc Catalog also allows users to preview the data on a map. It also provides the ability to view and manage metadata for spatial datasets. Arc Map is the application used to view, edit and query geospatial data, and create new maps. The Arc Map interface has two main sections, including a table of contents on the left and the data frame(s) which display the map. Items in the table of contents correspond with layers on the map. Arc Toolbox contains geoprocessing, data conversion, and analysis tools, along with many functions in Arc Info. It is also possible to use batch processing with Arc Toolbox, for frequently repeated tasks.

In this study, Arc GIS 10.3 is used for setting projection for all the SWAT inputs such as DEM, landuse and soil map. Georeferncing of soil map and the toposheets required for the study area has been carried out using this tool. Digitisation and the preparation of soil map for the study area has also been done with this software.

3.3.2 ERDAS Imagine 2015

ERDAS Imagine is an image processing high end software with raster graphics editor abilities designed by ERDAS for geospatial applications. The latest version, ERDAS Imagine 2015 is used in this study. The software is aimed primarily at geospatial raster data processing and allows the user to prepare, display and enhances digital images for mapping use in GIS or in computer aided design (CAD) software. It consists of a set of tools allowing the user to perform numerous operations on multispectral images and generate an answer to specific geographical queries. In this study, land use map of the study area has been prepared using the ERDAS software. Supervised classification on the false colour composite has yielded the land use.

3.3.3 Soil and Water Assessment Tool (SWAT)

SWAT is the acronym for Soil and Water Assessment Tool, a physically based, conceptual, continuous, a river basin or watershed scale model that was developed by Jeff Arnold in the early 1990s for the United States Department of Agriculture (USDA) Agricultural Research Service (ARS). SWAT was developed to assist water resource managers in assessing the impact of management and climate on water supplies and also to predict sediment and agricultural chemical yields in large complex watershed with varying soils, land use and management conditions over long periods of time.

The SWAT model is a continuation of thirty years of non-point source modeling. In addition to the Agricultural Research Service and Texas A&M University, several federal agencies including the US Environmental Protection Agency, Natural Resources Conservation Service, National Oceanic and Atmospheric Administration and Bureau of Indian Affairs have contributed to the model.

SWAT requires specific information about weather, soil properties, topography, vegetation and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, and crop growth, nutrient cycling is directly modeled by SWAT using this input data.

SWAT can be used to simulate a single watershed and its processes or a system of multiple hydrologically connected watersheds. Each watershed is first divided into sub basins and then into hydrologic response units (HRUs) based on the landuse, soil and slope distributions.

The major components of SWAT model include weather, hydrology, erosion, soil temperature, plant growth, nutrients, pesticides, land management, channel and reservoir routing. The model divides the watershed into multiple subbasins, which are then further subdivided into hydrological response units (HRUs) to estimate the various hydrologic processes. These HRUs consist of homogeneous landuse, management, soil and slope characteristics.

In this study, Arc SWAT which is a SWAT Arc GIS interface, developed by United States Department of Agriculture (USDA) Agricultural Research Service (ARS) has been used. It is very user friendly and freely available and is widely used by hydrologists. SWAT and the Arc SWAT interface are public domain software and presently been used in many parts of the world. Support is available through the SWAT user website and several user groups and discussion forums. In this context, Arc SWAT interface is used for the purpose like setting up of SWAT Project, automatic watershed delineation, HRU Analysis and definitions, writing input tables, editing SWAT inputs and also for the SWAT simulation. The methodology of SWAT model shown in fig. 1.

3.3.3.1 Arc SWAT toolbar items

The Arc SWAT toolbar includes SWAT project setup, watershed delineator, HRU analysis, write input tables, edit SWAT input and SWAT simulation.

3.3.3.1.1 Swat project setup menu

The SWAT Project Setup menu contains seven items that control the setup and management of SWAT projects. A SWAT project comprises of a project directory which contains an Arc Map document, two geo databases, and a subdirectory structure for storing temporary GIS datasets, and SWAT 2012 input files.

New SWAT project

The New SWAT Project command is used to create a new SWAT project directory structure.

Open SWAT map document

It opens an existing SWAT project ArcMap document.

Save SWAT project

This command saves the current SWAT project you are currently working on.

Copy SWAT project

This command is used to copy the entire contents of the specified SWAT project to a new project folder.

Delete project

The Delete project command deletes the Arc SWAT project.

Arc SWAT help

The Arc SWAT help command carries the Arc SWAT documentation.

About Arc GIS Arc SWAT

This command opens a dialog that explains the current version of the Arc SWAT extension being run.

3.3.3.1.2 The watershed delineator menu

The watershed delineator menu comprises of two commands that are required to perform sub basin delineation and evaluate the results.

Automatic delineation

The automatic delineation command accesses the dialog box used to import topographic maps and delineate the watershed.

Watershed reports

The watershed reports command provides access to the topographic report generated by the interface. Area elevation data (hypsometric information) of the watershed is provided by this report.

3.3.3.1.3 The HRU analysis menu

The HRU analysis menu contains three commands that perform the land use, soils, and slope analysis used to generate SWAT HRUs.

Land Use/Soils/Slope Definition

The Land Use/Soils/Slope Definition command accesses the dialog box used to import land use and soil maps, link the maps to SWAT databases and perform an overlay.

HRUs definition

The HRUs distribution command accesses the dialog box used to define the number of HRUs created within each sub basin in the watershed.

HRU analysis reports

The HRU analysis reports command lists various HRU analysis reports generated by the interface. To access a particular report, highlight the name of the report and left mouse click. The report of interest will display in a text editor.

3.3.3.1.4 The write input tables menu

The input menu contains the commands which generate the Arc SWAT geodatabase files used by the interface to store input values for the SWAT model.

Weather stations

The weather stations command loads weather station locations and data for use.

Write SWAT input tables

The write SWAT input tables command opens up an interface to manage the creation of Arc SWAT geodatabase tables that store values for SWAT input parameters. Initial SWAT ASCII input files are also generated.

3.3.3.1.5 The edit swat input menu

The edit SWAT input menu allows the user to edit the SWAT model databases and the watershed database files containing the current inputs for the SWAT model. Seven items are listed on the edit input menu

Databases

The databases command allows the user to access the SWAT model databases from within a project. SWAT databases may be edited at any time during the development of a SWAT project. The SWAT databases must be edited to their desired content prior to writing the SWAT Input tables in order to be reflected in the model input files.

Point source discharges

The point source discharges command allows the user to access/define the point source loadings for all sub basins with point source discharges. Edits made to point source discharges using the Arc SWAT interface are reflected only in the current SWAT project.

Inlet discharges

The inlet discharges command allows the user to access/define loadings for upstream sections of the watershed not directly modeled in the current project.

Edits made to inlet discharges using the Arc SWAT interface are reflected only in the current SWAT project.

Reservoirs

The reservoirs command allows the user to access/edit input parameters for any reservoirs located within the watershed. Edits made to reservoirs using the Arc SWAT interface are reflected only in the current SWAT project.

Sub basins data

The Sub basins data command allows the user to access/edit input parameters for land areas, channels, ponds/wetlands, and groundwater systems within the watershed. Edits made to sub basin data using the Arc SWAT interface are reflected only in the current SWAT project.

Watershed data

The Watershed data command allows the user to access/edit input parameters that are applied to the watershed as a whole. Edits made to watershed using the Arc SWAT interface are reflected only in the current SWAT project.

Re-Write SWAT input files

The Re-Write SWAT input files command allows users to re-write the ascii SWAT input files (.sub, .mgt, .hru, etc.) after the SWAT geodatabase files have been edited.

Integrate APEX model

The integrate APEX model command allows the user to specify subbasins within the current SWAT model that they wish to simulate using an existing APEX model. The APEX model project needs to have been developed using the APEX Arc GIS interface.

3.3.3.1.6 The swat simulation menu

The SWAT simulation menu allows the user to run the SWAT model and perform sensitivity analysis and calibration. Five items are listed on the SWAT simulation menu.

Run SWAT

The run SWAT command allows the user to modify parameters in three SWAT input files, the input control code file (.cod), the basin input file (.bsn), and the watershed water quality input file (.wwq), as well as set up and run the SWAT model.

Read SWAT output

The read SWAT output command allows the user to import the primary text output files written by SWAT into an Access database. In addition, the dialog opened by the command allows the user to save a SWAT simulation to a permanent folder on disk.

Set default simulation

The set default simulation command allows the user to reset the SWAT simulation inputs to use as the active default simulation. If a simulation has been saved by the user 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.

Manual calibration helper

The manual calibration helper command opens a dialog that provides a tool to allow users to make parameter changes to specified HRUs during manual calibration. All the parameters for SWAT must be in the same projected coordinate system. Here, the projected coordinate system is WGS_1984_UTM_Zone43.

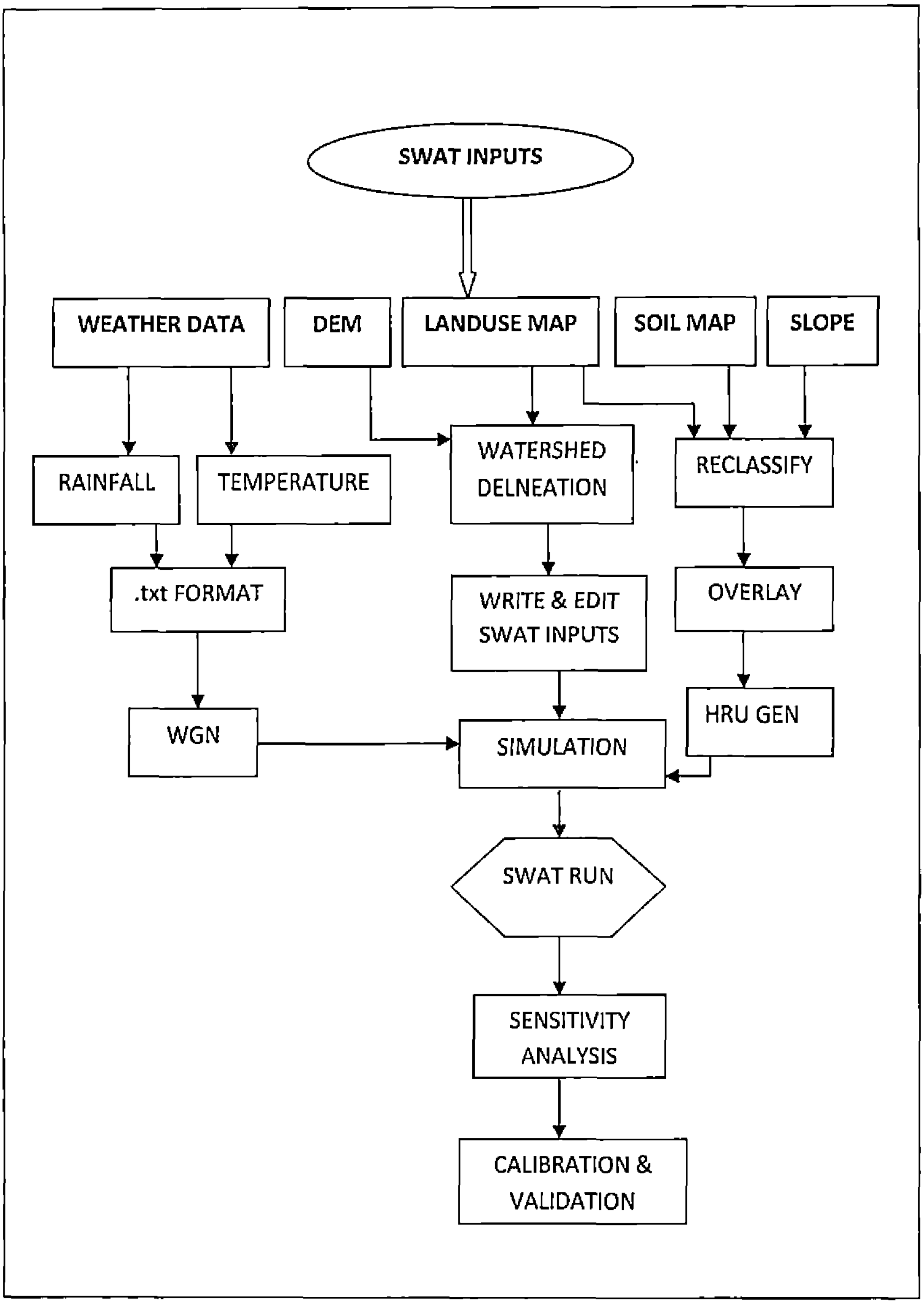


Fig. 1. Flow chart for the methodology of SWAT model

3.4 GIS maps required for SWAT

3.4.1 DEM

The delineation process requires a Digital Elevation Model (DEM) in ESRI grid format. The watershed delineation tool uses and expands Arc GIS and Spatial Analyst extension functions to perform watershed delineations. The DEM must be in a projected coordinate system before watershed delineation in Arc SWAT. The projection assigned was WGS_1984_UTM_Zone43. Delineation of the main and sub watershed boundaries and other topographic information of the watershed like elevation, direction of slope length etc from the DEM depend upon the occurrence of DEM.

3.4.2 Drainage network

SWAT requires digitized stream network for the accurate delineation of streams and sub watersheds. Drainage network is prepared in toposheets with the help of Arc GIS 10.3. This must be in a shape file format.

3.4.3 Land use map

Land use map can be in grid or shape format. Projection of the map should be same as that of the DEM. Accuracy of the HRU analysis depends on the accuracy of the landuse map. Land use map generated using ERDAS imagine 2015 and the details of land use is prepared in dBase files. The flow chart for the preparation of landuse is explained in fig. 2.

3.4.4 Soil data

Soil map is another important map layer that is to be supplied to the SWAT model for the HRU analysis. Attribute information are stored in the same dBase file format. Soil Plant Atmosphere Water (SPAW) is a daily hydrologic budget model used for calculating the characteristics of soil. The SPAW computer model estimates the daily content and movement of water and nutrients for farm fields and their soil, plus daily water budgets for agricultural wetlands, ponds and reservoirs. Soil Water Characteristics (SWC) is the program which estimates soil water tension, conductivity and water holding capability based on the soil texture, organic matter, gravel content, salinity, and compaction.

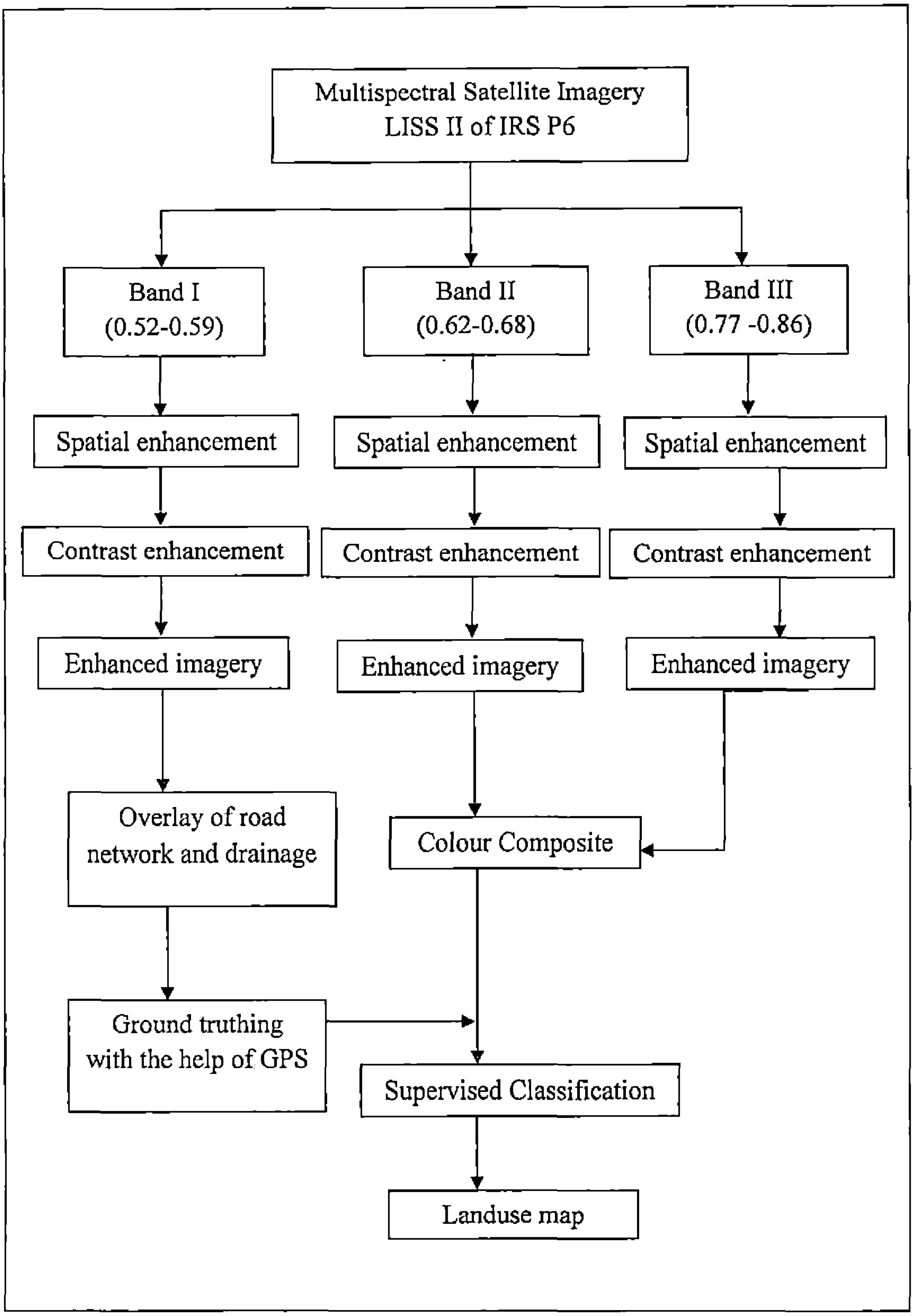


Fig. 2. Flow chart for the preparation of landuse map

3.4.5 Climate Change data

Climate change data is used to study the future prediction of climate change. Climate change data extracted from Marksim DSSAT weather generator. These include projected changes in daily rainfall (mm) and Temperature (°C) using Representative Concentration Pathway (RCP) 4.5 scenario starting from 2021 to 2030. RCP 4.5 is a scenario of long term global emissions of greenhouse gases (GHGs), short lived species and landuse , land cover which stabilizes Radiative Forcing (R.F) at 4.5 W/m^2 (approximately 650ppm CO_2 equivalent in the year 2100 without ever exceeding the value). The Ensemble mean data of seventeen General Circulation Models (GCMs) have been used for the period starting from 2021-2030 show in table 2.

