IMPACT OF CLIMATE CHANGE ON WATER RESOURCES OF KURUMALI RIVER BASIN

By

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DECLARATION

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Abbreviations

Abbreviation	Expansion
AGWA	Automated Geospatial Watershed Assessment
AOGCM	Atmosphere Ocean General Circulation Model
ASCII	American Standard Code for Information Interchange
AWC	Available Water holding Capacity
BD	Bulk Density
CAD	Computer Aided Design
CCAFS	Climate Change , Agriculture and Food Security
COD	Coefficient of Determination
DEM	Digital Elevation Model
DSSAT	Decision Support System for Agro Technology Transfer
DTM	Digital Terrain Model
ENSO	El-Nino Southern Oscillation
ERDAS	Earth Resource Data Analysis System
ESRI	Environmental System Research Institute
GCM	General Circulation Model
GHG	Green House Gases
GIS	Geographic Information System
GIUH	Geomorphic Instantaneous Unit Hydrograph
GPS	Global Positioning System
HRU	Hydrological Response Units
IMD	India Meteorological Department
IPCC	Inter-governmental Panel on Climate Change
IRS	Indian Remote Sensing
ISRO	Indian Space Research Organisation
KFRI	Kerala Forest Research Institute
LISS	Linear Image Sensing Satellite
LULC	Land Use/Land Cover
NOAA	National Oceanic and Atmospheric Administration
NIR	Near Infra-Red
NSE	Nash Sutcliffe Efficiency

RCM	Regional Climate Model
RCP	Representative Concentrated Pathway
RH	Relative Humidity
SOI	Survey of India
SPAW	Soil Plant Atmosphere Water
SST	Sea Surface Temperature
SWAT	Soil and Water Assessment Tool
SWC	Soil Water Characteristics
SWIR	Short Wave Infra-Red
SRTM	Shuttle Radar Topography Mission
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey
UTM	Universal Time Meridian

CHAPTER 1
INTRODUCTION

Land, water and air are the most important and indispensable natural resources, supporting all forms of life on earth. Existence of life in the universe is governed by the presence of air and water. Natural resources have seamless influence on the healthy and sustainable environment. Natural resources are very much important to sustain the complex interaction between living and non-living things. Human being takes immense benefit from this interaction. Population is increasing rapidly and the demand for natural resources are also rising at a faster pace especially land, water and biomass resources. Increased demand causes exploitation of natural resources at an unreplenishable rate. Among these natural resources, the role of water is paramount for a sustainable environment.

Rate of water consumption has been considered as a parameter of social development. Most of the developing countries are depending on Agriculture as the major contributor of their economy. In such countries, where agriculture or livestock sector plays a key role in their socio-economic growth, the water resources management must be given top most priority in their developmental activities. Considering any regions in localities in the world, long term water resources management is, thus, becoming a key driver for sustainable development by meeting the increasing water demand for irrigation, domestic, industries and fisheries applications and mitigating the excess water induced disasters, mainly flood.

Geological studies suggest that large amounts of water have likely flowed on the earth for the past 3.8 billion years. As seen in satellite pictures, one of the most unique features of earth is the water in both liquid and frozen forms that covers approximately 75 per cent of the earth's surface. Total water content over earth is about 1.39 billion cubic kilometres (Graham, 2000). Because of its great abundance on the earth's surface, water is an important constituent influencing the weather. Existence of water on earth in three states, *viz.* solid as ice, liquid as water drops and gas as water vapour is in various degrees of freedom. It has been the endeavour of human kind from time immemorial to utilise the available water resources. The dynamic nature of water can be explained in terms of hydrologic cycle which includes the science of occurrence, movement and distribution of water.

The hydrological cycle is a continuous process, with no beginning or end. The water cycle is the movement of water in the environment by evaporation, condensation and precipitation and it simply referred as a multi-phased journey system. Because, it describes the pilgrimage of water as water molecules make their way from the earth's surface to the atmosphere and back again. This gigantic system, powered by energy from the sun, is a continuous exchange of moisture between the oceans, the atmosphere and the land. The components of hydrologic cycle is broadly classified as transportation components (includes precipitation, evaporation, transpiration, infiltration and runoff) and storage components (includes soil moisture storage, ground water storage). Together, evaporation, sublimation and transpiration plus volcanic emissions account for all the water vapour in the atmosphere. The basic aspect is that the total water resources of the earth is constant and the sun is the source of energy for the hydrologic cycle. Water management is the key aspect of any environment and socio-economic system.

According to Inter – governmental Panel on Climate Change (2007), climate change is the change in the state of the climate that can be identified (*viz.* using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. According to United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods. 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). Concentration of long lived greenhouse gases have increased significantly in atmosphere since pre-industrial times, tending to warm the surface and produce other climate changes. Changes in weather and climate accompanied by the rising global temperature is the clear cut evidence of climate change. Extreme events like increased flood and drought occurrence rate, heat and cold wave are the results of climate change. Climate change has the potential to alter the prevalence and severity of extreme meteorological events like storms, floods and droughts.

Increased greenhouse gas and aerosol concentrations may profoundly affect atmospheric water vapour concentration, clouds, and precipitation patterns. Warmer condition will accelerate the hydrologic cycle, altering precipitation, the magnitude and timing of runoff and the intensity and frequency of floods and droughts. Water delivers major impacts of climate change to society, for example, to the energy, agriculture, and transport sectors. Most of the climate change studies and model outputs indicate that changes in the radiative flux at the earth's surface affect the surface heat and moisture budgets, thereby involving the hydrological cycle. The overgrowing population and recent unfair weather conditions are putting water resources under pressure and calling for new approaches for water planning and management. Unscientific exploitation of water resources within any watershed which is the natural drainage basin significantly upsets the efficient distribution and utilisation of water.

Watersheds are the natural divides of the land areas and hence, the conservation of land, water and biomass resources have to be planned on watershed basis. A watershed is the geographic area through which water flows across the land and drains into a common water body. Watershed is synonymous with other terms such as catchment area and drainage basin. All lands on earth are part of one or other watershed. Watershed plays a significant role in the society as providing adequate supply of water for drinking and other household purposes, irrigation purposes, agriculture/livestock production, recreation and other aesthetic requirements. Watershed management is the process of organizing the utilization 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. The main objective of watershed management is to prevent watershed degradation occurring mainly due to the faulty management of land, water and vegetation through the activity of human. The consumption or use of the natural resources on upland watersheds must also be balanced with the needs of people living downstream.

Hydrologists and water management planners have a dilemma on future demand and availability of water. Climate change and its potential hydrological impacts are increasingly contributing to this uncertainty. Increasing global average temperature will lead to a more vigorous hydrological cycle with changes in precipitation and evapotranspiration rates which are regionally variable. These changes will in turn affect water availability and runoff and thus may affect the discharge regime of rivers. Human survival requires adequate and safe water resources.

The future of those resources hinge on our understanding of the delicate balance of water in our earth system. Major inputs of hydrologic cycle are rainfall and other sources of precipitation. The quality and quantity of storm water is affected by all the land-mining, agriculture, urban development and other anthropogenic activities within a watershed. The imbalance between demand and supply is advocating to develop new approaches for water harvesting and management strategies. 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). Understanding the possible impacts of climate change on water resources is of utmost importance for ensuring their appropriate management and utilization. Most of the hydrological processes are complex and difficult to learn in detail. In this context, the study has been envisaged with the following objectives given below.

1. To identify the best suitable General Circulation Model (GCM) for analysing climate change for the study area.
2. To assess the impact of climate change on the hydrologic regime of *Kurumali* sub Basin of *Karuvannur* River and thereby to evaluate the water resources availability of the basin
3. To suggest soil and water conservation practices for the watershed on a pilot scale.

CHAPTER 2
REVIEW OF LITERATURE

The term 'Climate' has very wide variety of meaning. For a geologist or geomorphologist, climate is an external agent which forces many phenomena of interest. For an agriculturist, climate is an influencing crop growth parameter which shows year to year variabilities. Climate is generally thought of as the average weather conditions at a given location over long time.

Water is a necessary factor for the development and nourishment of life. Water is the only known substance that can naturally exist as solid, liquid and gas on earth's surface. The total quantity of water present over the earth's surface is about 1.39 billion cubic kilometres and around 96.5% of this total amount is seen in oceans. Approximately 1.7% is stored in the polar icecaps, glaciers, and permanent snow, and another 1.7% is stored as groundwater, lakes, rivers, streams, and soil. Finally, a thousandth of 1% exists as water vapour in the Earth's atmosphere (Graham, 2000). As per this statistics, trace amount of water is available for the daily uptake by organisms. So, the demand for water is extremely high.

Climate change is not merely a change in daily weather system but, it is a significant change in parameters averaged across the entire planet. Based on the range of emission scenarios presented to the Intergovernmental Panel on Climate Change (IPCC), carbon dioxide concentrations are expected to increase from the baseline concentration of 330 ppm to 549 ppm, 856 ppm and 970 ppm for the B1, A2 and A1F1 greenhouse gas emission scenarios respectively, by the end of the twenty-first century (IPCC, 2007).

Climate change may either be due to internal or due to external forcing. Global warming is considered as the key evidence for climate change. All scientific analysis show that earth's average surface temperature has increased by more than 0.8°C over the past 100 years. The rapid increase of temperature has happened during the last 35 years (1980-2015). Consequences of climate change is visible in whole natural resources like water, soil, land and vegetation, air and ecosystem.