3.4.6 Attribute data required by SWAT

The precipitation gauge location table should have .txt (.text) extension. Daily precipitation data table must be formatted only as an ASCII text file. The temperature gauge location table should have txt extension. Daily maximum and minimum temperature data table must be formatted only as an ASCII text file. Other weather parameters like solar radiation, wind velocity, relative humidity can be included in weather generator (WGN) text file. The daily records must be listed in sequential order. The land use and soil look up table is used to specify the SWAT land cover or plant code and the type of soil to be modeled for each category in the soil map grid respectively. Both the table must be formatted as dBase format. In the case of climate change data also, it must be in the same text file format to run in the SWAT

Table 2. General Circulation Models used for the study

S. N	Model	Institution
1	BCC-CSM 1.1	Beijing Climate Center, China Meteorological Administration
2	BCC-CSM 1.1(m)	Beijing Climate Center, China Meteorological Administration
3	CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organisation and the Queensland Climate Change Centre of Excellence
4	FIO-ESM	The First Institute of Oceanography, SOA, China
5	GFDL-CM3	Geophysical Fluid Dynamics Laboratory
6	GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory
7	GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory
8	GISS-E2-H	NASA Goddard Institute for Space Studies
9	GISS-E2-R	NASA Goddard Institute for Space Studies
10	HadGEM2-ES	Met Office Hadley Centre
11	IPSL-CM5A-LR	Institut Pierre-Simon Laplace
12	IPSL-CM5A-MR	Institut Pierre-Simon Laplace
13	MIROC-ESM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
14	M0IROC-ESM-CHEM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
15	MIROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
16	MRI-CGCM3	Meteorological Research Institute
17	NorESM1-M	Norwegian Climate Centre

3.5 Important equations used in SWAT for predicting runoff

SWAT allows a number of different physical processes to be simulated in a watershed.

The hydrological cycle as simulated by SWAT is based on the water balance equation

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \qquad (3.1)$$

Where, SW_t is the final soil water content (mm H_2 O), SW_0 is the initial soil water content on day i (mm H_2 O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2 O), Q_{surf} is the amount of surface runoff on day i (mm H_2 O), E_a is the amount of evapotranspiration on day i (mm H_2 O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2 O), and Q_{gw} is the amount of return flow on day i (mm H_2 O).

3.5.1 Surface Runoff

The SWAT provides two methods for estimating surface runoff: the SCS curve number and the Green-Ampt infiltration method. The SCS curve number method estimates surface runoff from daily rainfall using initial abstractions (surface storage, interception, and infiltration before runoff) and a retention parameter varies with respect to changes in soil, land use, management, and slope and soil water content.

The daily surface runoff is given by

$$Q_t = \frac{(R_t - 0.2S)^2}{(R_t + 0.8S)} \qquad (3.2)$$

Where, Q_t is the accumulated runoff or rainfall excess, R_t is the rainfall depth for the day and S is the retention parameter and calculated as

$$S = 25.4\frac{1000}{CN} - 1 \qquad (3.3)$$

Where, CN is the curve number for the day. 0.2S is taken as Initial abstraction I_a. Runoff will occur only when $R_t > 0.2S$. The SCS curve number is a function of the soil's permeability, land use and antecedent soil water condition. SCS defines three antecedent moisture conditions : I for dry (wilting point), II for average moisture condition and III for wet (field capacity). The curve numbers I and III can be calculated from curve number II. The curve number for moisture conditions I and III are calculated with the equations

$$CN_1 = CN_2 - \frac{20(100-CN_2)}{[100-CN_2+e^{(2.533-0.0636(100-CN_2)}]} \quad (3.4)$$

$$CN_3 = CN_2 * e^{0.00673(100-CN_2)} \quad (3.5)$$

Where, CN_1 is the moisture condition I curve number, CN_2 is the moisture condition II curve number, and CN_3 is the moisture condition III curve number.

3.5.2 Base flow

The steady state response of base flow to recharge is given as:

$$Q_{gw} = \frac{800 * K * h}{L_{gw}^2} \quad (3.6)$$

Where Q_{gw} is the groundwater flow, or basin flow, into the main channel on the day I (mm), K is the saturated hydraulic conductivity of the aquifer (mm/h), L_{gw} is the distance from the ridge or sub basin divide for the groundwater system to the main channel (m), and h is the water table height (m).

Results & Discussion

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Existing management practices

The results of the survey conducted at the Soil Survey Department of Kerala state indicate that one of the major measures of soil and water conservation undertaken in the watershed are stone pitched contour bunds in land slopes ranging from 10 to 40 per cent. Contour bunding has been adopted in slope groups of 5 to 20 per cent. Moisture conservation pits have been provided in slopes ranging from 2 to 40 per cent slopes. In rubber plantations having slopes from 5 to 30 per cent, staggered trenches have been constructed. Plate 1 shows an overview of Kurumali river basin.

The existing management practices in the south western region of the watershed are described as follows:

The area coverage of stone pitched contour bunds was 1.3 ha, which was constructed in a land slopes between 10 to 40 per cent. The number of moisture conservation pits (200 per ha) were adopted in this region and its area coverage is estimated as 9.5 ha. Moisture conservation pits have been provided in slopes ranging from 2 to 40 per cent. Retaining walls were also adopted in this region for a length of 2.2 km. Check dam is constructed in this area and their cumulative capacity is about 1250 m^3. This part of study region was supplied with 3500 planting material and for augmenting agrostological measures

The central part of the watershed has got stone pitched contour bunds, with approximate area coverage of 2.0 ha adopted in areas having slope of 10 to 40 per cent. This region is well covered with moisture conservation pits, retaining walls and contour bunds. The area coverage of moisture conservation pits were calculated as 1.5 ha. Retaining walls were provided for a length of 1.5 km. Agronomic measures were also well established in this region as part of soil and water conservation. Planting materials of 5528 numbers were supplied as part of agrostological measures. A financial support of Rs. 2.13 per running metre was given for agrostological measures on bund.

The north western part of study region has stone pitched contour bunds in an area of 1.7 ha. Moisture conservation pits are provided in 0.8 ha. Contour trench is also adopted in this region. Three new farm ponds were constructed in this area for recharging water and also to raise the ground water table. This water can be used at the time of water shortage. It is well protected and maintained properly from dust particles, other debris, wastes etc. Earthen bunds are constructed in those areas prioritised for interventions. This region was supplied with 5160 plants for agrostological measures. The existing soil and water conservation measures of Kurumali sub basin are shown in plate 2 to plate 5.

Plate 1. Kurumali river basin

Plate 2. Contour Bund

Plate 3. Live fencing

Plate 4. Loose boulder check dam

Plate 5. Moisture conservation pit

4.2 Climatic characteristics of watershed

4.2.1Rainfall

The annual distribution of rainfall over the Kerala state is characterised by four seasons, viz., South West monsoon (June –September), North East monsoon (October- November), winter (December-February) and summer (March- May). Kerala receives highest amount of rainfall during the South West monsoon period and this accounts for about 75 per cent of the annual rainfall (3000 mm), followed by North East (20 per cent) and the balance is received during the winter and summer season (5 per cent). The annual average rainfall of Kurumali sub basin from year 1993 to 2012 is determined as 2829 mm with a S.D of 748 mm. It is found that the variation of rainfall between months is very high (Fig. 4). Rainfall in July is the highest, (654 mm) with a S.D of 244 mm and contributes about 30 per cent to the annual rainfall, followed by June and August with magnitudes of 617 mm (S.D. 165 mm) and 417 mm (S.D.156 mm) respectively. Rainfall in January is the lowest (4.19 mm) with a S.D. of 9 mm and contributes only little to the annual rainfall followed by February with 10 mm of rainfall (S.D of 27 mm) and December having 16 mm rainfall with a S.D of 24 mm.

The annual rainfall distribution of the Kurumali watershed follows very close to the state average. The fig. 3 shows the highest amount of annual rainfall, among the collected data was in the year 2007 (3992 mm) followed by 1993 (3579 mm), whereas the lowest amount was received in 2012 with 2170 mm and considered as one of the driest year. Studies of temporal variation in monthly, seasonal and annual rainfall over Kerala for 1871–2005 by Krishnakumar *et al.* (2009) reported a significant decrease in South West monsoon rainfall and an increase in rainfall in the post-monsoon season. Seasonal decline of rainfall is more predominant in June and July but not so in August and September within the monsoon season. Analysis of monthly rainfall clearly depicts highest values of rainfall during July when compared to June.

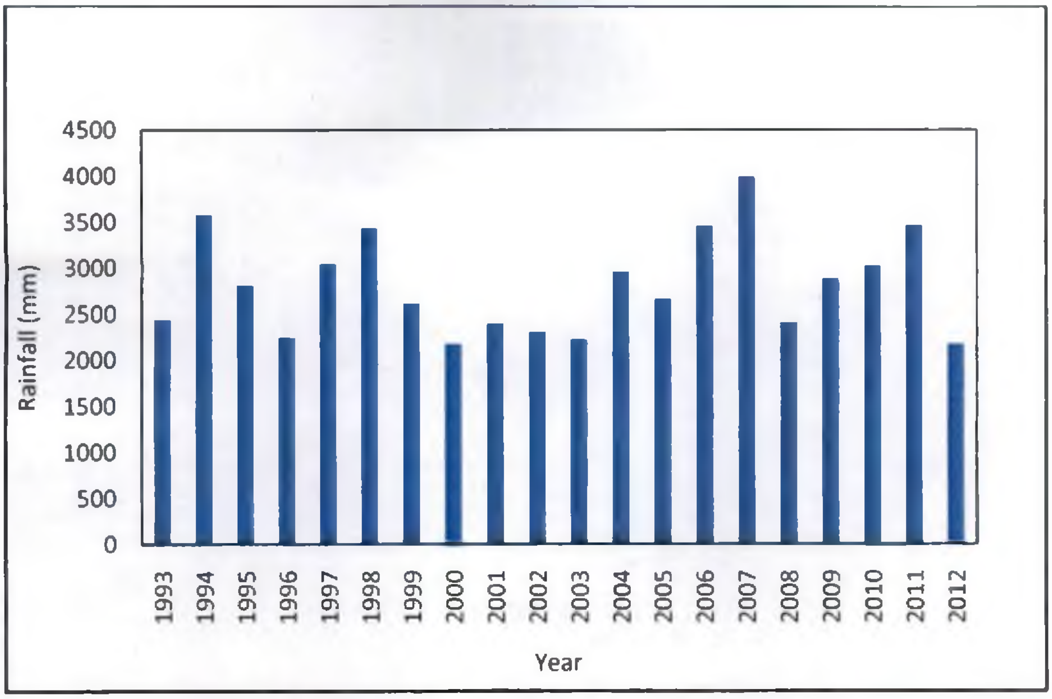


Fig. 3. Annual rainfall of Kurumali sub basin

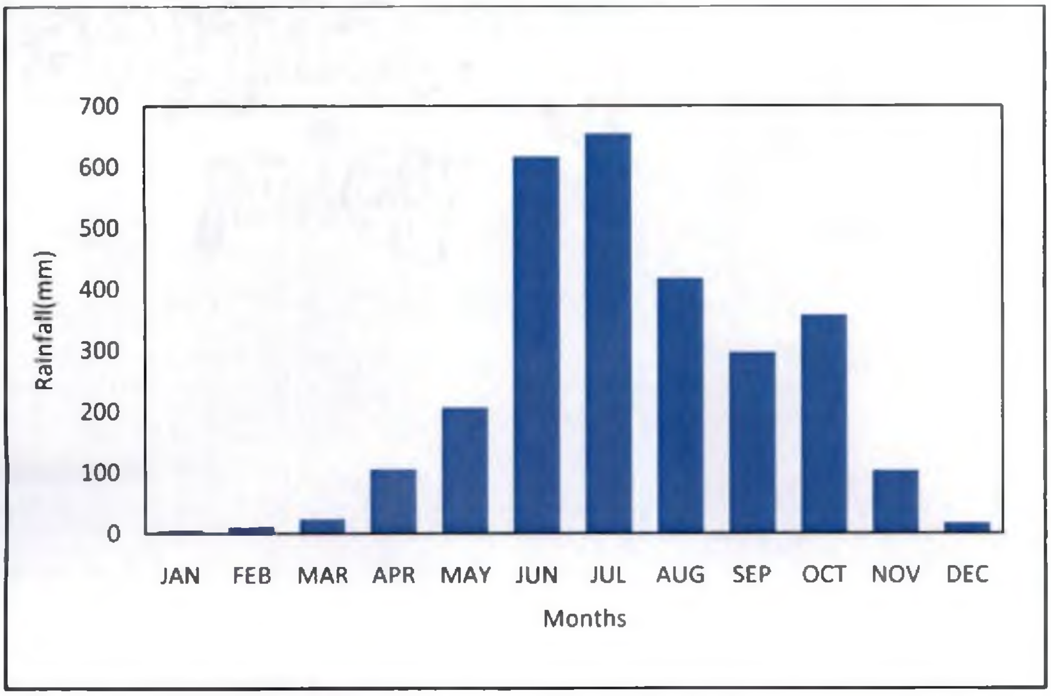


Fig. 4. Mean monthly rainfall of Kurumali sub basin.

4.2.2 Temperature

Temperature is one of the most sensitive indicators of dynamic and physical processes in the atmosphere. The temperature at any place is influenced by a number of factors like latitude, season, altitude, proximity to ocean, time of day, wind direction and speed and present weather condition. The graph of maximum and minimum temperature for the study area is shown in the fig. 5. The highest maximum temperature was observed in March (35.6°C) followed by April (34.7°C) and February (34.5°C) while lowest maximum temperature was seen in July (29.1°C) followed by August (29.6°C) and June (30.1°C). The highest minimum temperature was recorded in April (24.918 °C) followed by May (24.75° C) whereas the lowest minimum temperature was observed in January (22.33 °C) followed by December (22.56 °C).

4.2.3 Relative Humidity

On the basis of time of observation of relative humidity, it is classified as Relative Humidity I (RH I) and Relative Humidity II (RH II) and the measurements are observed at 7.25 LMT and 14.25 LMT. Normally higher values are observed for RHI. The fig. 6 depicts that the RH I is maximum in July (94.6per cent) followed by August (94.0 per cent) and June (93.7 per cent). It is also observed that temperature is minimum during July (29.1°C), followed by August (29.6°C) and June (30.1°C) and it goes in line with the relation between air temperature and RH. The decrease in relative humidity towards midday tends to be the smallest in summer. During the same period, reduced value of solar radiation was also observed. In areas with high relative humidity, the transmission of solar radiation reduces because of atmospheric absorption and scattering. The minimum value of relative humidity is observed in January (73.8 per cent) followed by December (74.9 per cent) and February (77.3 per cent).

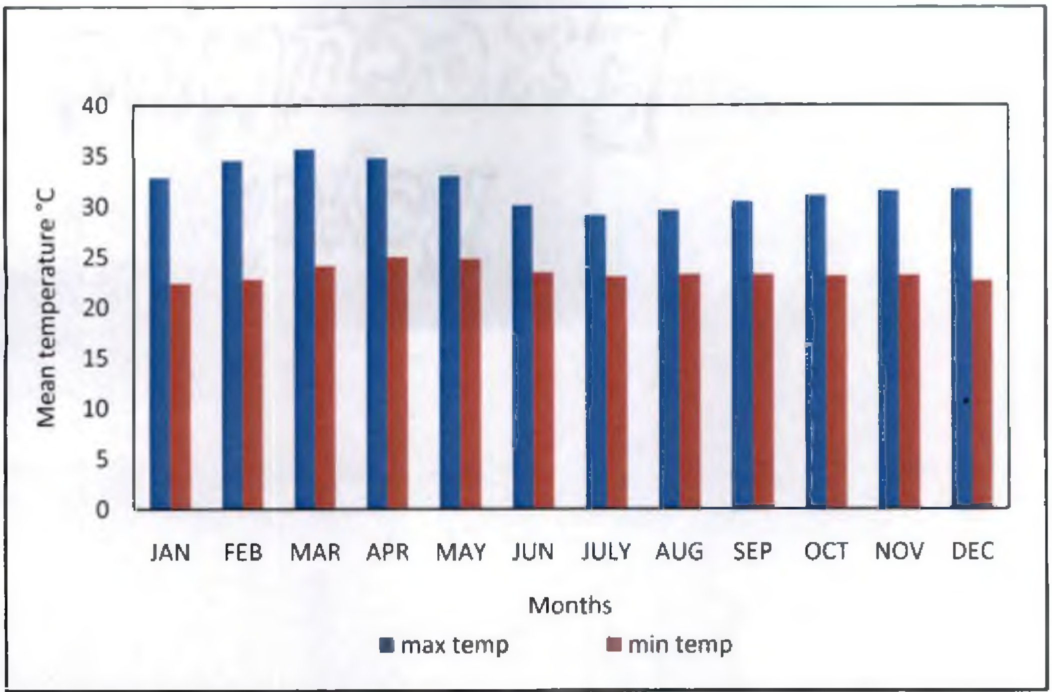


Fig. 5. Mean Monthly maximum and minimum temperature of Kurumali sub basin

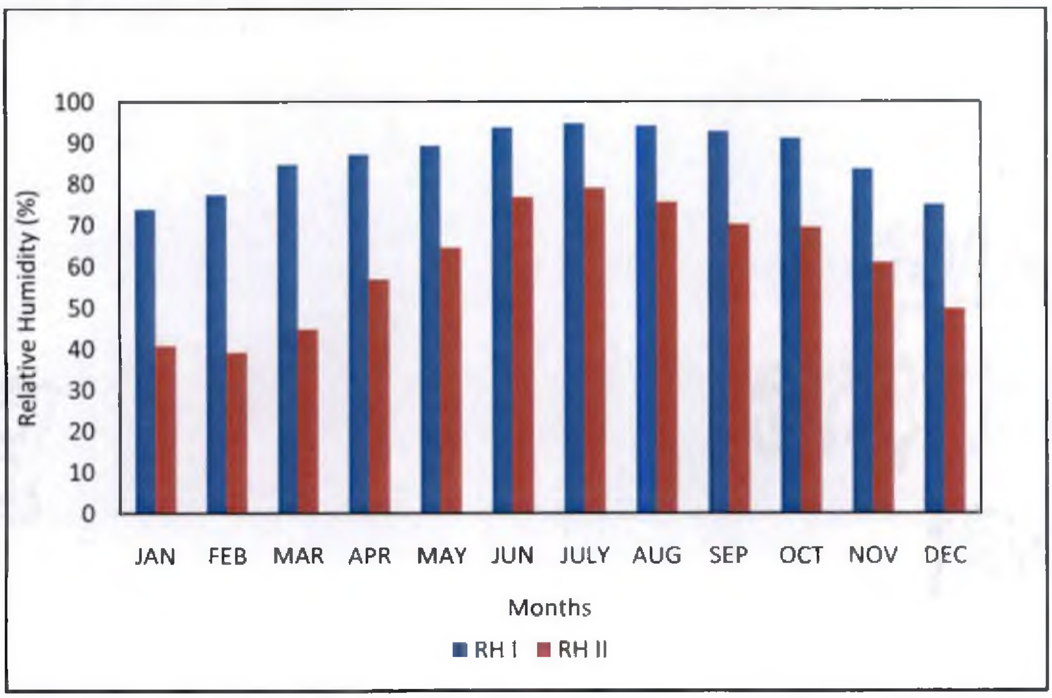


Fig. 6. Mean monthly relative humidity of Kurumali sub basin

4.2.4 Wind velocity

The wind velocity of the study area shows very high seasonal variation where winds are predominantly from the East during the period from November to March and from West for the rest of the year. In general, winds are very fast during afternoons when the thermal circulation is best developed and weak during night. The fig. 7 shows a decreasing trend from January to October and from November onwards the trend becomes increasing and the trend ceases by February of next year and it becomes cyclic. The maximum wind velocity is obtained in month of January (7.8 km/h) followed by December (7.6 km/h), February (5.62 km/h) and November (4.77 km/h) whereas minimum is observed in October (2.92 km/h) followed by September (2.89 km/h) and August (3.13 km/h).

4.2.5 Sunshine hours

The mean monthly sunshine hours of the watershed is presented in the fig. 8. From July onwards, the graph shows a gradual increase of sunshine hours. July is the month which receives minimum amount of sunshine hours (2.33h) followed by June (3.43 h). The maximum sunshine hour is recorded in February 9.03 h followed by January (9.20 h) and March (8.69 h).

4.2.6 Pan evaporation

The pan evaporation rate of Kurumali sub basin is higher during the months of December to April because of more bright sunshine hours and less number of rainy days. Among these months, the highest value recorded in January (6.1 mm/day), followed by March (5.9 mm), February (5.8 mm/day), December (5.3 mm) and April (4.9 mm/day). It is also observed that the evaporation rate is less during the South West monsoon months of June to October. The least value recorded in July (2.8 mm/day), followed by June (3.1 mm/day) and August (3.1 mm/day). All the details of mean monthly pan evaporation are shown in fig. 9.

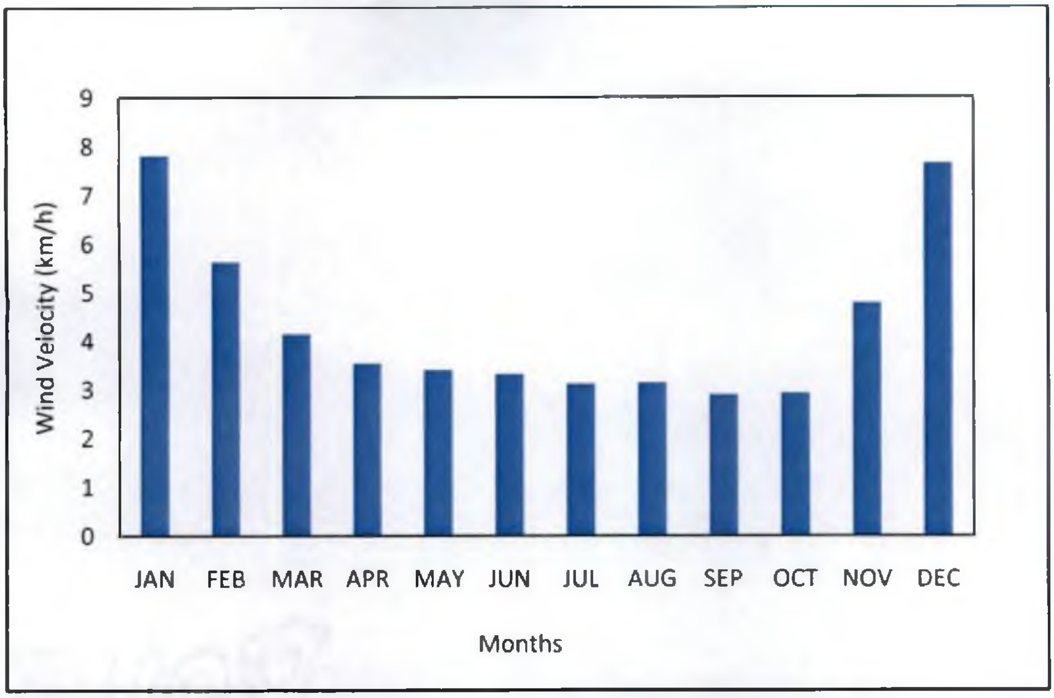


Fig. 7. Mean monthly wind velocity of Kurumali sub basin

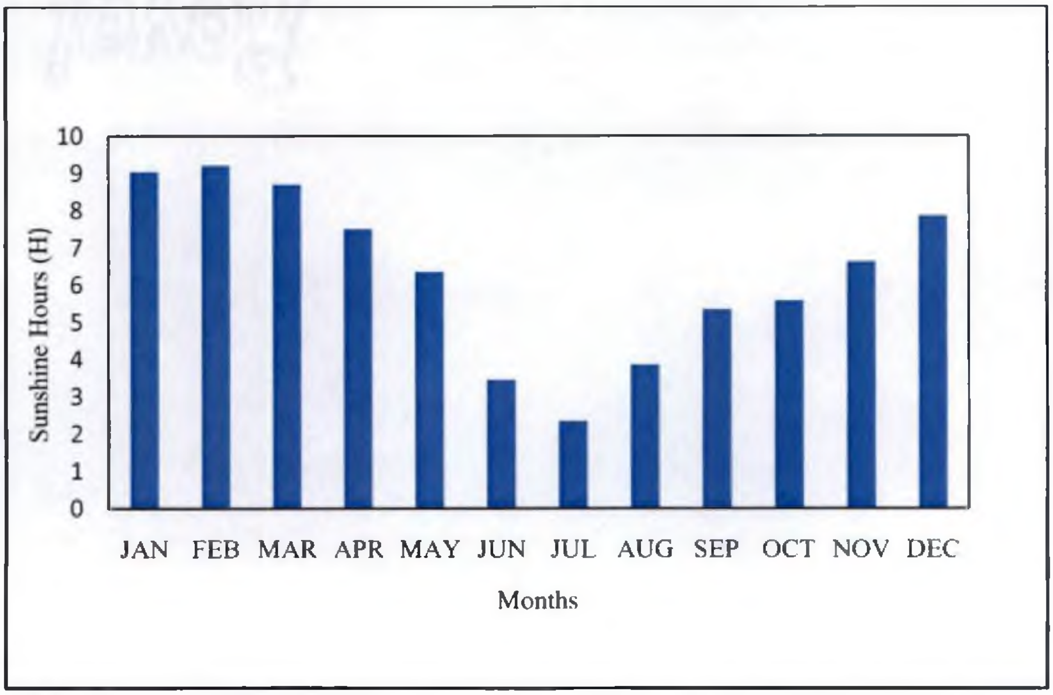


Fig. 8. Mean monthly sunshine hours of Kurumali sub basin

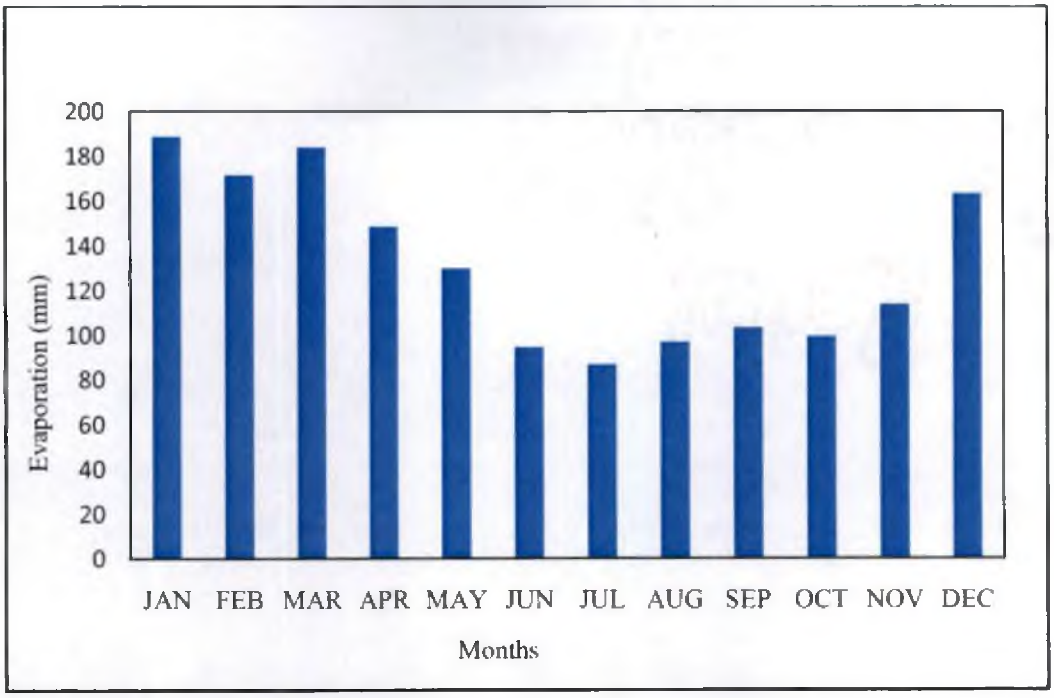


Fig. 9. Mean monthly pan evaporation of Kurumali sub basin

4.3 Physiographic characteristics of the watershed

4.3.1 Watershed delineation

Watershed boundary corresponding to Kurumali outlet having latitude 10°24'4" North and longitude 76°16'56" East has been delineated using Soil and Water Assessment Tool (SWAT) model. SRTM DEM of 30 m spatial resolution was used for the delineation. Datum and projection used were WGS_1984 and UTM_Zone43. Delineated watershed with the sub basins within it is shown in fig. 10. Total area of the watershed is 422.57 km^2 with a maximum length is 32.35 km and maximum width 20.37 km with a length width ratio of 32: 20. Twenty five sub watersheds have been delineated in the main watershed by assigning a threshold area for the generation of stream lines as 1000 ha.

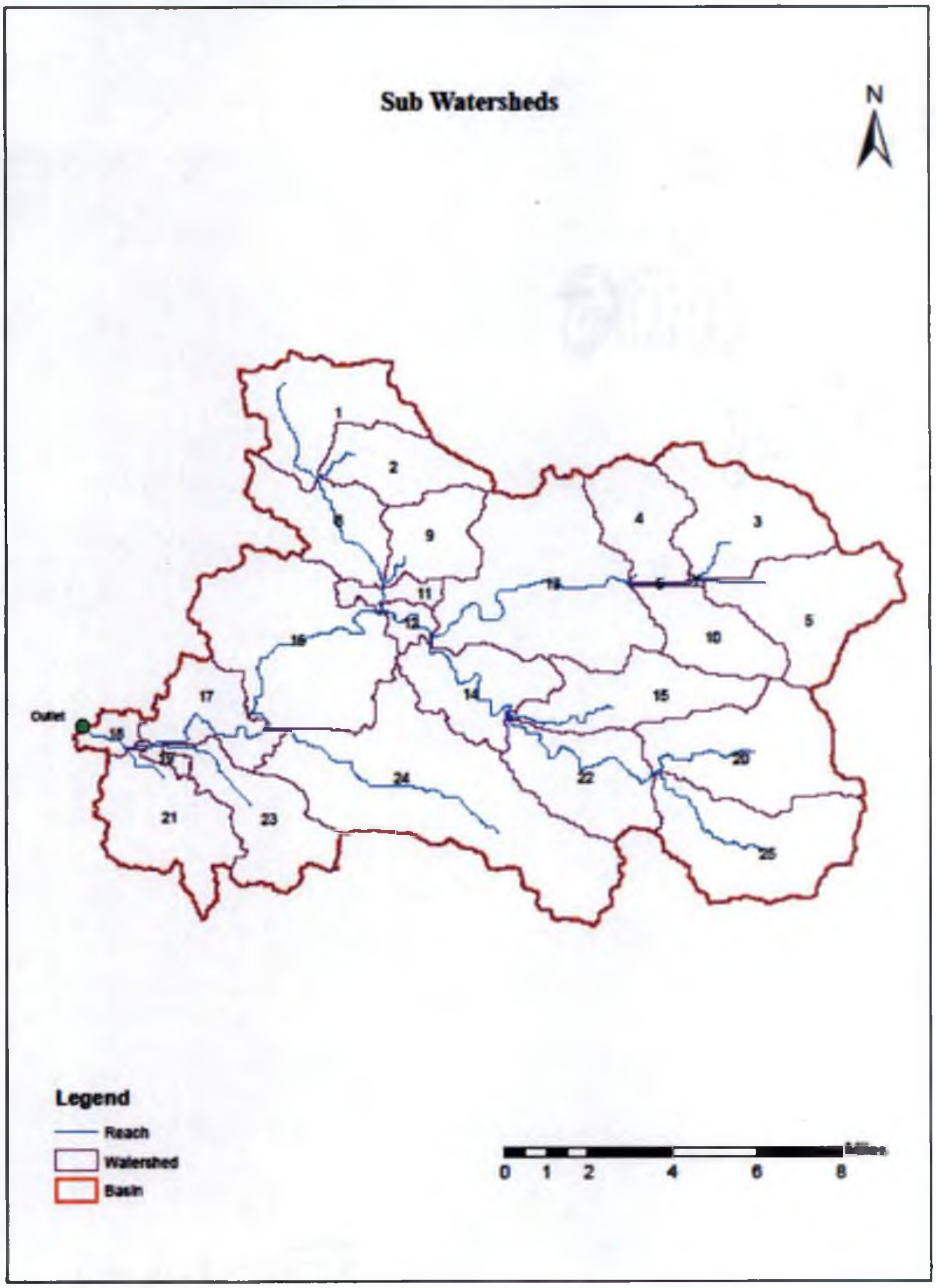


Fig. 10. Delineated watersheds with sub basins generated by SWAT model.

4.3.2 Topographic features

The classified DEM of the Kurumali watershed is presented in fig. 11. Elevation of the watershed ranges from 2 to 1149 m. Area elevation details of the watershed is shown in the hypsometric curve (Fig. 12). A hypsometric curve is an empirical cumulative distribution function of elevations in a catchment or it is a curve showing the relationship of area to elevation for a specified terrain. A hypsometric curve is plotted in which the x-axis represents elevation (m) and the y axis represents percentage (per cent) area above that elevation. The curve shows how much area lies above a particular value of elevation. About 80 per cent of the area of the watershed lies in 10 to 300 m elevation. Table 3 provides the topographical details of 25 sub watersheds generated by SWAT model, including information on mean elevation, standard deviation of elevation and the geographical area of each watershed. All the 25 sub watersheds have different mean elevation and S.D. The sub watershed No. 5 has highest mean elevation 455.06 m with S.D. of 253.79 followed by watershed No. 3 and 2, while lowest for SW No. 18 with a mean elevation of 11.54 m and S.D. 6.38. Mean elevation of various subwatersheds varies from 11.54 to 455.06 m. Fig. 10 shows the sub watershed No. 24 having largest area of 52.21 km^2 followed by sub watershed No. 13 (41.19km^2), whereas the smallest areal spread is for sub watershed No. 6 (0.14 km^2) followed by sub watershed No. 7 with an area of 0.20 km^2.