Climate change is a part of the earth's natural variability which makes evolution. Presence of greenhouse gases has a significant role in the warmth of earth. If they are not present in considerable concentrations, the status of the earth may become cooler. Atmosphere is constituted by certain gases, dust particles and water vapour. Atmosphere acts like a blanket over the earth's surface maintains global average temperature as such. Increasing carbon dioxide concentration is an indicator of global warming and climate change. Since 1800, the concentration of atmospheric carbon dioxide has increased by 40% with more than half is increased after 1970 (Royal society, 2010). Unless any change in the concentration of gases, global average temperature keeps its normal value. Though greenhouse gases comprise only a tiny fraction of atmosphere, they are very much critical for keeping the planet warm enough to support life.

IPCC defines 'Climate change' as the change in the state of the climate that can be identified (may be using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer (IPCC, 2011). In most of the climate change studies, temperature is considered as an explanatory variable and precipitation is the explained variable.

2.1 CLIMATE CHANGE AND WATER RESOURCES

Surface, sub surface and groundwater flow are the major water conveyance pathways in any river system. Streamflow is mainly altered by both climatic variations over a river basin as well as changes in land use, land cover and stream characteristics. Walter Langbein (1949) attempted to explain the major driving forces of hydrologic components. This can be a strong evidence for accounting the variations in streamflow with respect to the anthropogenic influences of climate change.

According to Schaake *et al.*, (1990) anthropogenic release of carbon dioxide increases the temperature which will lead to increased evapotranspiration rates, reduced runoff and more frequent drought events. Water availability is a significant concern in regions throughout India particularly in domestic and industrial use, irrigation, hydropower and environmental flows. The efficient use of reservoir storage as well as related surface water and ground water management are the optimal strategies that employed by water managers for the water availability enhancement. Impact of climate change on water quality resulting local and short term impacts on ecological thresholds are of greatest concern, rather than the annual medians that are commonly reported (Murdoch *et al.*, 2000). Increased air temperature increases the water temperature which can affect habitat suitability and the chemical properties of water. Altered water temperature in reservoirs disturbs the chemistry of the water body and it influences the potential for algal blooms. Increased distribution of algal blooms can further reduce oxygen levels (Poff *et al.*, 2002). Environmental drivers like agricultural and land management practices confound interpretations of past and future climate impacts (Whitehead *et al.*, 2002).

Hodgkins *et al.*, (2003) pointed that temperature rise is expected to change toward more rain and less snow. Such precipitation shifts would affect the origin, timing and pattern of streamflow leading to less runoff from spring snowmelt and more runoff from winter rainfall, particularly reported in northern New England and Western United states. Increasing temperature ultimately enhance the rate of potential evapotranspiration and thereby decrease the amount of water that then reaches streams, lakes and reservoirs. Climate change could have far reaching consequences for water resources and ecology of fresh water environments (Arnell, 2004). At the global scale, annual runoff change in some regions experiencing an increase, particularly at higher latitudes and in others a decrease.

The third IPCC Assessment Report (IPCC AR3, 2004) concludes that changes in annual streamflow usually relate well to changes in total precipitation. When compared to continental scale runoff, it has been found that, an increase in runoff during the 20th century for Asia, North America and South America, a decrease in runoff for Africa and no significant change in Europe. In the case of precipitation, a net precipitation increase for Asia, North America and South America (except Chile), precipitation decreases across virtually all of Africa and a combination of both increases and decreases in precipitation in Europe. This trend can easily explain the observed changes in continental scale runoff both on empirical and theoretical grounds.

Third Assessment Report of IPCC incorporates numerous hydrological impact assessment studies at regional to global scales. Some of these studies dealt with significant trends in some indicators of river flow and some have demonstrated statistically significant links with trends in temperature or precipitation. And the interesting fact is that, many more studies have found no trends or unable to separate the effects of variations in temperature and precipitation from the effects of human encroachment in the catchment such as land use change and reservoir construction. Annual variation in river flow is also very strongly influenced in some regions by large scale atmospheric circulation patterns associated with variability systems especially ENSO that operate at within decadal and multi decadal time scales.

A study conducted at United States depicts the complete picture of anthropogenic influence on climate change and corresponding changes in the socio-economy of US. Annual precipitation over the southwestern US has decreased and warmer trends have been observed. Also, it suggests that, drought frequency and severity have increased in this region (Groisman *et al.*, 2004; Ellis *et al.*, 2010).

During 20th century, there is a 4% increase in global total runoff per 1° C rise in temperature (Labat *et al.*, 2004). This annual runoff change can be mainly attributed by the climate change related issues. Together with changes in land cover, systematic changes in the climatic variables involved in the water cycle (viz. precipitation, temperature, evapotranspiration) may induce alterations in the runoff (Beniston, 2005).This has been challenged due to the effects of non- climatic drivers on runoff and bias due to the small number of data points (David *et al.*, 2005).

Gedney *et al.*, (2006) gave an evidence that increased carbon dioxide enhances runoff at global scale. The basic principle behind the global warming is that, it alters air potential to absorb water with rising temperatures. As a result, potential evapotranspiration alters (Jha *et al.*, 2006). Global mean runoff has been predicted to increase by approximately 5% as a result of reduced evapotranspiration due to doubling of carbon dioxide alone (Leipprand, 2006).

Global warming is affecting all aspects of water resource management and aquatic ecosystem protection in all over the world. Rising temperature, snowpack degradation, glaciation sea level rise and escalating size and frequency of flood events are just some of the impacts of climate change that have vast and significant implications for the management of water resources. All meteorological observations show that, most of the natural systems are being affected by regional climate change particularly temperature increase and weather extremities. Reconstruction of earth's climate over the past 2,000 years have shown that while temperature has varied on multiple time scales there appears to have been a significant increase during the most recent 100 years (National Research Council, 2006).

The Climate Change Science Program's Synthesis and Assessment Product 4.3 (2008) and the American Water Works Association Research Foundation's Primer (Miller and Yates, 2006) also provide useful summaries and descriptions of potential climate change impacts on water resources. Increased sea surface temperature alters ocean circulation pattern which results a change in the intensity and frequency of coastal storms under future climatic conditions (Knutson *et al.*, 2008). Freshwater resource projections in post climate change scenarios are expressed in terms of annual river discharges (Kundzewicz, 2008).

Gardner (2009) pointed that, any decrease in runoff may threaten surface water supplies and riparian habitats and may also alter fluvial geomorphic processes. Presently, most of the climate change forecast on runoff are largely based on regionalized Global Circulation Models (GCMs). Attempts have been made to forecast the effects of climate change on streamflow based primarily on historical records of discharge and climatic conditions in particular river basins. If any case to assess the effect of climate change on runoff over a large area, then the hydrologic or empirical models must be applied to sufficiently large number of watersheds representative of the area. 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).

Climate change impact assessment studies are very much relevant in present conditions for the better and sustainable development. Water resource management is one of the most important society linked sector that has to be in a highly efficient and systematic way. Climate information is used by decision makers throughout water resource management. Hydrological effects of climate change estimated quantitatively and this will be helpful in understanding potential water resource problems and making better planning decisions (Raneesh and Santhosh, 2011). They quoted some scientific study results related to the hydrological effects of climate change. They made a conclusion as climate change is expected to have an impact on hydrological systems because of changes in precipitation, temperature and evapotranspiration which are the primary input parameters for the terrestrial part of the hydrological cycle.

IPCC (2013) has reported that the average global temperature will increased by about 4.6 °C under high emission scenario by the end of 21st century with the doubling of the carbon dioxide concentration in the atmosphere. Stream flows may rise drastically in the monsoon season, but will decrease in the non-monsoon season due to the projected future climate change (Rao *et al.*, 2014).

2.2 CLIMATE MODELLING

Climate models are used to understand the factors creating climate in the past, present, and future. General Circulation Models (GCMs) are three dimensional complex models which are the best tool in the study of climate variability and climate change. They are coupled with different numerical models that represent several sub systems of the climate system (atmosphere, hydrosphere, lithosphere, cryosphere and biosphere). With respect to the inter annual variability, it has been found that some GCMs reproduce important patterns of variability of the atmospheric flow and of the Sea Surface Temperature (SST) at mid latitudes. However, at finer spatial resolution with few grid distance scale, GCMs have much smaller skill (Grotch and MacCracken, 1991).

A detailed comparison of the regional performance of low resolution GCMs in the Mediterranean basin can be found by Cubasch *et al.*, (1996). They concluded that, the skill of these models in simulating the observed climate is much higher for near surface air temperature than for precipitation. Model simulation response to climate change by doubling of atmospheric carbon dioxide concentrations are not univocal. Different combinations of coupling produce temperature change patterns that are negatively correlated to each other.

Global climate is, to a great extent, the response to the differential solar forcing, the earth rotation, and the large- scale structure of the earth's surface (land-sea distribution, topography). On the other hand, the regional climates are the response of the global climate to regional details. Therefore, GCMs are able to simulate the global climate adequately even though none of the regional climates is simulated skilfully (Zorita and Storch, 1998).

Statistical or dynamical methods can be used to downscale information from coarse – resolution General Circulation Models to the basin scale for hydrologic modelling. Downscaling is a tool for the analysis of General Circulation Models (GCMs) data at regional scales. Statistical downscaling uses empirical relations between the parameters and phenomena reliably simulated by GCM at grid scales and surface predictants at sub grid scales (Antolik, 2000). Regional climate models simulations with initial and lateral boundary conditions from GCM output are used in dynamic downscaling process (Giorgi *et al.*, 2001). Current versions of atmosphere-ocean GCMs (AOGCMs) have generally well simulated the present day climatic features at the large and continental scale (Houghton, 2001). Unweighted multi-model means are used in multi-model projections for long term climate change used in reports of IPCC (IPCC, 2001).

Multi-model ensembles are defined as a set of model simulations from structurally different models where one or more initial condition ensembles are available from each model (Doblas *et al.*, 2003). Scientifically accurate, reliable and timely climate studies are essential for accurate unbiased climate change analysis. Currently, there is substantial tension between providing tools at the space and time scales useful for water resources decisions. Consequently, an integrated approach to impact assessment is required in which high resolution climate change scenarios drive process-based models of freshwater systems to quantify the likely hydrological, water quality and ecological impacts (Worrall *et al.*, 2003).

Numerical models are the essential fundamental tool for the predictions and projections of weather and climate at different time scales of days to centuries. Since, weather is chaotic, the predictions are sensitive to the value of observations used to initialize numerical models (Palmer, 2005). Long term projections of climate change are typically averaged over decades and are largely insensitive to small variations in initial conditions. In general, climate system is highly complex, it remains fundamentally impossible to describe all its processes in a climate model. Predictions for the El Nino Southern Oscillation (ENSO) and seasonal forecasts from multi-model ensembles are generally found to be better than single model forecasts (Palmer *et al.*, 2005).

Regional level of General Circulation Models known as Regional Climate Models (RCMs) are considered the most advanced tool currently available for simulating the effects of increasing greenhouse gases on the global climate system (Alley *et al.*, 2007).

Fowler *et al.*, (2007) reviewed the current available downscaling literature specifically for hydrological impacts. They conclude that, simple statistical downscaling seem to perform as well as more complicated methods in reproducing mean climatic characteristics.

GCMs consistently project increase in average temperature across the globe. This increase has expected to be strongest in inland and at higher latitudes, with lesser warming along the coasts. Warming is especially pronounced in high latitudes in winter. Warming air can hold more moisture, it may further accelerate warming with perhaps twice the effects of increased carbon dioxide alone (Dessler *et al.*, 2008).

Buytaert *et al.*, (2009) studied the vulnerability of freshwater resources to changing climate. He examined the effects of climate change on components of the hydrologic budget. The most common approach has been to combine basin scale hydrologic models with climate change scenarios derived from General Circulation Model output.

2.3 WATERSHEDS AND THEIR FEATURES

The concept of watershed should be understood by those working in the area of natural resources. Watershed is an area that draining to a common point by a network system of drains. Traditionally a watershed can be defined as an area through which water flows across the land and drains into a common water body. Highest ridgeline principle is the fundamental base for delineation of any watershed. The fact is that, all lands on earth are part of one or other watershed.

Now, the scientists agreed that, the natural balance of the earth's climate is undergoing changes in response to climate variability including changes in precipitation (quantity, intensity), occurrence of extreme events, solar variability and increasing concentration of greenhouse gases and aerosols. Finally, these changes affect atmospheric water vapour concentrations, clouds, precipitation patterns, runoff and stream flow patterns (IPCC, 2001).

Many studies have been done regarding the observed and projected changes in climate for 21st century, describes some of the direct and indirect effects of these changes on watershed hydrology and explains how these changes will interact with existing impacts.

The importance of watershed is that all natural resources are enacted simultaneously within each watershed and they are conserved from a highest ridgeline to lowest point without taking the interference of the ecological balance to achieve the sustainable development (Kumar, 2002). Water has played a vital non-replaceable role in the existence of life on earth. Hydrology and water resources will be affected by the climate change, since they are closely linked to climate. The total demand and supply of water and ecosystem services provided by healthy scientifically managed watersheds are priceless. The amount and quality of watershed services depend on the state and condition as when watershed is under stress or degrade, critical services can be threatened. Presently, essential watershed services are threatened by a variety of human impacts. In many areas, watershed systems have suffered from significant alterations of natural flow patterns, water pollution and habitat degradation and fragmentation (Postel and Richter, 2003).

Forested watersheds stabilize stream banks, reduce storm runoff and erosion, prevent sedimentation and filter pollutants. Consequently, quality of such watersheds is typically the best. Water from these areas will be cooler and generally contains less sediments, nutrients and chemicals than water from other lands (Binkley *et al.*, 2004). Streams in such watersheds often provide high quality habitat for sensitive aquatic species. Good quality water is immensely valuable because it supports many uses, ranging from meeting basic human needs to providing habitat for rare and endangered species. It sustains fish, plants and wildlife; supports food, energy and industrial production.

Anthropogenic activities make several impacts on water quality which is 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 useful particularly in the development of an effective watershed management system (Gossain and Rao, 2004).

The most discussed environmental policy that was faced by society is the potential changes in the earth's water cycle due to climate change (Barnett *et al.*, 2005).

Several studies investigated the response of different soil and water erosion models to precipitation and land cover with a sensitivity analysis (Nearing *et al.*, 2005). They found that, relative results from such models were better than absolute predictions and soil erosion was more affected by changes in rainfall and land cover than was runoff.

The Automated Geospatial Watershed Assessment (AGWA) is a GIS interface tool used to automate the execution and parameterization of SWAT and KINEmatic and EROSion (KINEROS2) hydrologic models. By integrating these two models, hydrologic modelling and watershed assessment at multiple time and space scales became easy and efficient. AGWA tool is further developed for online decision support to provide ready access to environmental decision makers, resource managers, researchers and user groups (Goodrich *et al.*, 2006).

Adaptation actions should generally focus on maintaining or improving watersheds because healthy, resilient watersheds are more likely to supply desired ecological services in the face of climate change (US GAO, 2007).

Bates *et al.*, (2008) stated the importance of watershed may increase substantially in the next few decades as freshwater resources become increasingly scarce. Precipitation, evapotranspiration, surface runoff, subsurface and ground water flow are the components of the water balance. There are many direct and indirect factors influencing these components. Vegetation is one of the factor that 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. A change in catchment vegetation as a result of climate change directly or indirectly may affect the catchment water balance (Kim *et al.*, 2008).

Any watershed is characterized by several parameters such as size, shape, boundary, topography (length and degree of slope), geology, soil types, climate, land use, groundwater and drainage. Size determines the total catchment area of watershed. It can be square, rectangular, triangular and oval in shape. Length : Width ratio of the watershed in turn affects the manner in which water is disposed off. If any geòlogical formation and rock is present in the watershed that will affect the erodibility of channel and hill faces. Physical and chemical properties of soil influences the disposition of the water by way of infiltration storage. Judicious land use is the main item in watershed management. It must be according to capability of land. Drainage is the disposal of excess water to prevent flooding. Drainage characteristics like drainage density, pattern, and stream order have their effects on the disposal of runoff, sediment transport and surface storage. Water table and water quality affect runoff and production potential of watershed (Anwar, 2011). He aimed to determine the parameters of physical characteristics of the watershed that affects surface runoff and time of concentration. He developed the correlation between the watershed physics with the surface runoff coefficient. He found that, the mean slope of watershed the main river length factor, land use factor, topographic factor and land type factor influenced the surface runoff coefficient.

Watershed modelling is the use of mathematical or physical techniques to simulate hydraulic behaviour of water systems and make projections relating to water levels, flows and velocities. Such models can be from simple one dimensional to complex three dimensional models. HEC HMS is the hydrological model used for forecasting flood in a river basin. The inputs for this model is extracted using HEC heo HMS software which is compatible with ArcGIS (Chithra and Sumam, 2013).

Palaka and Sankar (2014) studied the general watershed morphometric characteristics associated with the watershed near Kosigi village in Kurnool district. For the analysis, they have used CartoDEM data from Indian Space Research Organization's (ISROs) Bhuvan portal. They prepared thematic maps from Digital Elevation Model (DEM) using ArcGIS tools.

Many studies used GIS as a platform for the Arc SWAT interface of SWAT model to assess the effect of climate change on river discharges. The inputs used for the SWAT model includes land use/ land cover maps from remote sensing data. Watershed delineation could be done automatically via Arc SWAT interface using the input DEM. ArcGIS is the interface tool between the processing and analyzing steps.

Edwards (2015) proposed the importance of streamflow and their draining features within the watershed. It is essential to consider these downstream impacts when developing and implementing water quality protection and restoration actions. Human habitation settles at downstream of any watershed and our everyday activities can affect downstream waters. Changes in the runoff and water quality will directly influence the daily domestic and industrial area of human settlements.

2.4 STUDY AREA- KURUMALI RIVER BASIN

All India Soil and Land use organization classifies watershed hierarchically in 5 stages. These are region, basin, catchment, sub catchment and watershed. At the regional level, watershed is further divided into sub- watershed, mini watershed and micro watershed. The classification is depicted as a table given below (Table: 1).

Kurumali River basin is taken as the study watershed. Since the area of the Karuvannur River is 1054 km^2, it could be included in Watershed level of macro delineation (As per the above table). Kurumali is a sub watershed of Karuvannur River basin and it was chosen to study the micro level planning for sustainable land water management studies conducted out by Kumar (2002). He covered the entire area of the watershed except the valley portions and conducted micro level studies on soil and water resources with people's participation.

Table: 1 All India Soil and Land use Watershed classification

Level	Hydrological units	Mean area (km^2)
Macro delineation		
01	Water resource region	>3,00,000
02	River basin	50,000 – 3,00,000
03	Catchment	10,000 – 50,000
04	Sub catchment	2,000 – 10,000
05	Watershed	500 – 2,000
Micro delineation		
06	Sub watershed	100 – 500
07	Mini watershed	10 – 100
08	Micro watershed	1-10
09	Nano watershed	< 1

2.5 SOIL AND WATER ASSESSMENT TOOL

Many studies have been done regarding the climate change and climate variability for 21st century using different models and scenarios that are describing some of the direct and indirect effects of these changes on watershed hydrology and explains how these changes will interact with existing impacts. Developing sustainable water resource management is very much crucial in this increased water demand scenario. Comprehensive watershed models are expected to be effective tool for aiding the sustainable management of land and water resources in any watershed.