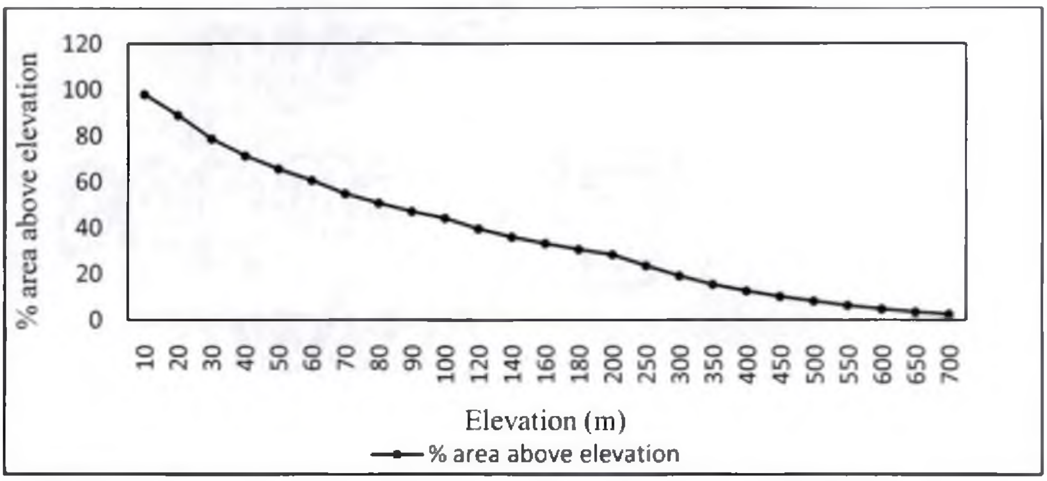


Fig. 12. Hypsometric curve of Kurumali sub basin generated by SWAT model

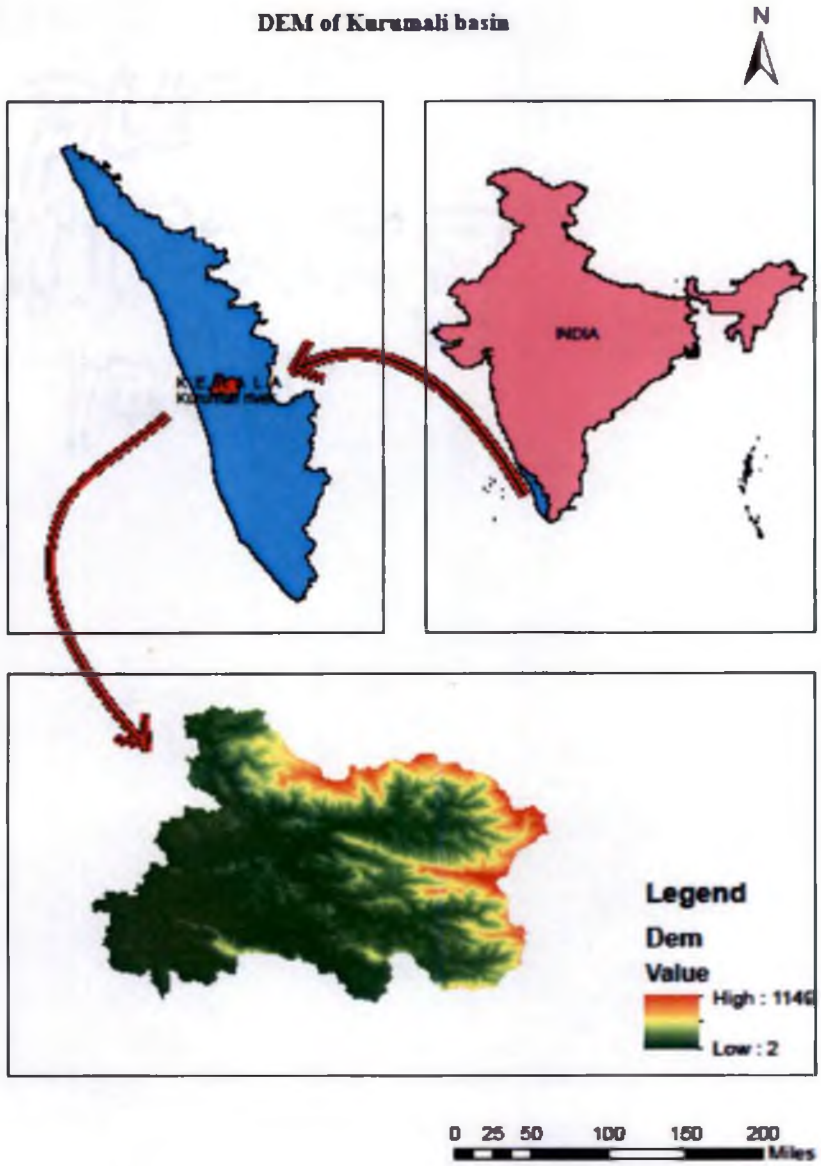


Fig. 11. Classified DEM of Kurumali sub basin generaeted from ArcGIS 10.3

Table 3. Topographic details of 25 sub watersheds generated by SWAT model

Subwatershed No.	Mean Elevation(m)	S.D of Elevation	Area (km^2)
1	123.94	95.56	19.34
2	355.46	158.19	12.74
4	264.83	178.36	13.39
5	455.06	253.79	21.97
6	66.67	3.20	0.14
7	72.51	15.74	0.20
8	87.73	71.08	14.73
9	233.04	181.83	11.36
10	248.89	185.73	12.58
11	47.01	27.43	3.44
12	36.73	12.98	2.82
13	211.49	194.41	41.19
14	74.96	48.83	15.29
15	264.56	175.30	17.77
16	36.64	21.98	38.12
17	18.08	12.98	12.73
18	11.54	6.38	3.10
19	12.12	6.61	1.30
20	295.91	200.73	25.50
21	20.56	10.22	20.04
22	94.15	57.83	18.74
23	38.21	54.78	17.12
24	57.44	54.23	52.21
25	195.81	138.97	25.95

4.3.4 Soil types

Digitised soil maps prepared in Arc GIS from conventional maps is presented in fig. 13 and the area representation of different soil types is given in table 4. Physical properties of soil generated by SPAW model is shown in table 5. There are 8 soil series that falls within the study area, viz., Ayyanthole, Mulayam, Maraickal, Vellapaya, Koottala, Vaniampara, Painkulam and Kulamavu. Majority of the soils have high sand and clay content with low fraction of silt. Organic matter (OM) content is high for Painkulam soil (7.26 per cent). Vaniampara soil also contains high OM content (4.27 per cent), so these soils can attribute to high productivity from the point of view of crop growth. Bulk density is high for Vellapaya soil with a value of 1.52g/cm^3. Available water content (AWC) is high for Ayyanthole, Vellappaya and Koottala with a value of 0.12 mm/mm. Kootala series is the major soil that falls within the study area (175.31 km^2) with 41.45 per cent coverage in the watershed followed by Vaniampara series having an area of about 94.84 km^2 (22.45per cent). Maraickal series has a geographical coverage of 3.83 km^2 area, with corresponding percentage coverage of 0.91per cent of the watershed. Mulayam series has an area extent of 4.05 km^2 and covers 0.96 per cent area of watershed.

4.3.3 Landuse

Landuse / land cover map of the watershed prepared using the supervised classification of the satellite imagery is presented in fig. 14 and table 6. Six different land use classes have been identified in the area viz., mixed crop, rice, rubber, forest and water. Mixed crop has got largest area (272.64 km^2) among all other land uses and it occupies 64.52 per cent area of watershed. The main type of agricultural practices seen in Kerala is homestead farming, mixed crop is considered as homestead agriculture. Followed by the main class is rice occupying 71.82 km^2 with percentage area coverage of 17 per cent. Though paddy area has decreased from their original acreages, its significant presence in the watershed is a welcome sign. Third important class is forest covering 43.44 km^2 and the percentage representation is 10.28. Some of the forests have been converted into agricultural lands, shelters and commercial plots. Water spread area is very small with a presence of 0.06 km^2, representing 0.01per cent area of watershed.

4.3.4 Slope map

The slope map generated in Arc SWAT is shown in fig. 15 and table 7. The entire Kurumali watershed has been classified into 3 slope classes for the division of Hydrological Response Units (HRU). Different slope classes considered were 0-5 per cent, 5-10 per cent and > 10 per cent. About 14.70 per cent area of the watershed falls under 0-5 per cent slope, 17.74 per cent is within 5-10 per cent slope and 67.56 per cent of the area falls under >10 per cent slope.

4.3.5 Description of channel reaches

Longest tributary channels of each sub basin and their properties are described in table 8. Among the 25 sub watersheds, sub watershed No. 24 has got the largest area of 52.21km^2 and the longest tributary channel (17.50 km). It has an average slope of 0.02 m/m and width of the channel is 13.84 m, followed by watershed No. 13, which has an area of 41.19 km^2, the length of longest tributary channel is 14.84 km, average slope is 0.053m/m and average width is 12.00 m. While the smallest sub watershed in terms of area is No. 6, the length of its longest tributary channel is 2.37 km, avg slope is 0.008m/m and and avg width is 0.41 m followed by sub watershed No. 7 having an area of 0.20km^2, length of longest tributary channel 2.86 km, slope and width respectively as 0.03m/m and 0.50 m.

A total of 816 HRUs have been generated within the subwatershed to simulate the hydrological processes present in the 25 sub watersheds. Typical 25 numbers of HRUs and their physical properties and area representation is presented in table 9.

Table 4. Soil types and their distributions generated by SWAT model

SOIL		
Series	Area (km^2)	Per cent Area of Watershed
Ayyanthole	5.87	1.39
Koottala	175.13	41.45
Kulamavu	18.18	4.30
Maraickal	3.83	0.91
Mulayam	4.05	0.96
Painkulam	73.38	17.37
Vaniampara	94.84	22.45
Vellapaya	47.23	11.18
Total	422.51	100

Table 5. Physical properties of soil generated by SPAW model

Soil Code	Soil Series	O.M (per cent)	Rock Wt (per cent)	B.D (g/cm^3)	Soil_AWC (mm/mm)	Soil_K (mm/h)
AYYAN	Ayyanthole	1.82	0	1.46	0.12	5.5
MULAY	Mulayam	0.50	0	1.55	0.09	2
MARAI	Maraickal	1.60	0	1.45	0.11	3
VELLA	Vellapaya	1.08	35.94	1.52	0.12	11.5
KOTTA	Koottala	1.47	0.58	1.35	0.12	7
VANIA	Vaniampara	4.27	41.03	1.18	0.06	71
PAINK	Painkulam	7.26	18.52	1.27	0.07	27
KULAM	Kulamavu	4.52	13.33	1.28	0.10	26

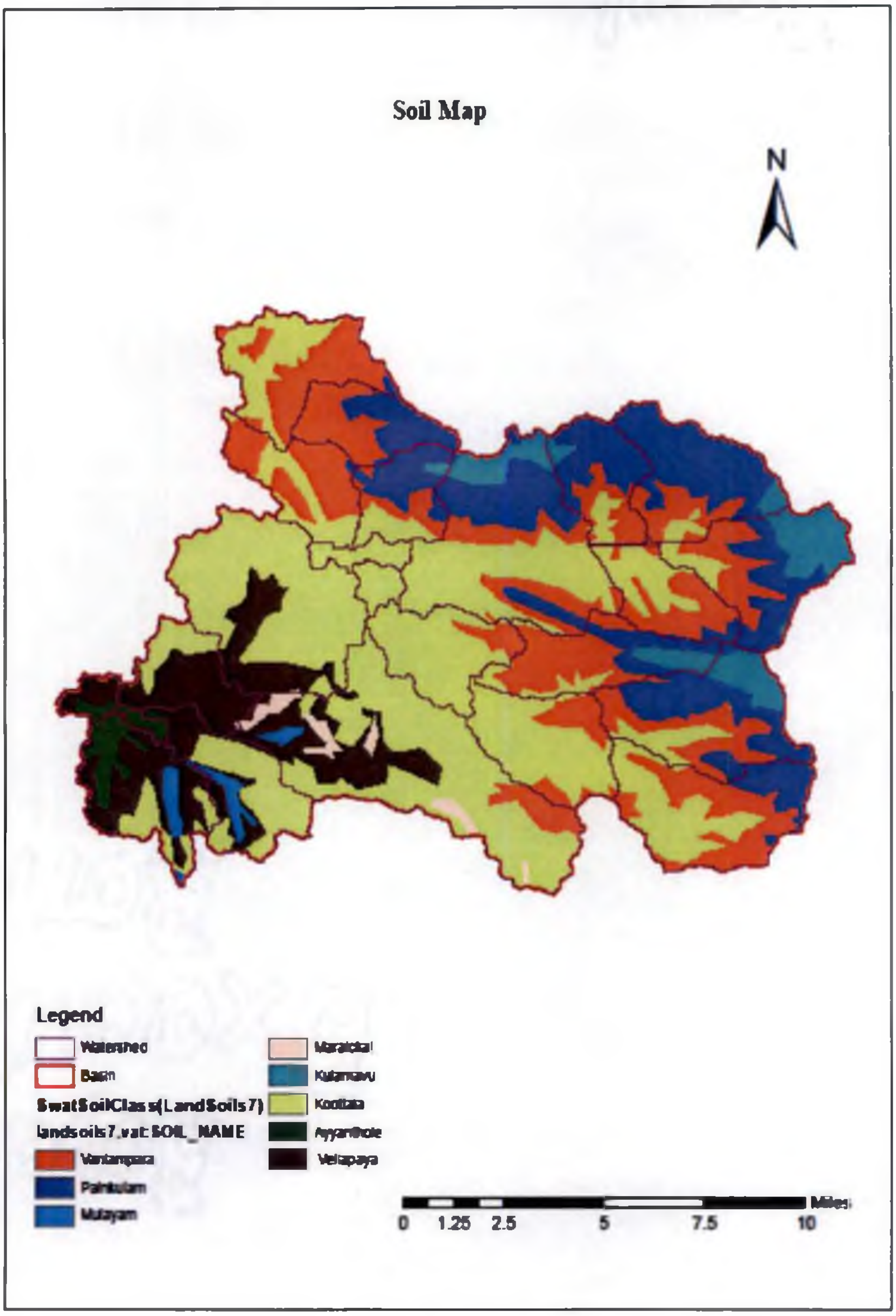


Fig. 13. Soil map of Kurumali sub basin generated by SWAT model

Table 6. Landuse pattern and distributions generated by SWAT model

LANDUSE		
Class	Area(km^2)	Per cent Area of Watershed
Mixed Crop	272.64	64.52
Water	0.06	0.01
Rice	71.82	17.00
Rubber Tress	34.61	8.19
Forest	43.44	10.28
Total	422. 57	100

Table 7. Land slope distribution generated by SWAT model

SLOPE		
Classes	Area (km^2)	Per cent Area of Watershed
0-5	62.13	14.70
5-10	74.96	17.74
>10	285.47	67.56
Total	422.56	100

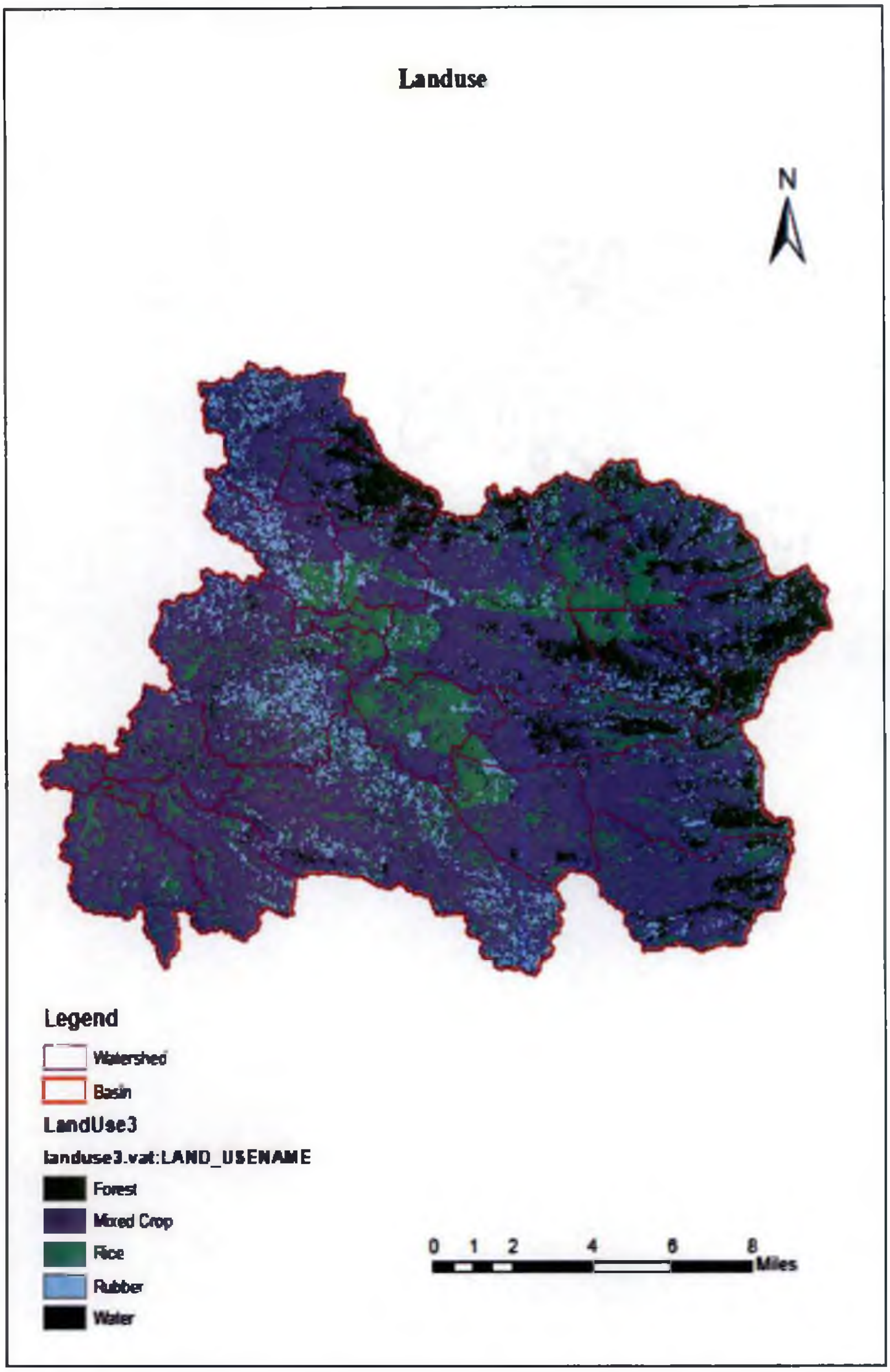


Fig. 14. Landuse map of Kurumali sub basin generated by SWAT model

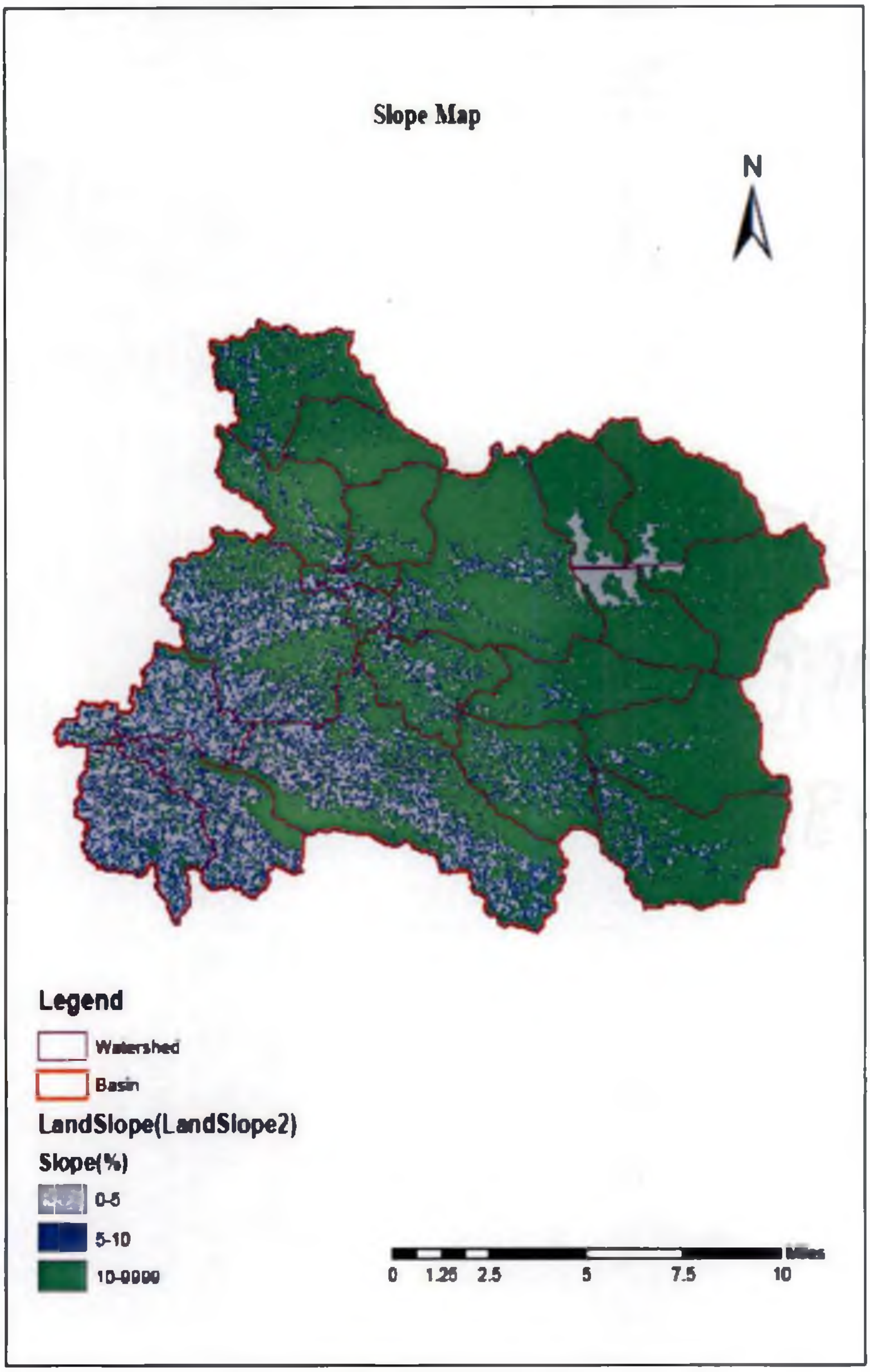


Fig. 15. Slope map of Kurumali sub basin generated by SWAT model

Table 8. Description of channel reaches generated by SWAT model

No.	Longest tributary channel length (km)	Avg. slope of tributary channel (m/m)	Avg. width of tributary channel(m)
1	12.434	0.038	7.631
2	9.080	0.085	5.940
3	8.196	0.095	7.938
4	5.536	0.123	6.120
5	9.699	0.109	8.237
6	2.377	0.008	0.413
7	2.860	0.031	0.503
8	9.028	0.018	6.481
9	7.028	0.107	5.547
10	7.959	0.102	5.896
11	3.700	0.046	2.708
12	3.446	0.009	2.406
13	14.844	0.053	12.009
14	7.961	0.041	6.628
15	12.146	0.065	7.251
16	10.757	0.004	11.464
17	7.493	0.011	5.936
18	3.349	0.001	2.546
19	3.200	0.006	1.517
20	10.539	0.069	9.007
21	8.603	0.005	7.794
22	10.970	0.033	7.488
23	10.423	0.034	7.091
24	17.503	0.020	13.844
25	11.718	0.062	9.101

Table 9. Physical properties of HRUs generated by SWAT model

Sub basin No.	HRU No.	Landuse	Soil	Slpoe	Area(ha)	per cent watershed Area	per cent sub area
1	24	Mixed crop	Vaniaampara	>10	679.03	1.61	35.10
	17	Mixed crop	Koottala	>10	434	1.03	22.47
2	51	Mixed crop	Vaniaampara	>10	481.54	1.14	37.79
	53	Forest	Painkulam	>10	341.77	0.81	26.82
3	92	Mixed crop	Painkulam	>10	691.76	1.64	33.48
	100	Forest	Painkulam	>10	351.68	0.83	17.02
4	137	Mixed crop	Painkulam	>10	426	1.01	31.80
	140	Mixed crop	Vaniampara	>10	142.88	0.34	10.67
5	193	Forest	Kulamavu	>10	362.62	0.86	16.50
	187	Mixed crop	Vaniampara	>10	343.19	0.81	15.62
6	201	Rice	Koottala	0-5	10.46	0.02	69.81
	204	Rice	Vaniampara	0-5	1.79	0.00	11.95
7	211	Rice	Vaniampara	0-5	5.18	0.01	24.89
	212	Rice	Vaniampara	>10	4.90	0.01	25.53
8	244	Mixed crop	Vaniampara	>10	536.52	1.27	36.40

	236	Mixed crop	Koottala	>10	181.35	0.43	12.30
9	277	Mixed crop	Painkulam	>10	348.66	0.83	30.67
	281	Mixed crop	Vaniampara	>10	143.16	0.34	12.59
10	315	Mixed crop	Vaniampara	>10	261.23	0.62	20.75
	326	Forest	Vaniampara	>10	195.40	0.46	15.52
11	328	Rice	Koottala	>10	98.27	0.23	28.56
	334	Mixed crop	Koottala	>10	68.09	0.16	19.79
12	348	Mixed crop	Koottala	>10	55.45	0.13	19.62
	341	Rice	Koottala	5-10	53.85	0.13	19.05
13	378	Mixed crop	Koottala	>10	882.07	2.09	21.41
	383	Forest	Painkulam	>10	860.01	2.04	20.88
14	414	Mixed crop	Koottala	>10	453.15	1.07	29.62
	413	Mixed crop	Koottala	5-10	131.56	0.31	8.60
15	458	Mixed crop	Vaniampara	>10	593.39	1.40	33.49
	456	Mixed crop	Painkulam	>10	199.84	0.47	11.25
16	489	Mixed crop	Koottala	>10	883.68	2.09	23.18
	490	Mixed crop	Koottala	5-10	615.74	1.46	16.15
17	536	Mixed crop	Vellapaya	0-5	354.88	0.84	27.88
	534	Mixed	Vellapaya	5-10	280.28	0.66	22.02

		crop					
18	557	Mixed crop	Vellapaya	5-10	68.56	0.16	22.08
	555	Mixed crop	Vellapaya	5-10	91.19	0.22	29.37
19	568	Mixed crop	Ayyanthole	0-5	39.89	0.09	30.45
	567	Mixed crop	Ayyanthole	5-10	38.57	0.09	29.45
20	601	Mixed crop	Painkulam	>10	703.92	1.67	27.60
	605	Mixed crop	Vaniampara	>10	483.33	1.14	18.95
21	649	Mixed crop	Vellapaya	0-5	386.48	0.91	19.28
	648	Mixed crop	Vellapaya	5-10	362.99	0.86	18.11
22	672	Mixed crop	Koottala	>10	649.32	1.54	34.63
	675	Mixed crop	Vaniampara	>10	324.519	0.77	17.31
23	705	Mixed crop	Koottala	0-5	265.85	0.63	15.53
	706	Mixed crop	Koottala	5-10	260.86	0.62	15.23
24	753	Mixed crop	Koottala	>10	1134.35	2.68	21.72
	752	Mixed crop	Koottala	5-10	620.27	1.47	11.88
25	806	Mixed crop	Vaniampara	>10	731.08	1.73	28.17
	800	Mixed crop	Koottala	>10	599.62	1.42	23.11

4.4 Observed river flow

River flow measured at Kurumali river gauging station managed by the Department of Water Resources is presented in fig. 16. The mean monthly river flow shows that the river is live only during the period from June to December. From January to May, the stream is completely dry. This reveals that the lag time of base flow is very less and all stored groundwater get depleted very quickly.

4.5 Calibration and validation of SWAT model

SWAT is a physically based distributed watershed model involving a number of parameters related to the estimation of surface runoff, lateral flow, ground water flow, deep aquifer recharge and evapotranspiration (ET). Hence, calibration and validation of the model assumes great significance in order to get reliable results. The model has been calibrated with 4 years of observed river flow from 1996 to 1999 and is validated using 2 years data from 2000 to 2001. The river flow simulation of the model for the default parameters are shown in fig. 17. Simulation results of calibrated model are shown in fig. 18. The annual model output of the river flow for the calibrated one shows close matching with the observed one. The estimated and observed river flow for the calibration and validation period are shown separately in 19 and 20. A very high Nash Sutcliffe Efficiency (NSE) of 0.88 and Coefficient of Determination (COD) 0.96 has been obtained for the calibration period. Corresponding NSE and COD of the model simulation for the validation period were 0.90 and 0.99. The very high NSE and COD are the clear indication of the good model prediction of the river flow. A similar study carried out by Sathian (2009) also reported that the prediction accuracy of the model was good as indicated by the time series, NSE and R^2. The importance of model calibration at different time scales has also been reported by (Sudheer *et al.*, 2007). Another study carried out by Ajeeth and Thomas, (2013) estimated a high values of NSE and COD, 0.76 and 0.82 respectively and they have considered these as the measures of model performance. Another similar study by Adeniyi *et al.*, (2014) estimated a very good value for NSE and R^2 (greater than 0.7) for both calibration and validation period. These performance evaluation study with SWAT model suggested that this model could be a promising tool to predict water balance and water yield for the sustainable management of water resources.

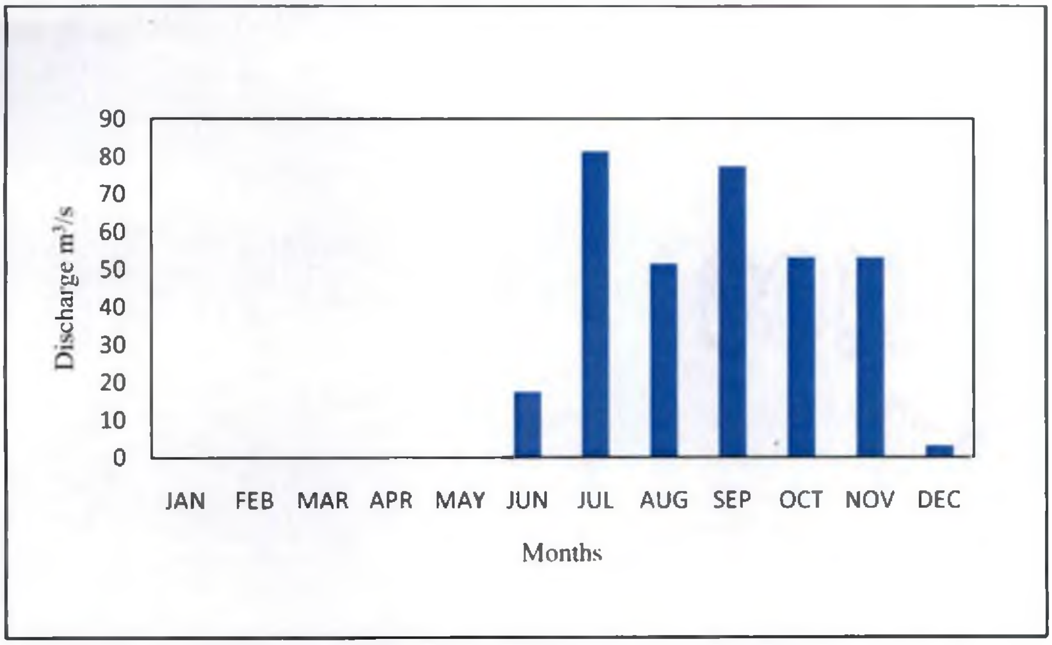


Fig. 16. Mean monthly measured river flow at Kurumali sub basin

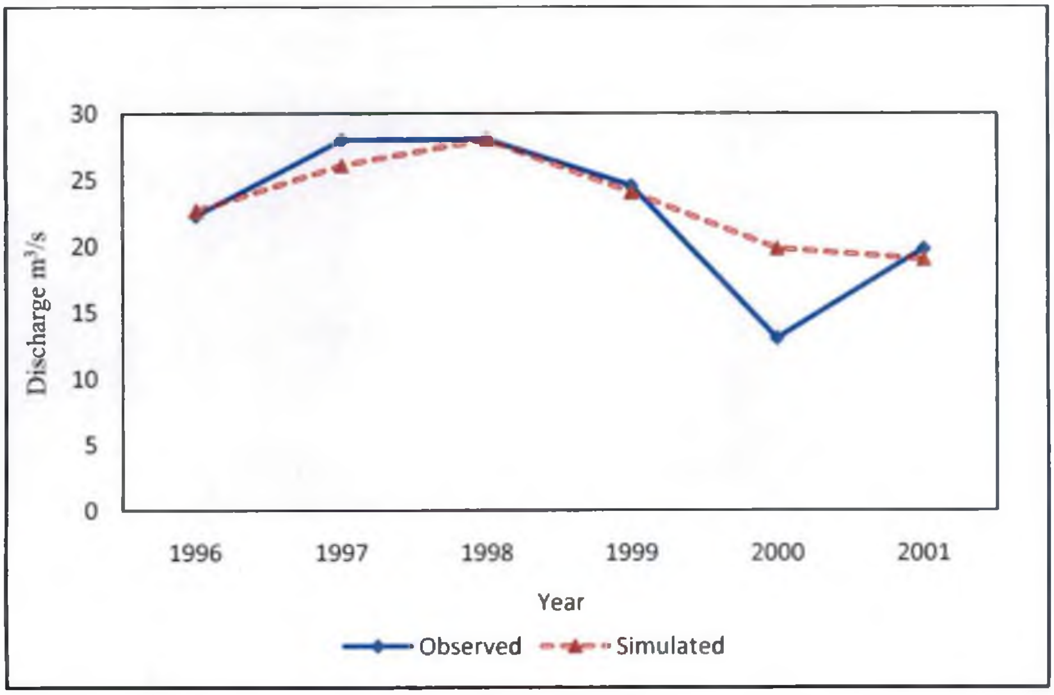
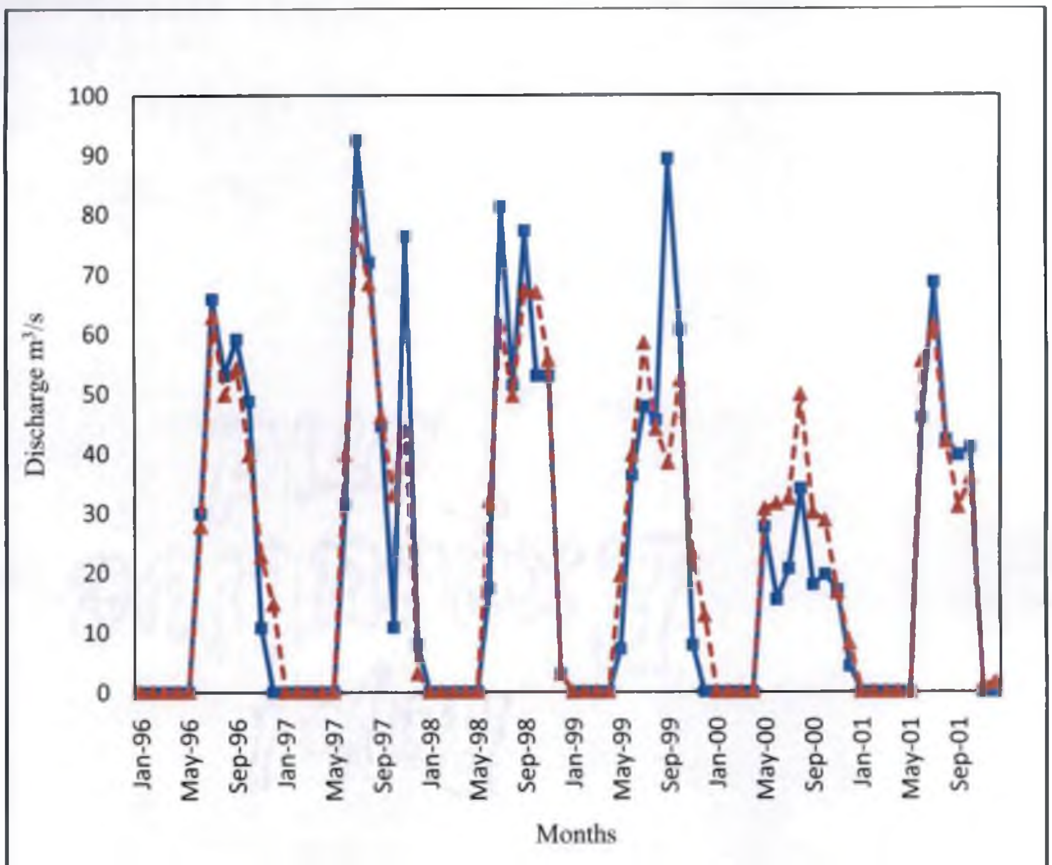