Soil and Water Assessment Tool (SWAT) has undergone continued review, updating and expansion of capabilities as an impact assessment tool. Regular studies on the SWAT applications have been mainly done by Arnold, Fohrer and Neitsch. They compiled stream kinetic routines from the QUAL2E model (Brown and Barnwell, 1987).

Increased carbon dioxide concentrations in atmosphere directly affect plant physiology as it reduces the stomatal conductance and leaf area increase as ambient carbon dioxide rises (Field *et al.*, 1995). Soil and Water Assessment Tool (SWAT) is a physically based watershed scale model exploring the effects of climate and land management practices on water, sediment and agricultural chemical yields. It simulates hydrological and plant growth cycles, sediment transportation, agricultural chemical yields. All such simulations are to be done on a daily time step (Arnold *et al.*, 1998). He explained that, the A1F1 emission scenario (970 ppm of carbon dioxide and increase of 6.4° C) would raise the water yield by 36.5 % in the northern San Joaquin valley watershed. But, a drawback of this study has been pointed as it did not consider the stomatal conductance reduction and leaf area increase of specific vegetation types. The primary hydrological processes within SWAT includes water balance, crop related processes such as crop yields, nutrient cycling and pesticide movement.

Based on primitive knowledge, SWAT input parameter values were successfully estimated without calibration in a wide variety of hydrologic systems and geographic locations using readily available GIS databases (Srinivasan *et al.*, 1998).

SWAT has been used successfully by researchers, for distributed hydrologic modelling and water resources management in watersheds with various climate and terrain features. Arnold *et al.*, (1999) reported that, SWAT played as an efficient tool during a monthly stream flow simulations in the Texas Gulf Basin with drainage areas ranging from 10,000 to 1, 10, 000 km^2.

SWAT model has several modifications in different pathways. Eckhardt and Ulbrich (2003) incorporated stomatal conductance and leaf area index (LAI) into a conceptual eco-hydrological model SWAT-G which predicts climate change impacts in a low mountain range catchment. Van Liew and Garbrecht (2003) described that SWAT is capable of providing necessary hydrologic simulations related to the impacts of climate variations on water resources of the Little Washita River experimental watershed in south-western Oklahoma.

Most relevant application of SWAT model is that the practical utilities of several conservation practices, which accounts terraces, strip cropping, contouring, grassed waterways, filter strips and conservation tillage. Subsurface tile drainage is simulated in SWAT 2005 with improved routines that are based on the work performed by Du *et al.*, (2005) and Green *et al.*, (2006).

Quantification of recharge rates in particular their spatial distributions is imperative for proper management and protection of groundwater resources and critical for hydrologists, land managers and policy makers for several decades (Giri *et al.*, 2005). Initial SWAT-G model includes percolation, hydraulic conductivity and interflow functions to provide improved flow predictions for low mountain ranges in Germany (Lenhart *et al.*, 2005).

In the standard SWAT, a doubling of carbon dioxide concentration would lead to a decrease of 40% stomatal conductance reduction irrespective of the land cover type (Neitsch *et al.*, 2005). This reduction is assumed to be linear over the carbon dioxide concentration range between 330ppm and 660ppm. Theoretically SWAT is able to estimate spatial recharge rate and nitrate leaching to deep soil layers and can be used for analysing the impact of land use. However, the SWAT model can only be used for watersheds where it has been calibrated. Groundwater recharge can be calculated for each hydrological response unit (HRUs) within the SWAT model.

Jha *et al.*, (2004, 2006) studied the climate change effects on snowfall, evapotranspiration and runoff using the standard Soil and Water Assessment Tool (SWAT) in combination with General Circulation Models (GCMs) for the Upper Mississippi River basin. By doubling of baseline carbon dioxide to 660 ppm is reported to increase the average annual streamflow by 36% and change of -20% and 20% in precipitation with current rainfall patterns changed the total water yield by – 49% and 58% respectively.

The SWAT model has been used for studying the potential effects of increased carbon dioxide and consequent climate change at the watershed scale (Gassman *et al.*, 2007). Zhang *et al.*, (2008) studied the efficiency of SWAT for snowmelt driven runoff modelling in the 1, 14,345 Km^2 headwaters of the Yellow River in China. Impacts of land cover change or land use pattern change on total water yields, groundwater flow and quick flow in the Motueka River catchment, which have been studied by Cao *et al.*, (2009) using SWAT.

A major study regarding hydrology of the watershed has been done by Ficklin *et al.*, (2009). He suggested that, increased carbon dioxide and climate change are expected to alter regional hydrological conditions significantly and result in a variety of impacts on water resource systems.

Srinivasan *et al.*, (2010) concluded that, SWAT was able to provide a satisfactory hydrologic modelling performance in accordance with the given appropriate data for the Upper Mississippi River Basin without calibration.

The conceptual lumped model like XAJ model does not consider land use changes directly and it does not have functions for simulating the effect of agricultural activities on water availability. So, the spatially distributed well oriented models like SWAT can be utilised for the improved watershed analysis (Shi *et al.*, 2011).

Wu *et al.*, (2011) modified the standard SWAT model to represent a more mechanistic description of vegetation type specific responses of stomatal conductance reduction and leaf area increased to elevated carbon dioxide based on plant physiological studies. Also, dynamic increase in carbon dioxide at monthly scale considered for evaluating how incrementally increasing carbon dioxide affected the watershed hydrology of the upper Mississippi River basin.

Ajeeth and Thomas (2013) studied the water balance of Karuvannur River basin. They reported that, suitability and acceptance of this model has been well established. Model inputs include DEM, land use, soil and climate data.

Rivaz and Lizama (2014) described that, GIS is the framework within which spatially distributed data were collected and prepared model input files. GIS based tools like AGWA SWAT can be used to illustrate the effects of land use practices on runoff and to support watershed wide land use management decisions.

Based on such studies, SWAT can be considered as a best tool for the impact assessment studies on basic natural resources of a watershed.

2.6 REMOTE SENSING AND WATERSHED STUDIES

Runoff and erosion studies can be conducted successfully only with the help of remote sensing tools. One of the key point in the evolution of runoff models in the last few years, is the inclusion of soil surface characteristics together with their spatial distribution and temporal evolution. These characteristics have a strong influence on runoff which determines the partition of rain between the soil layers and on the transfer function which controls the movement of water over the surface.

Remote sensing is the process of obtaining information about an object area or phenomenon without coming direct contact with it. Remote sensing and Geographic Information System has become one of the most exciting field of science with rapidly expanding opportunities. One of the simplest definition of remote sensing is that, it is the practice of deriving information about the earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth's surface.

Various tools of remote sensing and GIS can be applied to partially reconstruct the drainage network and simulate the drainage pattern of runoff distribution. The Geomorphic Instantaneous Unit Hydrograph (GIUH) adopted by Gupta *et al.*, (1980) is one of the most commonly used method for determining rainfall-runoff response. According to Arnoff *et al.*, (1989), GIS is a computer based tool for mapping and analysing things that exist and events that happen on earth. It is a set of tools for collecting, storing, retrieving at will transforming and displaying spatial data from the real world for a particular set of purpose.

Many scientists have used Digital Terrain Models (DTM) to study the hydrological and geomorphic responses of rainfall (Young *et al.*, 1989). A GIS supports the import of external data (such as remote sensing) and the selection and transfer of data into application oriented, analytical models (Antenucci *et al.*, 1991).

Remote sensing has vast and extended applications in hydrology. They are related to the investigation of cloud cover, impervious surfaces, floods, land use, radiation, snowfall, snow cover, soil moisture and surface temperature and important applications for monitoring and forecasting. Engman and Gurney (1991) and Haefner and Pampaloni (1992) give an overview of the variety of remote sensing applications in hydrology with examples.

Estes (1992) stated that, GIS can provide resource managers and decision makers with tools for effective and efficient storage and manipulation of remotely sensed information and other spatial and non-spatial information.

For processing and analysing remotely sensed data in hydrological applications, multispectral, multi-temporal, multi sensor, multi variate and non- real time concepts have been considered. Sensor systems on earth resource satellites are the basis for local and regional (1:25,000 to 1:5, 00,000) scale analysis. Weather satellite data are preferred for regional scale studies to global scale studies. The synergism between GIS and remote sensing enables hydrologists to model temporal and spatial variations of hydrological processes efficiently. Due to the synergism, in most of the hydrological applications, either remote sensing or GIS techniques are used (Fabbri, 1992).

For the hydrological applications of image processing of remotely sensed data and spatio-temporal analysis with GIS a complete integration of GIS and DBMS is necessary. In addition, digital cartography should be integrated leading to the new iconic informatics science (Li Deren, 1992).

Now, scientists recognised the importance of soil surface conditions and the need to take into account the spatial and temporal heterogeneity of the physical medium (Valentin and Bresson, 1992). Remote sensing can play a significant role in acquiring relevant data.

Geographic Information System (GIS) and other interface tools are used to support the input of topographic, land use, soil and other data in digitized format into SWAT. Srinivasan and Arnold (1994) mentioned that, the first GIS interface program developed for SWAT was SWAT/GRASS which was developed within the GRASS raster based GIS.

GIS is a link between the primary raster data and different software packages. GIS based hydrological modelling was used to assess the climate change impacts on the hydrological regime of the Cauvery River basin in India. SWAT is the hydrological model used in this study (Arnold *et al.*, 1995).

GIS can be described as an organised collection of geographic data, computer software, and hardware and designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced information (ESRI, 1995).