Fig. 17. Annual river flow: Observed Vs Simulated


100
90
80
70
60
50
40
30
20
10
0
Discharge m³/s
Jan-96
May-96
Sep-96
Jan-97
May-97
Sep-97
Jan-98
May-98
Sep-98
Jan-99
May-99
Sep-99
Jan-00
May-00
Sep-00
Jan-01
May-01
Sep-01
Months

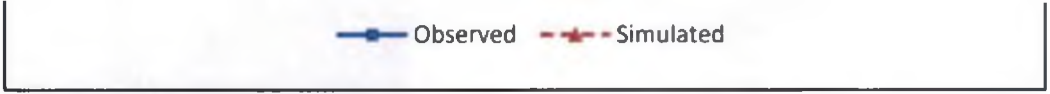


Fig. 18. Monthly river flow: Observed Vs Simulated

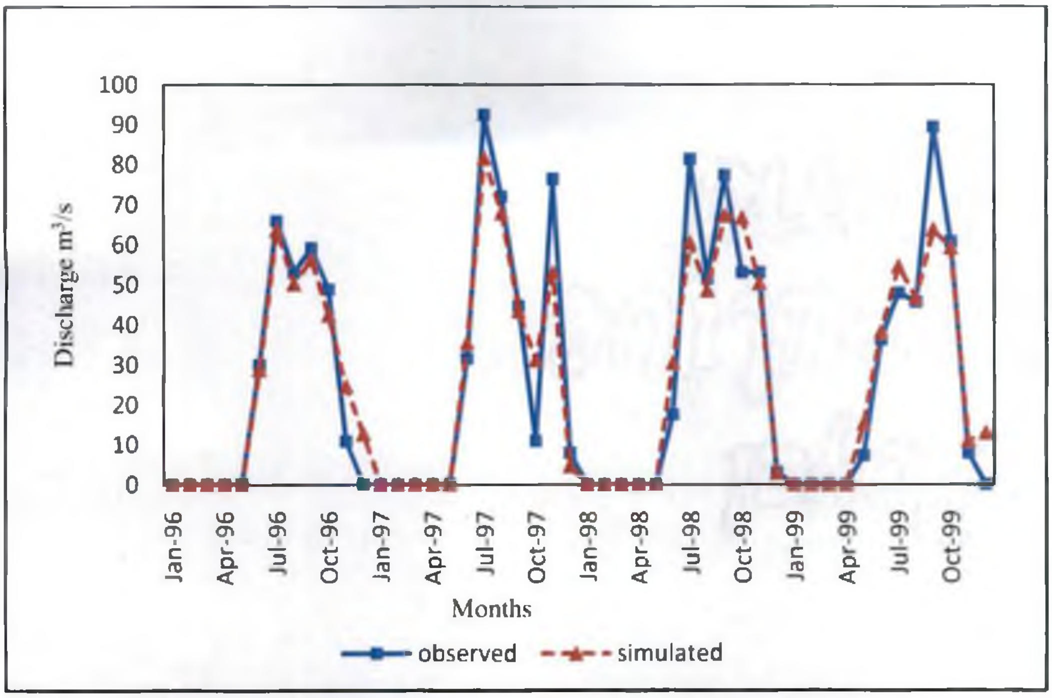


Fig. 19. Monthly average river flow (Calibration period)

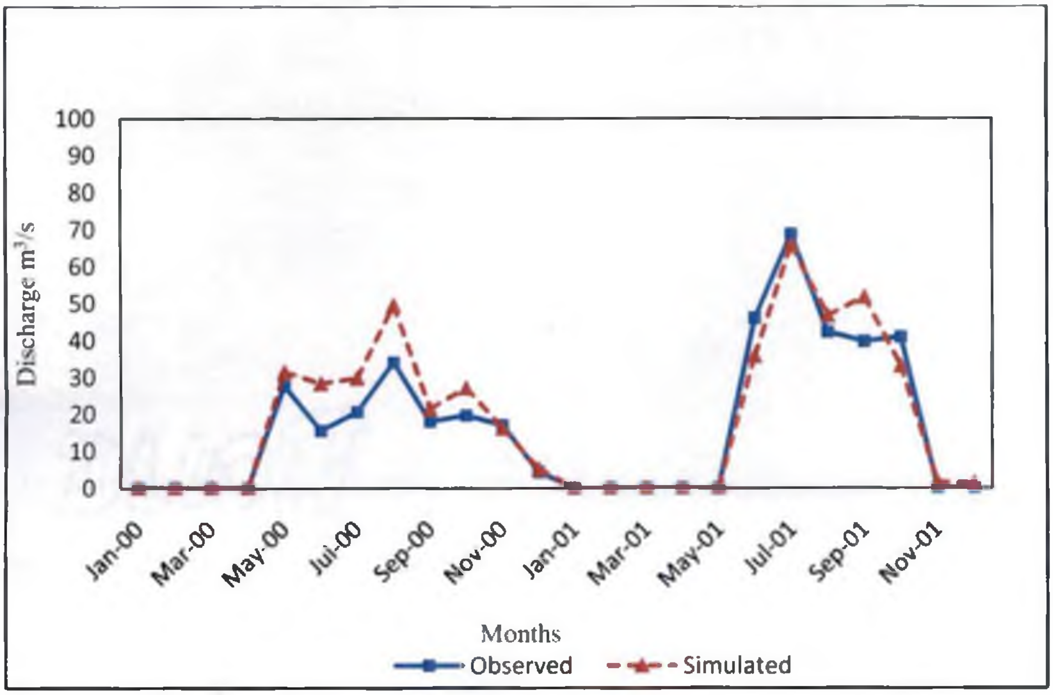


Fig. 20. Monthly average river flow (Validation period)

4.6 Water balance of the basin for existing period

Different components of the water balance of the Kurumali sub basin has been determined using the calibrated and validated SWAT model and the results are presented in fig. 21. The most important water balance components considered are surface runoff (SUR_Q), lateral flow (LAT_Q), ground water flow (GW_Q) and evapotranspiration (ET). The study revealed that a properly calibrated watershed model could be of great help in the basin level water balance. A similar study conducted by Sathian and Syamala (2009), also supporting to this result obtained from the present study. The water balance components are showing variations between years. All the components are shown as percentage of annual rainfall of the respective years. Analysis of the results shows that GW_Q has the highest share of the water balance with values ranging from 63 per cent (1998) to 66 per cent (2001). It can be seen that surface runoff varies between 9 per cent to 14 per cent of the respective annual rainfalls of the years considered. Lateral flow lies within the range of 12 per cent to 13 per cent of the annual rainfall, and 14 per cent to 15 per cent of the annual river flow. In case of base flow, its proportion as a percentage of total rainfall lies within the range of 69 per cent to 74 per cent. ET as a percentage of annual total rainfall is within the range of 11 per cent to 15 per cent. The average values for Surface runoff, lateral flow, base flow and evapotranspiration of the basin were 306.59 mm, 339.23 mm, 1649.68 mm and 337.46 respectively. The table 10 shows the percentage rainfall contributions with respect to all water balance components.

Fig 22 shows the schematic representation of Hydrologic cycle. This is the hydrology output obtained from the SWAT model. The hydrologic cycle and water distribution is clearly explained in this figure. All the units are expressed in mm. The annual average precipitation of Kurumali sub basin obtained for the period starting from 1993 to 2012 was 2829 mm. Surface runoff, lateral flow and return flow contributes to the river flow. Return flow or base flow is slower than lateral flow and surface runoff. The water that moves back to the atmosphere in the form of evaporation and transpiration and its value estimated as 357.4 mm.

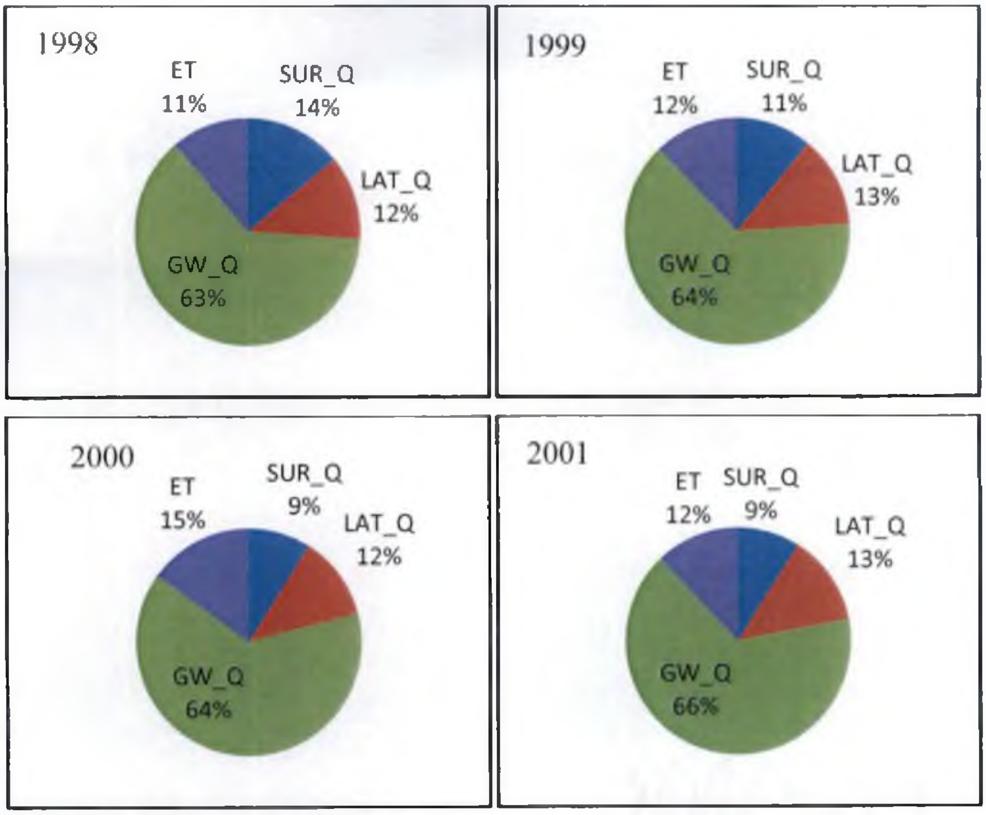


Fig. 21. Water balance of Kurumali basin for different years expressed as a percentage of annual rainfall for the existing period

Table 10. Water balance components of Kurumali sub basin for existing period generated from SWAT model

Year	SUR_Q (mm)	SUR_Q (RF per cent)	LAT_Q (mm)	LAT_Q (RF per cent)	GW_Q (mm)	GW_Q (RF per cent)	ET (mm)	ET (RF per cent)
1998	475.84	17	400.52	14	1933.95	69	364.77	13
1999	311.30	13	346.65	15	1732.09	72	343.70	14
2000	208.63	11	277.14	15	1339.50	73	323.34	18
2001	230.59	11	332.59	15	1593.17	74	318.06	15

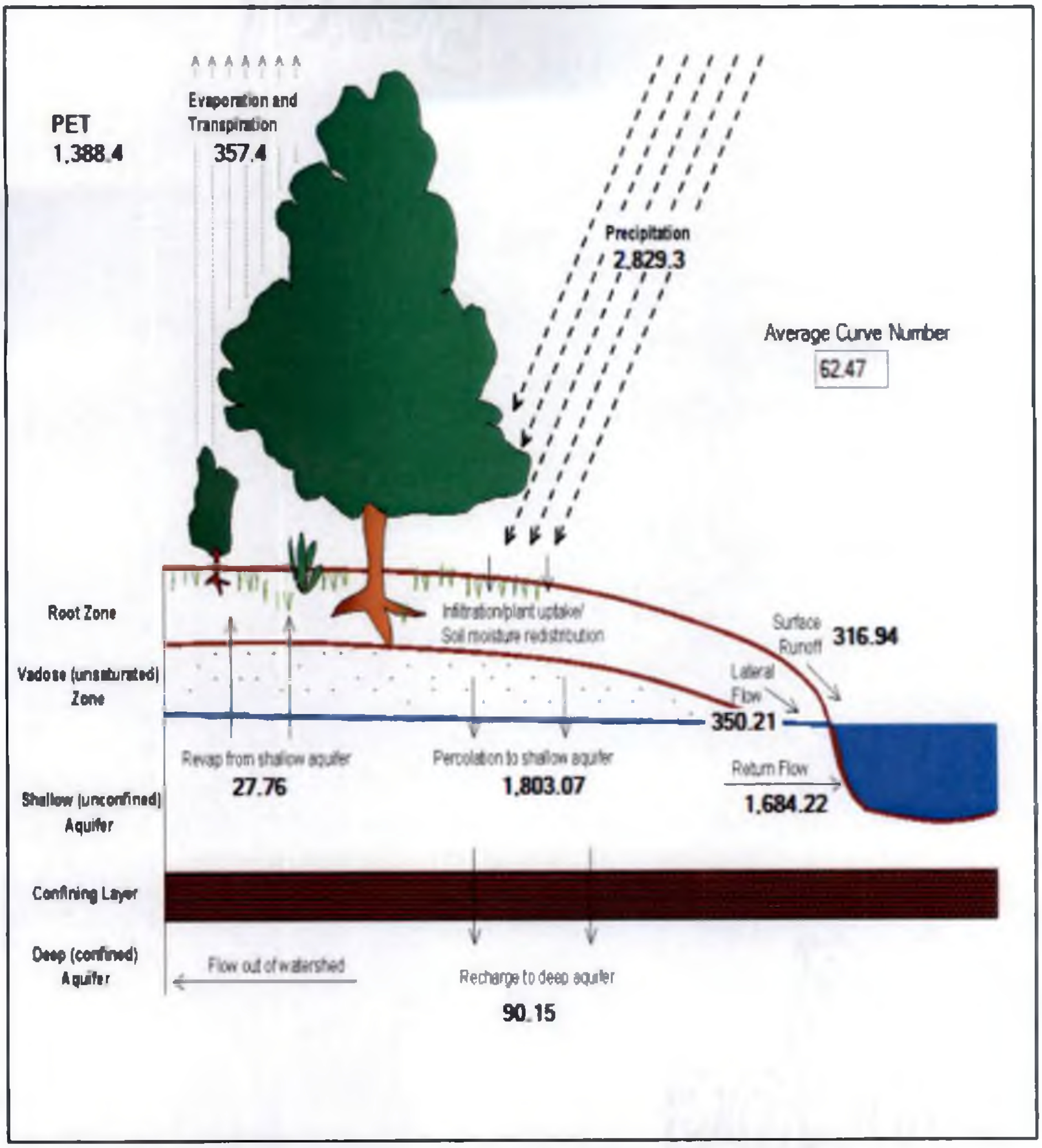


Fig. 22. Schematic representation of hydrologic cycle for the existing period generated by SWAT model.

4.7 Climate Change data

Predicted climate data of rainfall and temperature has been taken for the 10 years period 2021-2030. Predicted annual rainfall is shown in fig. 23. Predicted values of average annual rainfall shows an increase (29 per cent) from the existing annual average rainfall .The graph also depicts an increasing trend starting from 2021 to 2030, least amount of predicted rainfall was in 2021 (3558.5 mm) and highest was in 2030 (3750.5 mm) whereas in existing period (1993-2012) shows a decreasing trend as shown in fig. 3. The result obtained from this study clearly supports to the finding of another study carried out by Goswami, *et al.* (2006).

They reported that rising global surface temperature and the stability of the Indian monsoon rainfall over the past century has been a puzzle. By using a daily rainfall data set, they have shown significant rising trends in the frequency and the magnitude of extreme rain events, and also reported that a significant decreasing trend in the frequency of moderate events over central India during the monsoon seasons from 1951 to 2000. The seasonal mean rainfall does not show a significant trend, because the contribution from increasing heavy events is offset by decreasing moderate events. The study cautions that a substantial increase in hazards related to heavy rain is expected over central India in the future.

Average monthly rainfall values of the existing and predicted rainfall depicts great variation for all the monsoon months as shown in fig. 24. Rainfall Trend analysis studies carried out by Guhathakurta *et al.* (2011) for 36 subdivisions of the country revealed that the contribution of June and July rainfall is decreasing while that of August and September is increasing. The contribution of June rainfall is increasing in 19 sub divisions and decreasing in 17 sub divisions. July rainfall is decreasing in Central and west peninsular India, while the contribution of August rainfall is increasing in all these sub divisions (south interior Karnataka, East MP, Vidarbha, Madhya Maharashtra, Marathwada, Konkan and Goa and North interior Karantaka). This is true for the case of existing period. But future period shows an increasing amount of rainfall (1173.22 mm) in June followed by July and considerably fewer amounts are obtained in September (8.33mm).

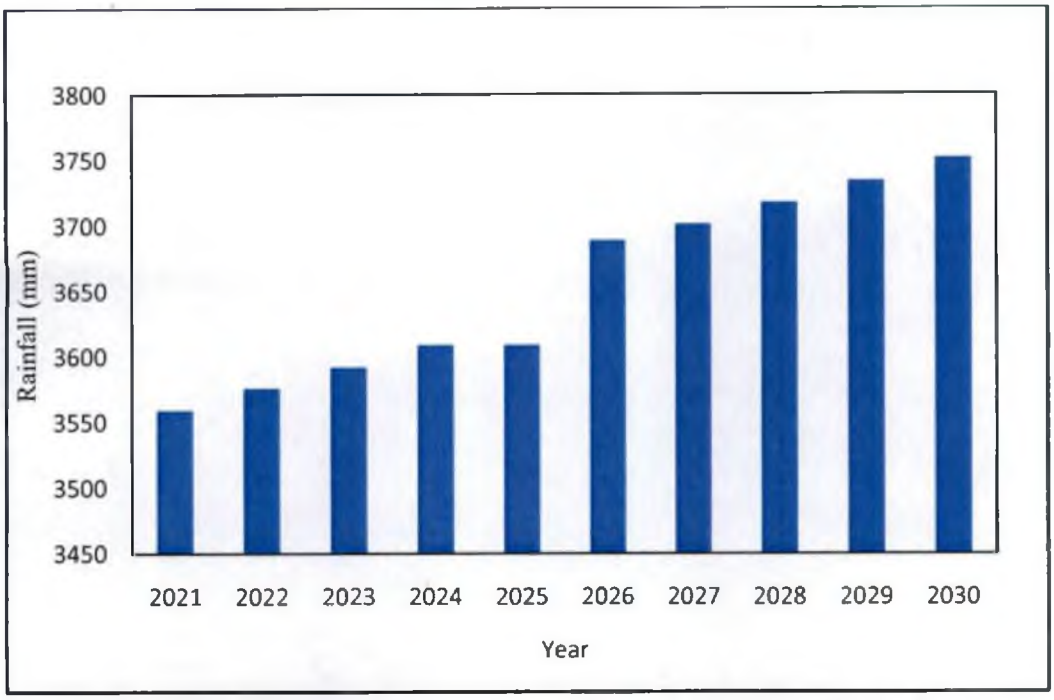


Fig. 23. Predicted values of annual rainfall

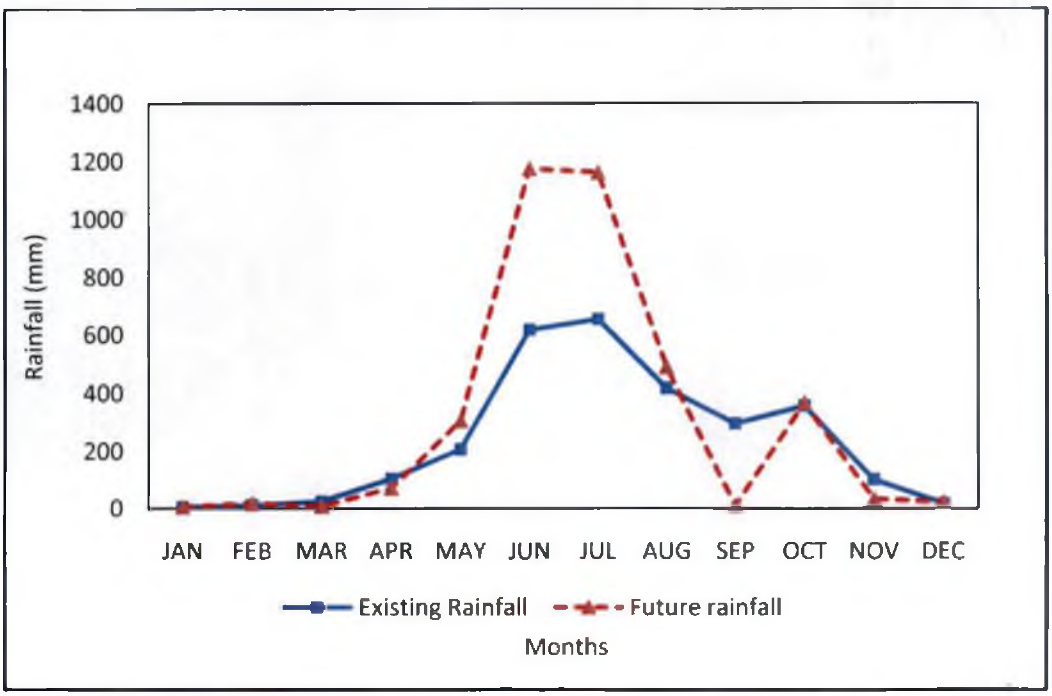


Fig. 24. Existing Vs future: Mean monthly rainfall

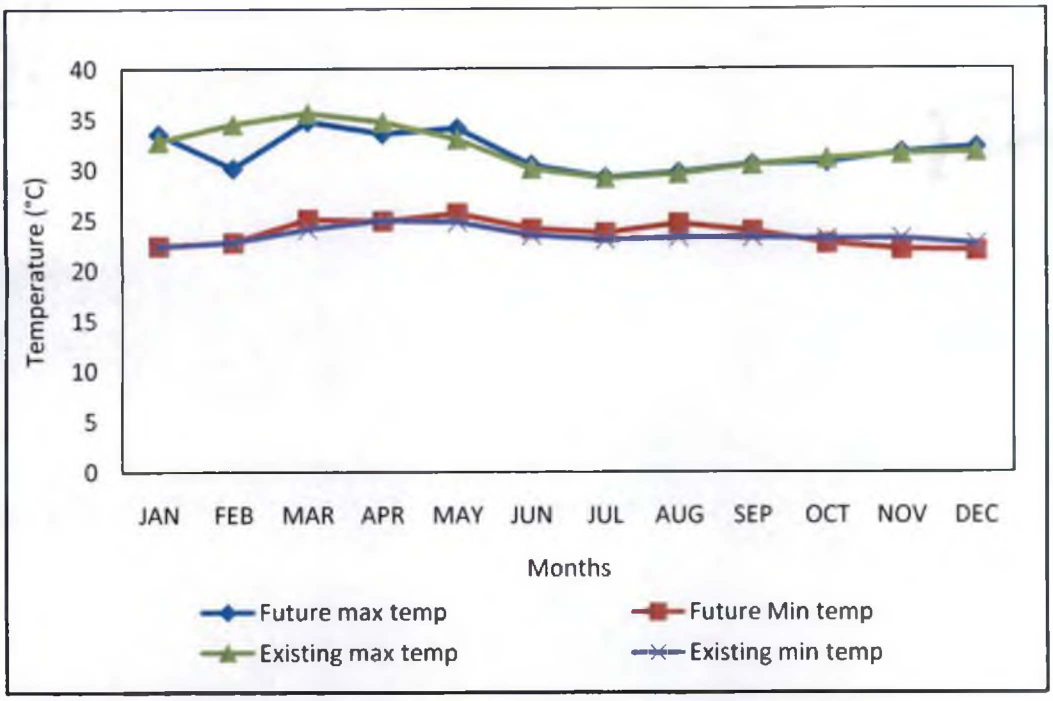


Fig. 25. Existing Vs future: Max. and Min. temperature

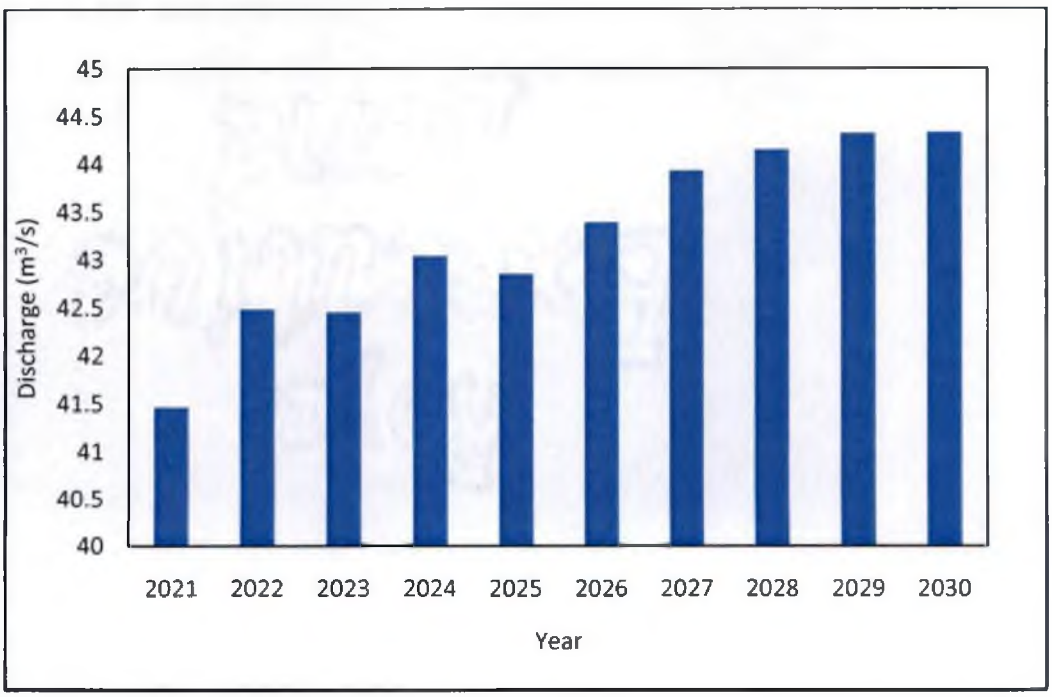


Fig. 26. Future annual river flow

Mean monthly future predicted and existing values for the maximum and minimum temperature for the study region starting from 2021 to 2030 and 1993 to 2012 respectively are shown in fig. 25. Future temperature trend shows that there is a decline of about 0.9 per cent in the case of maximum temperature whereas in the minimum temperature, there is an increase of 1.04 per cent for the overall mean monthly value. In the case of maximum temperature, only February month shows a declining value for future period. The maximum temperature observed in February during future period was 30.09 °C whereas in existing period, the maximum temperature estimated was 34.48 °C. It had estimated a 12 per cent decline in future maximum temperature in February month and rest of the months do not show any appreciable change for the maximum temperature as well as minimum temperature.

The mean annual value for future river flow shown in fig. 26 is considerably higher (46 per cent) than existing river flow drawn in fig. 27. The values of future and existing river flow were 43.24 m^3/s and 23.22 m^3/s respectively. Monthly mean values of river flow for the future period under consideration is shown in fig. 28. The future scenario of summer river flow is negligible as in the case of existing whereas, for the monsoon months future river flow shows a tremendous increase. In the case of June, the increase is 504 per cent and for July, it is 57 per cent and August corresponding value is 108 per cent.

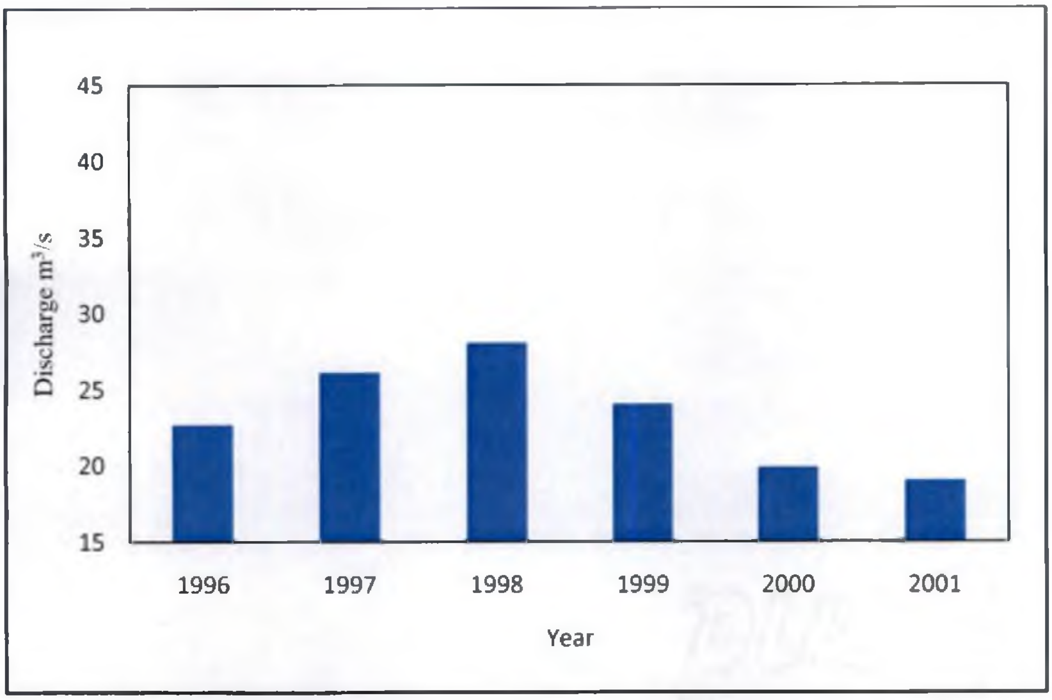


Fig. 27. Existing annual river flow

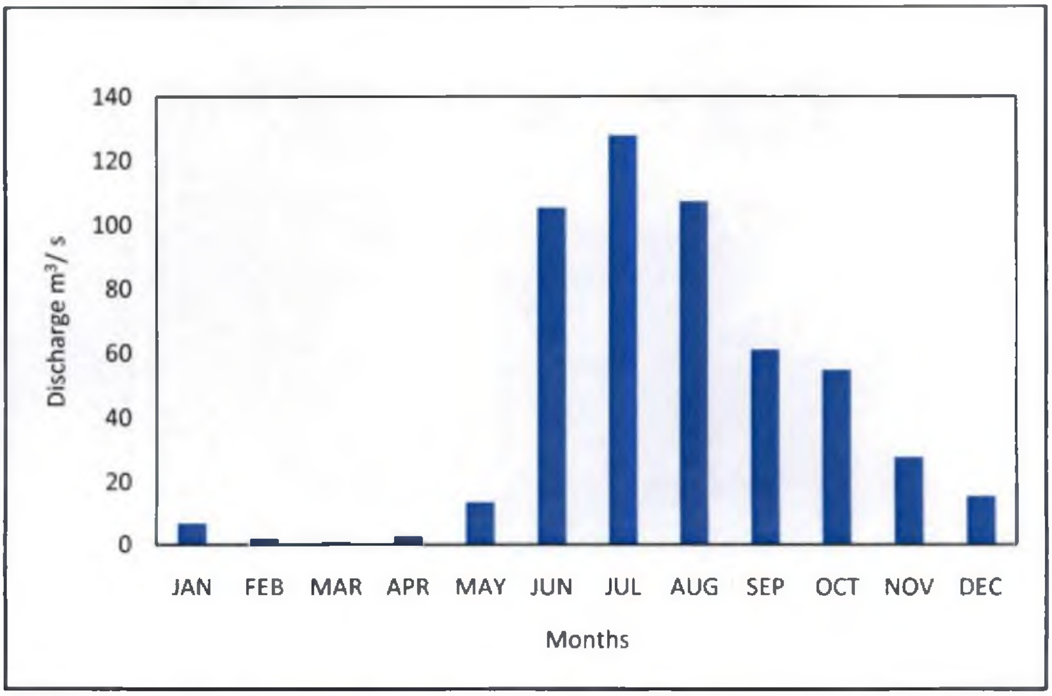


Fig. 28. Mean monthly river flow for future data

4.8 Water balance for the predicted climate

Water balance of the basin for the predicted climate is shown in fig. 29. For future prediction period also, same water balance components were taken as same as for existing data. Water balance components considered were surface runoff (SUR_Q), lateral flow (LAT_Q), ground water flow (GW_Q) and evapotranspiration (ET). The components were showing variations between the years. All the components are shown as a percentage of annual rainfall of the respective years. Analysis of the results depicted that GW_Q (base flow) has the highest share to the water balance with values ranging from 50 per cent (2025) to 53 per cent (2028). The contribution of base flow as a proportion of total river flow is 60 per cent to 61 per cent. It is followed by surface runoff which varies between 21 per cent to 24 per cent between the years considered. This increase is justified by the 29 per cent increase in the amount of rainfall obtained for the future period (2021-2030). ET values contributes 13 per cent to 14 per cent of the total water balance. Lateral flow has got the lowest contribution in the water balance and is within the range of 12 per cent to 13 per cent of the rainfall and 14 per cent of the total river flow. Surface runoff, lateral flow, base flow and evapotranspiration of the basin were 756.9 mm, 407.6 mm, 1802.8 mm and 456.0 mm respectively.