Remote sensing and GIS can be used in combination with hydrologic models. It could be an efficient procedure, even though the integration of sensed data processing, GIS analysis, database manipulations and models into a single analysis system is a complex approach. Processing algorithms have to be adapted for more synthetic, integrative and automated analysis including contextual pixel analysis (Paola and Schowengerdt, 1995).

It manage geographically referenced information by compiling database and mapping software tools to analyse spatial relationships between phenomena. GIS evaluates geographical relationships through spatial analysis, database management and geographical display. Remote sensing provides information on the temporal variations of the selected study areas and record changes that can affect the hydrological behaviour of catchments (Mathieu *et al.*, 1996).

Several recent papers have treated remote sensing and GIS in the vast framework of integrated spatial analysis, considering remotely sensed imagery as one element of a GIS for earth's surface modelling.

Soil erosion is one of the strong environmental threat and causes high economic costs by its effects on agricultural production, infrastructure and water quality (Lal, 1998).

A GIS software can handle both vector and raster data. But, the remote sensing data belongs to the raster type, usually requires spatial data manipulation procedures that regular GIS does not offer. Results of remote sensing analysis usually combined within a GIS or into database of an area for further analysis (Levin, 1999).

Soil surface roughness is a parameter used in remotely sensed images for identifying terrain type features. It affects various hydrologic and erosion processes (surface depression storage, water infiltration and overland flow) (Govers *et al.*, 2000).

Rao (2000) suggested that, the geographical data play a key role in deriving information on natural resources and environment. Though topographical maps provide some spatial information about terrain and cultural features, it is not enough for development planning.

Difficulties to collect good quality data is the major limitation for the environmental impact assessment studies. Remote sensing provides homogeneous data over large regions with a continuous monitoring at a fixed period of time and can therefore, contribute to regional erosion assessment (Siakeu and Oguchi, 2000). Growth of world population drastically risen the pressure on the land and water resources, necessitates the application of technologies such as GIS to help maintain a sustainable water and food supply according to the environmental potential.

Moharana and Kar (2001) conducted a study titled as watershed simulation in a sandy terrain of the Thar Desert using GIS, in which simple Digital Elevation Model (DEM) under ARC/INFO is used to extract watershed boundaries and simulate the flow path of storm runoff.

Sarkar *et al.*, (2001) reported that, GIS is a potential tool for facilitating the generation and use of thematic maps, has been applied to estimate the groundwater potentiality of the Shamri micro – watershed in Shimla taluk. The parameters used for this study are drainage, lithology, slope and land use have been emphasised for delineation of potential zones.

Remotely sensed data is a very feasible alternative to manual observations with a very short time delay between data collection and transmission. Remote sensing data can improve information on crop conditions for an early warning system. It provides the most important informative contribution to GIS which furnishes basic informative layers in optimal time and space resolutions (Sivakumar and Hinsman, 2001).

Remote sensing offer possibilities for extending existing data sets. Remotely sensed imagery can be used as a data source supporting digital mapping (Slaymaker, 2001). Baghdadi *et al.*, (2002) have explained the physics of remote sensing image analysis using roughness coefficient parameter. They demonstrated the possibility of deriving surface roughness for bare soils from backscattering coefficient for high incidence RADAR images.

Giridhar and Viswanadh (2002) used GIS and remote sensing to estimate the runoff in a watershed. They have prepared the land use maps from Indian Remote Sensing (IRS) LISS- III imageries for Palleru sub basin using Earth Resource Data Analysis System (ERDAS). Daily runoff estimation is integrated in this study with the Arc GIS 9.1 software for data generation, storage and manipulation.

Topographic data are a prerequisite to any hydrologic impact assessment studies. Digital Elevation Models (DEMs) are the fundamental requirement for such studies in which elevation, slope intensity and aspect can be calculated. Ground based methods like traditional surveying and Global Positioning System (GPS) tools are the method of collecting topographical data. Now, the remote sensing has vast application opportunities and technical tools for the collection of accurate, precise, three dimensional topographical data in various formats. DEM from optic images such as ASTER, SPOT5, Ikonos or Quickbird have a vertical resolution of up to a few meters. DEM from RADAR images such as SRTM, Radarsat and ERS have a vertical resolution of 10m. When calculating flow directions the errors related to the precision of the DEM should be considered (Schmugge *et al.*, 2002).

Even some scientists have worked on the impact of soil erosion by water on global food security. Proper assessment of erosion problems is greatly dependent on their spatial, economic, environmental and cultural context (Warren, 2002). The advantages of remote sensing are highly important, especially for the production of lucid and synthetic information for decision makers.

The data collected from various sources manipulated and processed to form information which can be stored as a database and enables future use of stored data for an effective and efficient practices (Aravind and Rakesh, 2004).

Major environmental impacts of erosion are the emission of soil organic carbon to the atmosphere in the form of carbon dioxide and methane causing global warming (Lal, 2004). Remote sensing offered a very different type of data form that the researchers have traditionally worked with. Ratnam *et al.*, (2005) have done appreciable studies using remote sensing techniques and reached the conclusion that, remote sensing technique has emerged as a powerful tool in the recent years. Satellite remote sensing has the ability of obtaining synoptic view of large area at one time and very useful in analysing different geographical features. Aerial photo interpretation is the traditional remote sensing application for the geomorphological and hydrological studies. Since 1972, with the launch of Landsat-1, satellite imagery has become available in operational format.

It is generally agreed that, GIS is a computer based system whose component software is capable of using georeferenced data for a range of spatial analysis and outputs. In brief, GIS adds value to spatial data. By allowing data to be organized and viewed efficiently and integrating with other data thereby a new data format could be operated on, GIS creates useful information to help decision making (Heywood *et al.*, 2006).

Dinesh Kumar *et al.*, (2007) utilized the GIS tools to delineate the ground water potential zones of Muvattupuzha River basin, Kerala.

In recent decades, geomorphologists have made great efforts to develop regional and global land and soil databases. Currently, there are several georeferenced soil databases available at map scales less than 1:2,50, 000 referred as Harmonized world soil database developed by FAO- UNESCO (FAO *et al.*, 2008).

Remote sensing and GIS can be used for the prioritization of watershed for implementing interventions based on soil loss due to erosion and morphometric analysis. Related study could be done by Hlaing *et al.*, (2008) in Bago watershed, where soil erosion is determined using USLE. They developed the soil erosion maps from the available data.

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

Remote sensing data along with increased resolution of satellite platform makes the watershed management studies more improved and accurate work. It 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).

Ajeeth and Thomas (2013) suggested that, there are new development and improvements in the modelling systems that increasingly dependent on GIS techniques. Sarala (2013) conducted a morphometric analysis of Halia drainage area, has been carried out using geoprocessing techniques in GIS. The morphometric analysis of the watershed was carried out with the help of Shuttle Radar Topography Mission (SRTM) DEM. This study revealed that, SRTM DEM based hydrological evaluation was much realistic and precise compared to all other techniques.

Srinivasalu *et al.*, (2014) worked on land use analysis using remote sensing and GIS in Rajampet, Andhra Pradesh. They used high resolution IRS LISS - III satellite imagery for identifying the LULC classes. ERDAS and ArcGIS software were used to demarcate the LULC features of the study area. The LULC information used along with the other natural resources information like water, soil, and hydro – geomorphology will help in the efficient and optimal land use planning at the macro and micro level.

An interesting study conducted by Pervez and Henebry (2015) concluded that SWAT allowed to adjust the input parameters such as weather parameters, carbon dioxide concentration and land use. It describes the different approaches behind the impact of these parameters on plant growth, evapotranspiration, snow and runoff generation. SWAT can be a useful 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).

CHAPTER 3

MATERIALS AND METHODS

3.1 STUDY AREA

The Kurumali River is a sub basin of Karuvannur river. It is located at latitude 10°15' N to 10°40'N and longitude of 76° 00' E to 76°35'E, lying in Thrissur district of Kerala State. Karuvannur River is one of the major river in Thrissur district and it originates from Poomalai hills in Western Ghats. Karuvannur river discharges to Arabian Sea. The river has got two tributaries, *viz.* Manali and Kurumali. The Kurumali River is one of the two major tributaries of Karuvannur River. The Kurumali stream originates from Pundimudi in Western Ghats at an elevation of 1116m. Mupli stream joins with the Chimmony River at Elikkode, forming Kurumali River. It joins with Manali River at Palakkadavu and forms Karuvannur River. The Kurumali river joins with Manali at Palakkadavu to form Karuvannur river.

The outlet selected for the study is at Kurumali in Muriyad Grama Panchayath with latitude of 10°24'4'' N and longitude of 76°16'56'' E. Total catchment area of the Kurumali river is 422.57 km^2. Total catchment area of the Karuvannur river is 1054km^2 with a utilizable water resources of 623Mm^3 per annum. Of which, the net utilizable surface and ground water resources are 519.8 million m^3 and 103.2 million m^3 respectively (Ajeeth and Thomas, 2013). About 60 per cent of the total annual precipitation is received during south west monsoon period, 30 per cent from north east monsoon and 10 per cent from summer monsoon (pre monsoon). The average rainfall Kurumali sub basin are 2851 mm, 3011mm and 2858mm for high land, mid land and low land respectively.

3.2 SOURCES OF DATA

Climatological data (rainfall, temperature, wind speed, relative humidity, sunshine hours and evaporation), runoff, soil, Digital Elevation Model (DEM) and Land use and Land cover data are the preliminary input parameters of this study.

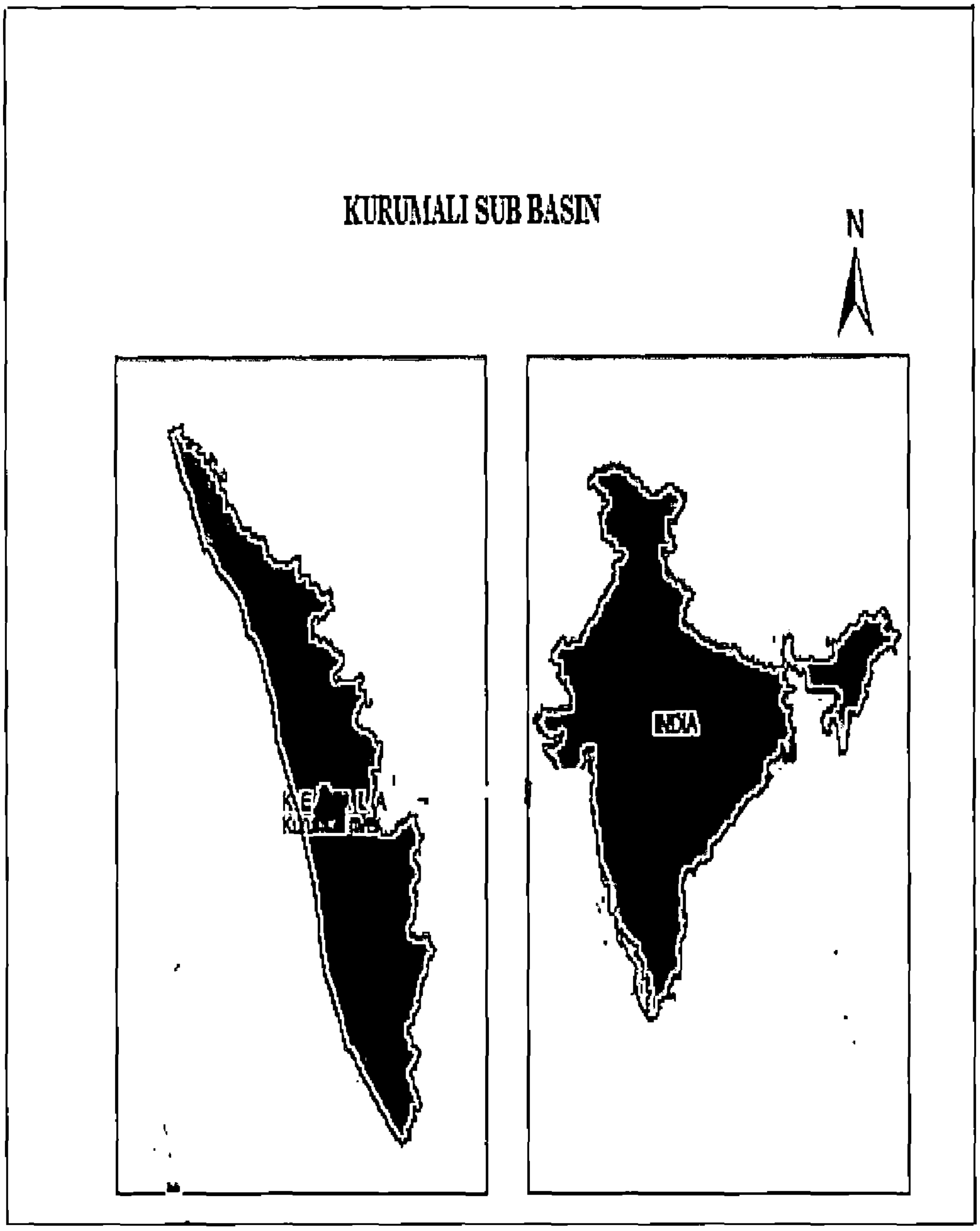

Fig. 1 Location map of study area

3.2.1 Climatological data

Daily weather data excluding rainfall *viz,* Temperature, Wind speed, Relative humidity, Sunshine hours and Evaporation have been collected from Agro meteorological observatory, Kerala Agricultural University (KAU), Vellanikkara which is located about 19.7 km away from the centroid of the study area. The data is collected for the period from 1993 to 2012. This agro meteorological observatory is installed and managed as per the norms and mandate of India Meteorological Department (IMD).

Maximum and minimum temperature is measured using mercury and alcohol thermometer respectively. Wind speed is measured using cup anemometer and wind vane depicts the wind direction. Pan Evaporimeter is used for evaporation measurements. All these measurements are carried out manually twice per day at 07.00 IST and 14.30 IST.

Daily rainfall data for the same period (1993 – 2012) has been collected from Echippara and Muply rain gauge stations. Kerala state Water Resource Department is responsible for the management and authenticity of these rain gauge data. Geographic location of these stations are 10°26' 27'' N, 76°27'00'' E and 10° 25' 00''N, 76° 23' 44'' E respectively.

3.2.2 Future climate data

For modelling the watershed processes, we require future projected climate data. Such projected data is obtained from MarkSim DSSAT weather file generator for the future 30 years. This data is used for predicting the future watershed processes and water resource availability using SWAT model. MarkSim provides projections on daily rainfall (mm), temperature (°C) and solar radiation using Representative Concentration Pathway for the future years.

MarkSim is a weather file generator, which is helpful to formulate future daily weather using different GCMs. The online MarkSim GCM is a stochastic weather generating platform that aims to generate daily weather data across the globe. MarkSim tool was developed by Waen Associates and is supported by the CGIAR research program on Climate Change, Agriculture and Food security (CCAFS). It can be used to generate daily data for multiple years that are characteristic of future climate for any point in the world. Latest version of MarkSim contains 4 RCPs and 17 GCMs. All these models are developed by different international agencies and renowned as IPCC climate models. In 2013, it was updated and add the combinations of any of these models and scenarios.

Downscaling has been carried out to simulate weather conditions at local areas. Downscaling is the procedure to take information known at large scales to make predictions at local scales. Among the two approaches for downscaling climate information, statistical downscaling method is used for this study. It consists of the development of statistical relationships between local climate variables and large scale predictors and then the application of such relationships to the output of global climate model experiments to simulate local climate characteristics in the future.

In climate change research, scenarios describe plausible trajectories of various aspects of the future that are constructed to investigate the potential consequences of anthropogenic forcing. They represent major driving forces, their impacts (physical, ecological and socio economic) and responses that are important for informing climate change policy. Representative Concentrated Pathways (RCPs) are used instead of emission scenarios in IPCC fifth assessment report. There are 4 RCPs. Their characters and descriptions of IPCC models are tabulated in table 2 and 3 respectively.

Table 2: Description of Representative Concentrated Pathways

RCP	**Description**
RCP 2.6	Its radiative forcing level first reaches a value around 3.1 Wm^{-2} mid-century, returning to 2.6 Wm^{-2} by 2100. Greenhouse gas emission and emission of air pollutants are reduced substantially over time.
RCP 4.5	It is a stabilization scenario where total radiative forcing is stabilized before 2100 by employing a range of technologies and strategies for reducing GHG emission.
RCP 6.0	It is a stabilization scenario where total radiative forcing is stabilized after 2100 without overshoot by employing a range of technologies and strategies for GHG emission reduction.
RCP 8.5	It is characterized by increasing GHG emissions over time representative of scenarios in the literature leading to high GHG concentration levels.

Table 3: General Circulation Models used in MarkSim tool

S. N	Model	Developer
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 Organization 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	Institute Pierre-Simon Laplace
12	IPSL-CM5A-MR	Institute 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	MIROC-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

3.2.3 Runoff data

The daily river flow of Kurumali River has been collected from Data Dissemination Centre, Jalavinjana Bhavan, Thiruvananthapuram for the period of 1993-2012. Stage level method is used to compute the discharge. Flow measurements are taken twice a day and the average value of daily river flow is used in this study.

3.2.4 Digital Elevation Model

A Digital Elevation Model (DEM) is a gridded array of elevations. It is a digital cartographic/geographic dataset of elevations in xyz coordinates. The terrain elevations for ground positions are sampled at regularly spaced horizontal intervals. DEM with 30m resolution of Shuttle Radar Topography Mission (SRTM –void/ Non void type) is used for the study. It is obtained from United States Geological Survey (USGS) earth explorer site (www.earthexplorer.usgs.gov.in).The SRTM digital elevation data produced by NASA is a major breakthrough in digital mapping of the world and provides a major in the accessibility of high quality elevation data for large portions of the tropics and other areas of the world. Void filled version of SRTM-DEM is the latest invention where the radar interferometric method is successful (Non-void). Most voids are filled with elevation data from the ASTER GDEM2 (Global Digital Elevation Model version 2).

DEM should be in Environmental System Research Institute (ESRI) grid format. This must be georeferenced with the projection of WGS 1984 UTM Zone 43 in a projected coordinated system.

3.2.5 Soil data

Soil texture, structure and organic carbon content are the characteristic features of any soil type. Soil data for Kurumali sub basin has been collected from Department of Soil Survey and Soil conservation, Kerala and Kerala Forest Research Institute (KFRI), Peechi. It comprises the major physical properties of the soil. All these factors determine the soil porosity and infiltration capacity.

Soil attribute information are stored in the same dBase file format. Soil Plant Atmospheric Water (SPAW) is a daily hydrologic budget model used for estimating the soil properties. It computes the daily movement of water and nutrients for soil layers. 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.

Table 4: 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	0.0
MULAY	Mulayam	58.39	4.15	36.46	0.26	0.50	0.0	0.01
MARAI	Maraickal	40.13	24.30	35.51	0.90	1.60	0.0	5.0
VELLA	Vellapaya	43.67	35.86	20.47	0.61	1.08	35.94	0.0
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	0.0
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	0.0

3.2.6 Land use and Land cover data

Land use map has been prepared by the supervised classification of the multispectral LISS III imagery collected from National Remote Sensing Agency (NRSA), Hyderabad. The Linear Imaging Self Scanning Sensor (LISS III) is a multispectral camera operating in four spectral bands. Two of which is in visible band and one each in Near Infra-Red (NIR) and Short wave Infra-Red (SWIR) range. The spatial resolution for visible (2 bands) and NIR (1 band) is 23.5m with a ground swath of 141 Km. The fourth band, SWIR has a spatial resolution of 70.5m with a ground swath of 148 Km. The repetivity of LISS III is 24 days.