Another striking difference was observed in the groundwater flow component of the water balance between the future and existing period. In the case of existing period, the base flow component was in the range of 63 to 66 per cent of the annual rainfall. On the other hand, the corresponding values for the future climatic scenario was considerably lower (50 to 53 per cent of annual rainfall). It shows that the percent component of groundwater decreases considerably as rainfall increases. The shortfall in the base flow is seen compensated by enhancement in the surface runoff. Surface runoff shows an increase from the range of 9 – 11 per cent to 21 – 24 per cent. This goes in line with the known fact that as rainfall increases, the total quantity of surface runoff and the proportion of surface runoff to the annual rainfall increases. This increase in surface runoff and decrease in base flow when expressed as a percentage of annual rainfall is corresponding to a projected rainfall increase of 29% for the future period under consideration in the study. Table 11 shows the percentage contribution of rainfall with respect to water balance components.

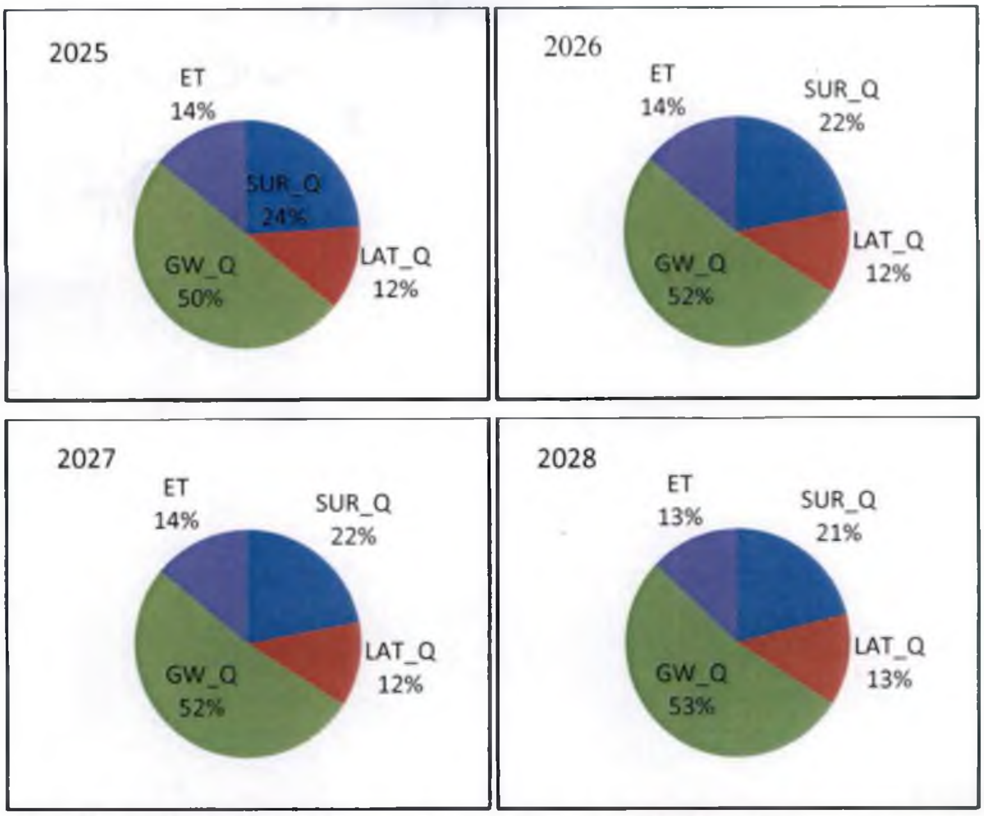


Fig. 29. Water balance of Kurumali sub basin for different years expressed as a percentage of annual rainfall for the future period

Table 11. Water balance components generated from SWAT model

Year	SUR_Q (mm)	SUR_Q (RF per cent)	LAT_Q (mm)	LAT_Q (RF per cent)	GW_Q (mm)	GW_Q (RF per cent)	ET (mm)	ET (RF per cent)
2025	776.1	27	394.31	14	1748.5	60	446.54	15
2026	752.82	25	409.2	14	1792.86	61	461.86	16
2027	745.84	25	412.7	14	1831.47	61	459.36	15
2028	752.94	25	414.04	14	1838.32	61	456.32	15

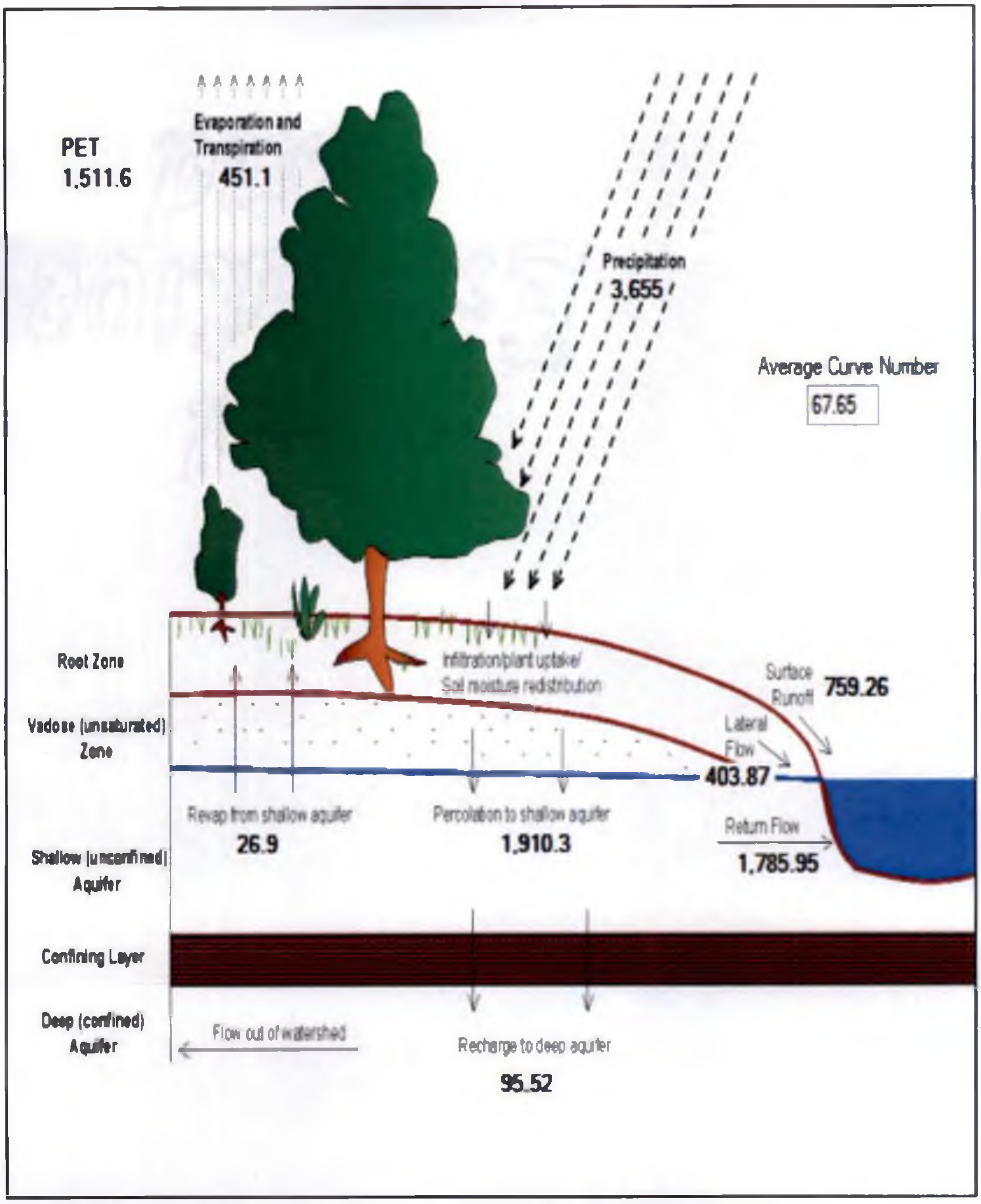


Fig. 30. Schematic representation of hydrologic cycle for the future period generated from SWAT model

Schematic representation of hydrologic cycle for the future period 2021 to 2030 generated by the SWAT model and all other water balance components are explained in fig. 30. All the units are expressed in mm. The annual average precipitation of Kurumali sub basin obtained was 3655mm. Surface runoff, lateral flow and return flow contributes to the total river flow. Return flow or base flow is slower than lateral flow and surface runoff. The water that moves back to the atmosphere in the form of evaporation and transpiration and the value estimated as 451 mm.

4.9 Management practices for the future

Mean value of predicted rainfall magnitude for the study area is very high compared to the mean value of the existing rainfall (29 per cent increase). As a consequence, surface runoff shows about 130 per cent increase and river flow shows an increase of about 30 per cent. As a result of higher rainfall and surface runoff, soil erosion due to water will be higher. In this study, SWAT model is used to quantify the existing and future runoff which helps in suggesting the watershed management practices for the future scenario. Though sediment outflow estimation is not made in this study, use of watershed models is a practical solution to predict the sediment outflow (Merritt, 2003). Soil and water conservation measures will have to be augmented in the watershed area, especially in more sloping terrains, considering the higher rainfall and runoff. It is possible to suggest land and water resources conservation activities on micro watershed basis because micro watershed is the basic unit under which all hydrologic processes are taking place (Sharma *et al.*, 1996). However, some guidelines for the soil and water conservation measures that need to be undertaken in the watershed for different slope groups is given under.

For areas with the slope more than 10 per cent, instead of contour bunds now constructed, further bunding may be taken up with graded bunds. This will avoid breaching and constant failure of bunds. Terracing will be suitable at even higher slopes, the places already conserved with terraces will have to be supplemented with shoulder bunds to facilitate reduction of runoff.

In the case of slope terrains, with slope ranging between 5 to 10 per cent, higher rate of soil erosion is expected in future. Contour bunds with supplemented bunds will be a better choice. Staggered contour trenches if constructed will also help to conserve soil and water. Construction of staggered trenches will be a better substitute for moisture conservation pits. The basins of perennial plants including coconut may be developed for better soil and water conservation. Centripetal bunds are better options for coconut trees.

Areas with lesser slopes that are up to 5 per cent are not provided with any conservation measures. These areas which are left to nature can be conserved effectively by adopting suitable biological measures of soil conservation. Contour vegetative hedges, cover crops and *Puertorican* types of terraces will be effective in conserving soil and water. The rain pits and trenches can also be effective in these areas.

Summary & Conclusion

CHAPTER 5

SUMMARY AND CONCLUSIONS

Climate change is a major threat to the humanity and scientists all over the world are debating on the issue such as its magnitude and impact on the ecosystem. Impact of climate change on water resources is one such issue seriously discussed and assessed by hydrologists. To evaluate the effect of climate change on water resources, study has to be carried out on a watershed basis. In Kerala, very fewer studies have been reported on the impact of climate change on watershed processes. Keeping this in mind, a study has been proposed to evaluate the changes that can happen on the hydrologic regime of a watershed due to changes in the climatic parameters, with the following objectives.

4. To identify the existing management practices of the selected watershed.
5. To study the effect of climatic parameters on important watershed processes.
6. To suggest modification of existing management practices using GIS techniques.

In the present study, Kurumali sub basin of Karuvannur river in Thrissur district, Kerala was selected for the estimation of surface runoff using the widely used SWAT model. The study included the climatic, hydrologic and topographic data collection of the watershed area, generation of future climatic data, preparation of land use map using image processing techniques and the analysis of spatial maps, attribute information and simulation of watershed processes using SWAT model. Climatic, hydrologic and soil data of the basin have been collected from Kerala Government agencies. Digital elevation model of the basin has been collected from USGS portal, satellite imagery from NRSA and future climate data from the Marksim DSSAT weather generator. Existing watershed interventions adopted in the study area have been collected from the Department of Soil Conservation, Government of Kerala.

The watershed simulation model used in this study, SWAT is a physically based deterministic, continuous watershed scale simulation model involving many weather and physical parameters related to the estimation of surface runoff, lateral flow, ground water flow, deep aquifer recharge and evapotranspiration (ET). In this study, river flow of the existing period (1993 to 2012) was collected and compared with simulated flow estimated by SWAT. The correlation between the two data sets was evaluated using statistical measures, such as, Nash Sutcliffe Efficiency (NSE) and coefficient of determination (R^2). Performance evaluation of the model was done for both calibration and validation period. The model outputs for the existing period for both calibration and validation showed good agreement between the observed flow and simulated flow as indicated by high NSE and R^2 values.

A very high Nash Sutcliffe Efficiency (NSE) of 0.88 and Coefficient of Determination (COD) 0.96 have been obtained for the calibration period. Corresponding NSE and COD of the model simulation for the validation period were 0.90 and 0.99. The very high NSE and COD are the clear indication of the good model prediction of the river flow. The study pointed out that SWAT model could be a promising tool to predict water balance for the sustainable management of water resource

The study revealed that average annual rainfall of the area was 2829 mm with a standard deviation of 748 mm. For the existing period, surface runoff, lateral flow, base flow and evapotranspiration of the basin were 306.59 mm, 339.23 mm, 1649.68 mm and 337.46 mm respectively and for the future period the values were 756.92 mm, 407.56 mm, 1802.78 mm and 456.02 mm respectively as simulated by SWAT model. The predicted average annual rainfall for the basin for the years 2021 to 2030 was 3655 mm, which was 29 per cent greater than the existing rainfall. River flow predicted for the basin for the changed climate was 46 per cent higher than the existing one. Similarly, surface runoff, lateral flow and base flow also showed considerable increase in the changed climatic scenario. Study concludes that soil and water conservation measures will have to be augmented and modified as rainfall and surface runoff would increase considerably in the future.

Future scope of work

1. Study can be extended to the complete basin of Karuvannur river with more distributed and more years of climate and hydrologic data.
2. Predicted climatic data of different models may be made use of in the study.

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Abstract

IMPACT OF CLIMATIC PARAMETERS ON WATERSHED MANAGEMENT PRACTICES USING GIS TECHNIQUES

by

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ABSTRACT OF THE THESIS

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ABSTRACT

Water is one of the most important natural resources supporting all forms of life on earth and the sustainable use and conservation of this resource has to be planned on watershed basis. Watershed is a land area which drains water received through precipitation to a common outlet, usually a small drainage channel to a river. Changes in weather parameters will lead to cascading effects on watershed hydrology, biomass production and many other natural processes. The changes in precipitation pattern with changes in intensity and frequency will give rise to corresponding changes in the surface runoff, lateral flow, base flow, evapotranspiration and soil erosion. Quantifying these hydrological processes are very important from the point of view of sustainable use of land and water and their conservation planning and implementation. Since the various watershed processes are interdependent, highly variable with respect to time and space, measurement of these natural processes at different spatial location is not an easy task. Watershed models are a solution to meet the challenge of estimating watershed processes to reasonable level of accuracy. Among the watershed models, physically based watershed models will be yielding better results as they are designed to simulate the physical processes more close to reality by considering maximum number of parameters governing those processes.

In the present study, Kurumali sub basin of Karuvannur river in Thrissur district, Kerala was selected for the estimation of surface runoff using the widely used SWAT model. The study envisaged to determine the impact of climate changes on various watershed processes using SWAT model. Secondary data on climate, river flow, DEM, soil map have been used and landuse map has been prepared from satellite imagery procured from NRSA. The river flow prediction efficiency of the calibrated watershed model has been tested by Nash Sutcliff efficiency (NSE) and Coefficient of Determination (COD). A very high Nash Sutcliffe Efficiency (NSE) of 0.88 and Coefficient of Determination (COD) 0.96 have been obtained for the calibration period. Corresponding NSE and COD of the model simulation for the validation period were 0.90 and 0.99. The very high

NSE and COD for both calibration and validations periods are the clear indication of the good model prediction of the river flow.

The study revealed that average annual rainfall of the area was 2829 mm with a standard deviation of 748. For the existing climatic scenario (year 1993 to 2012), water balance components including the surface runoff, lateral flow, base flow and evapotranspiration of the basin were 306 mm, 339 mm, 1649 mm and 337 mm respectively. The predicted mean annual rainfall for the basin for the years 2021 to 2030 was 3655 mm and the water balance components including the surface runoff, lateral flow, base flow and evapotranspiration of the basin were 756.92 mm, 407.56 mm, 1802.78 mm and 456.02 mm respectively. Future rainfall was 29 percent greater than the existing rainfall and the river flow predicted for the basin for the changed climate was 46 per cent higher than the existing one. Similarly, surface runoff, lateral flow and base flow also showed considerable increase in the changed climatic scenario. Study highlights that soil and water conservation measures, presently being practiced in the area, will have to be modified and augmented as rainfall and surface runoff showed remarkable increase for the future time period.