Land use map is generated using ERDAS Imagine 2015 software package and the details of land use is constructed in dBase files. Such maps can be 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 land use map. Flow chart for the preparation of land use map is given in figure 2.

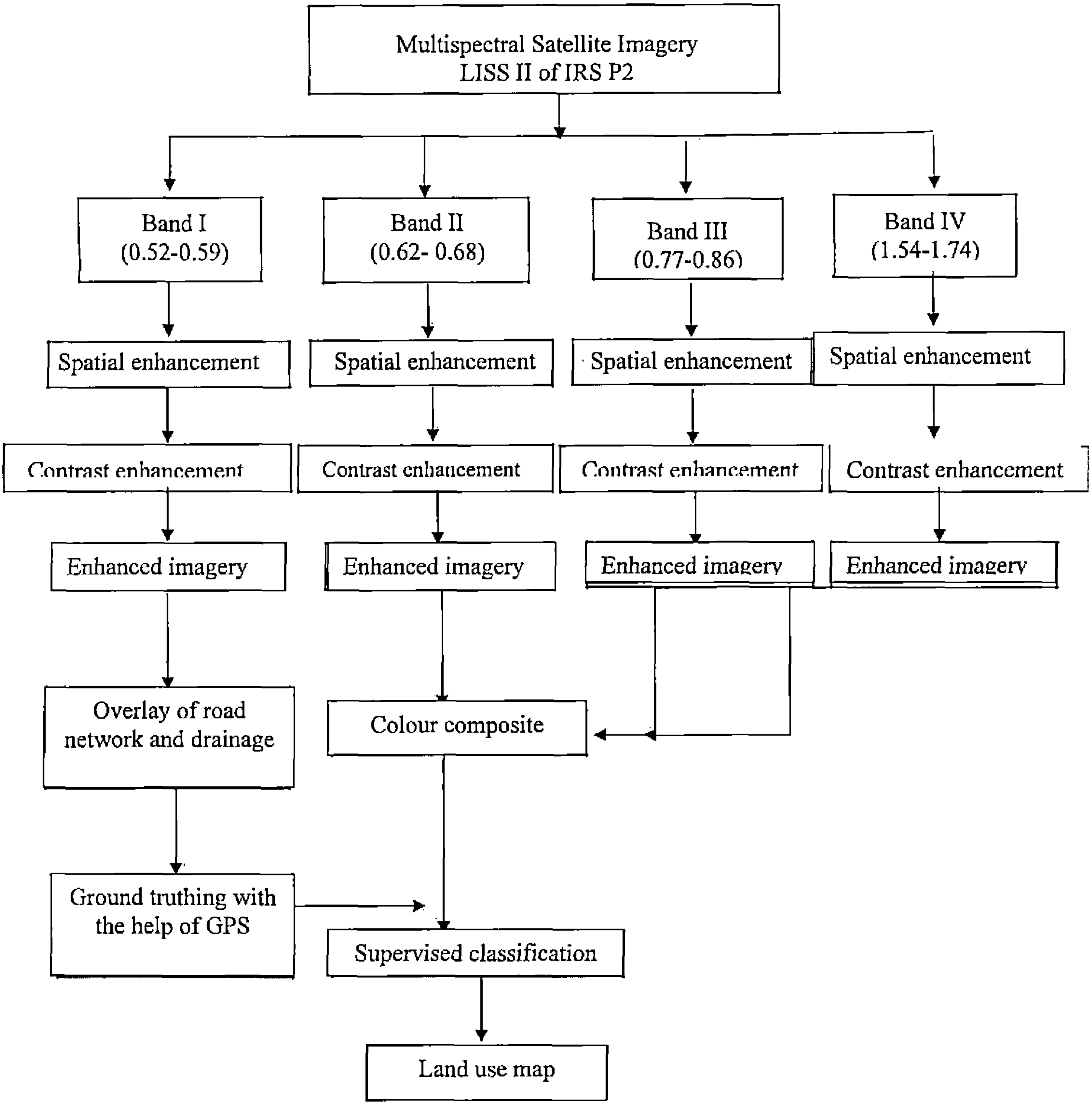

Fig. 2. Flow chart for the preparation of land use map

Table 5: Spectral range of each band in LISS III image

BAND	SPECTRAL RANGE
Band I (Green)	0.519-0.601 μm
Band II (Red)	0.631-0.692 μm
Band III (NIR)	0.772-0.898 μm
Band IV (SWIR)	1.547-1.748 μm

3.2.7 Topographic map

Topographic maps or topo sheets have been collected from Survey of India (SOI) prepared at 1: 50 000 scale. Topo sheet number 58B07 contains the required study area. Select this topo sheet from the group of other topo sheets of Thrissur district. An overview of terrain characters, drainage network, land use and land cover can be obtained from this topo sheet. Also, it could be a reference material for the drainage analysis and field visit.

3.2.8 Drainage Map

Digitized drainage network map has been prepared using ArcGIS 10.2.2 digitization tool. SWAT model needs perfectly digitized such maps for the accurate delineation of sub basins and watersheds. This must be in a shape file format.

3.3 SOFTWARE PACKAGES AND TECHNIQUES USED IN THE STUDY

3.3.1 Arc GIS 10.2

The purpose of GIS is to create, share and apply useful map based information products that add value to the work and to create and manage the necessary foundational geographic information to power the existing maps. ArcGIS allows people to create maps and geographic data and to access and use online GIS maps, data, reports and other informational products. It is mainly used for creating maps compiling geographic data, analysing mapped information, sharing and discovering geographic information in a range of applications and managing geographic information in a database. Environmental System Research Institute (ESRI) is the developer of ArcGIS. ESRI is an interior supplier of GIS software, web GIS and geodatabase management applications. Pioneer version was released on December 27, 1999 at New York. ArcGIS 10.2.2 version is used in this study for setting up the projections of input data files such as DEM, land use data and soil map. ArcGIS 10.2.2 version was released on April 15, 2014.

ArcGIS for Desktop integrates several applications including ArcMap, ArcCatalog, ArcToolbox and ArcGlobe. Easiness and suitability of ArcGIS is provided by these applications which allow users to author, analyse, mapping, manage, share and public geographic information. ArcMap is the fundamental application of ArcGIS used to view, edit and query geospatial data and create new maps. It acts as an interface between user and software. It has two sections, including a table of contents and the data frame(s) which display the map. ArcMap table of contents lists all the layers on the map and shows the features symbology. The table of contents helps to manage the display order of map layers and symbols too. The table of contents has several ways of listing layers: by drawing order, source and whether layers are selectable or visible. ArcCatalog is the data management and processing application used to browse datasets and files on the computer. ArcCatalog also allows users to preview the data on a map. It also provides the ability to view and manage metadata for spatial datasets. ArcToolbox consists of various tools such as georeferencing, analysis, drawing, editing and geocoding tools. It is also possible to use batch processing with Arc Toolbox, for frequently repeated tasks.

Digitization of raster image and construction of road, drainage network maps are also done by the tools in ArcMap. Outlet, catchment location and tributaries have been easily identified and digitized with this application. ArcGIS, which is a potential tool for facilitating the creation and use of thematic maps has been applied for the estimation the water resources availability for this study area. The parameters used for this study are drainage, soil properties and land use. ArcGIS is the platform on which the watershed model, SWAT works.

3.3.2 ERDAS Imagine 2015

An image is a digital picture or representation of an object. Remotely sensed image data are digital representations of the earth. Each pixel represents an area of the earth at a specific location. The data file value assigned to that pixel is the record of reflected radiation or emitted heat from the earth's surface at that location. It includes several bands of information. ERDAS Imagine programs can handle an unlimited number of bands of image data in a single file.

ERDAS Imagine is an image processing software with raster graphics editor capabilities designed by hexagonal geospatial applications. ERDAS Imagine 2015 is used in this study. This software package is aimed primarily at geospatial raster data processing and allows the user to prepare, display and enhances digital images for mapping 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 Imagine 2015 software. Supervised classification on the false colour composite has yielded the land use.

3.3.3 Soil and Water Assessment Tool (SWAT)

The Soil and Water Assessment Tool (SWAT) is an ultimate output of the continuous effort by United States Department of Agriculture (USDA), Agriculture Research Service. Jeff Arnold is the founder of SWAT model. It was developed in early 1990s. SWAT has a continuous long 30 years of experimental history. It has proven to be an effective tool for assessing water resources and availability of water. SWAT model is physically based, computationally efficient basin scale model. It is a continuous – time model that operates on a daily time step and is designed to predict the impact of management on water, sediment and agricultural chemical yields in ungauged watersheds. Several federal agencies like US Environmental Protection Agency, Natural Resources Conservation Service, National Oceanic and Atmospheric Administration and Bureau of Indian Affairs and some US universities have contributed to the model.

Major components/ input parameters of SWAT model are climate, soil, land use pattern, nutrient load and management factors. For precise and more accurate analysis, SWAT divides watersheds into multiple sub watersheds which are again divided into Hydrological Response Units (HRUs). This fragmentation process is based on the homogeneity in land use, management and soil characteristics. This subdivisions make the analysis easy. The HRUs represent percentage of the sub watershed area and are not identified spatially within the simulation of this model.

This model is used for the direct assessments of physical and hydrological processes of the watershed. It integrates those processes in each individual HRU and formulate simulations for the entire watershed. Major SWAT outputs will be in terms of weather, hydrology, soil erosion, nutrient load, plant growth, agricultural chemical yields, pesticides, land use management and channel and reservoir routing.

ArcSWAT is used for this study. It is a public domain software widely accepted by hydrologists. It is used for the setting up of SWAT new project, automatic watershed delineation, input editors and simulation. ArcSWAT deals hydrology with the help of natural water balance equation in accordance with soil characteristics. The water balance components include precipitation, surface runoff, infiltration, evapotranspiration, lateral flow, percolation and groundwater flow. Surface runoff volume is estimated and projected from daily precipitation by using SCS (Soil Conservation Service) curve number equation and Green – Ampt method is used for infiltration estimations. Penmann- Monteith method is used for the estimation of potential evapotranspiration in this study.

Water balance equation

$$\mathbf{SW_t = SW_0 + \Sigma\,(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})} \quad (3.1)$$

SWt ⟶ Final soil water content (mm)

SW0 ⟶ Initial soil water content on day I (mm)

t ⟶ Time (days)

Rday ⟶ Amount of precipitation on day i (mm)

Qsurf ⟶ Amount of surface runoff on day (mm)

Ea ⟶ Amount of evapotranspiration on day i (mm)

Wseep ⟶ Amount of water entering the vadose zone from the soil (mm)

Qgw ⟶ Amount of return flow on day i (mm)

Surface runoff estimation

Initial abstractions (surface storage, interception and infiltration before runoff) and retention parameters with respect to changes in soil, land use, management and slope are the influencing factors for the surface runoff. The SCS curve number method estimates surface runoff from daily rainfall.

The daily surface runoff is given by

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

Q_t ⟶ Accumulated runoff or rainfall excess

R_t ⟶ Rainfall depth for the day

0.2S is taken as Initial abstraction I_a. Runoff will occur only when $R_t > 0.2S$

S ⟶ Retention parameter

The curve number depends on soil type, antecedent moisture condition and land use or land cover.

Green-Ampt equation

$$f_p = m + n/F_p \text{ or } f_p = K[1 + \eta S_c/F_p] \qquad (3.3)$$

f_p ⟶ Infiltration capacity at any time t from the start of rainfall

K ⟶ Darcy's hydraulic conductivity

η ⟶ Porosity of the soil

S_c ⟶ Capillary suction at the wetting front

F_p ⟶ Accumulated infiltration volume

m, n ⟶ Green-Ampt parameters

Base flow

The steady state response of base flow recharge is given as,

$$Q_{gw} = \frac{800 * K * h}{L_{gw}^2} \qquad (3.4)$$

Q_{gw} ⟶ Groundwater flow into the main channel on the day i (mm)

K ⟶ Saturated hydraulic conductivity of the aquifer (mm/h)

h ⟶ Water table height (m)

L_{gw} ⟶ Distance from the ridge to the main channel (m)

3.3.3.1 Data table formats in SWAT

Both temperature and precipitation gauge location details should be incorporated as .txt file format. Daily precipitation, maximum and minimum temperature data should be given as ASCII text file. Other weather data such as wind speed, solar radiation and relative humidity can be added as weather generator (WGN) text format. Daily records should be series and sequential format. Both soil and land use details should be added as dBase format.

3.3.4 Climate Change projection data

Collect future climate projection data for 2050 from GFDL-ESM2M general circulation model. It was developed by Geophysical Fluid Dynamics Laboratory of the National Oceanic and Atmospheric Administration (NOAA). Goal of this coupled model is to create an efficient model that can realistically simulate a range of phenomena from diurnal scale fluctuations and synoptic scale forms to multi decadal climate change. It also aims the seasonal forecast and the simulation of global climate change.

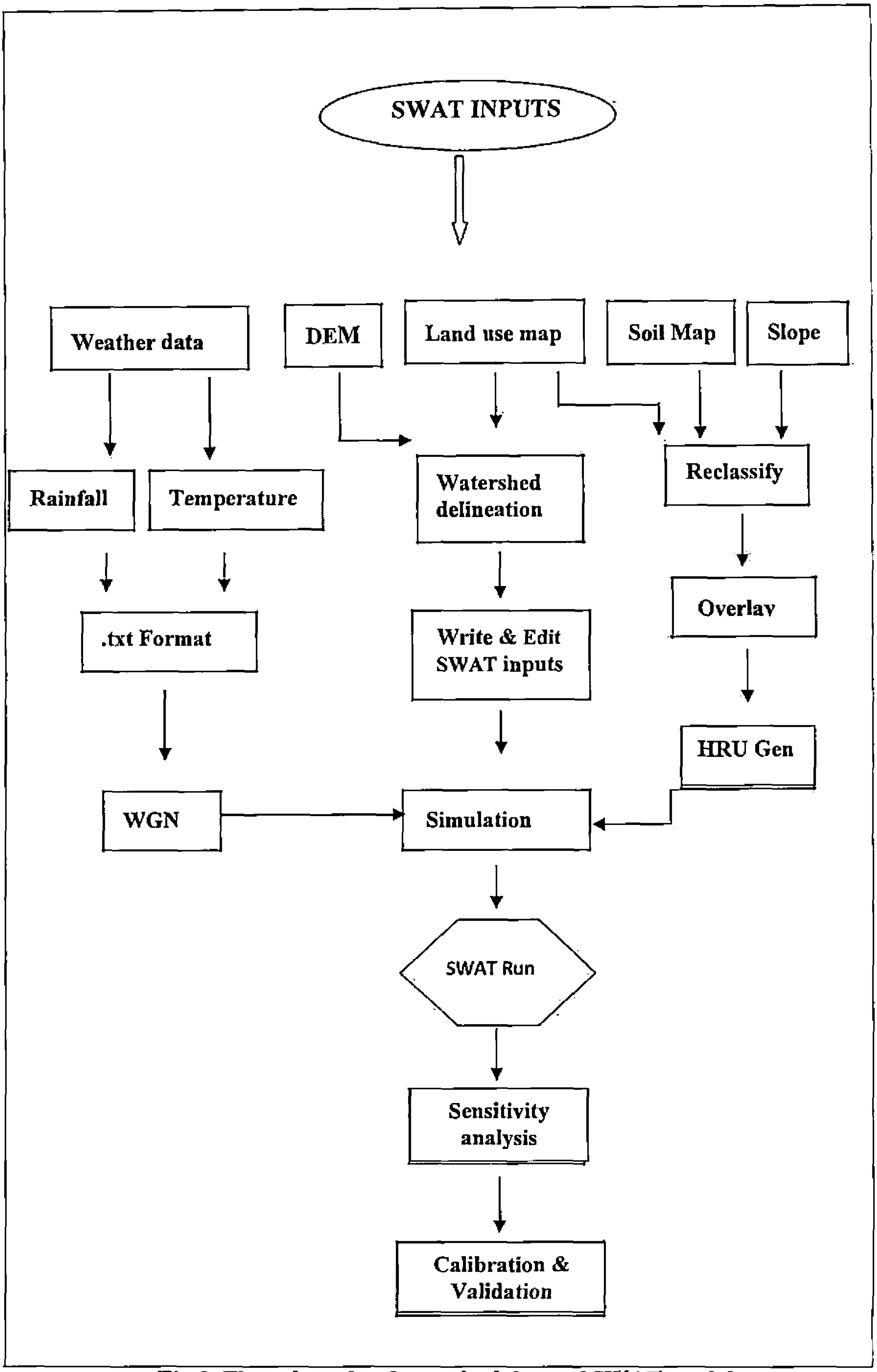

Fig.3. Flow chart for the methodology of SWAT model

3.4 ARCSWAT MENU BAR

SWAT project setup, watershed delineator, HRU analysis, write input tables, edit SWAT input and SWAT simulation are the different tool items included in the ArcSWAT menu bar.

3.4.1 SWAT project setup

This menu controls the project set up. It has seven sub tools such as New SWAT Project, Open SWAT Map document, Save SWAT Project, Copy SWAT Project, Delete SWAT Project, ArcSWAT help and About ArcGIS ArcSWAT.

3.4.2 Watershed delineator

This menu automatically delineate the sub watersheds and use to analyze the results. It has two sub tools. Automatic delineation menu delineate the current new watershed project. Watershed reports command gives the path to access the topographic report generated by the interface.

3.4.3 HRU analysis menu

It allows the physical and topographical feature analysis of the watershed. It has three commands. Land use/ soils/ slope definition menu helps to import corresponding data into the project. HRU definition command defines the newly generated HRUs. HRU analysis report tool helps to list out the entire reports that has been generated by the interface.

3.4.4 Write input tables menu

This menu construct the data detail tables in prescribed formats. Weather station details are added by inputting corresponding location details in .txt file format. Write input data tables command help to incorporate land use, soil and other parameters as necessary dBase files. It stores values for the accurate simulation by SWAT. Database update tool helps to update the already existing data files.

3.4.5 Edit SWAT input menu

It allows the user to edit the databases and tables. It has seven sub tools. Databases command helps to edit the database at any time of project setting within the project. The SWAT databases must be edited prior to writing the SWAT Input tables.

Point source discharges command allows the user to define the point source loadings for each sub basins. It can be reflected only in the current project. Inlet discharges command helps the user to create loadings for upstream sections of the watershed not directly modelled in the current project. Reservoirs option is needed to edit each reservoir data present in current project. Sub basins data command used to access the input parameters for topographical features, channels, ponds, wet lands, and groundwater systems within the watershed. Watershed data tool is used to edit the entire watershed area. Re-write input file command is used for editing the input data files and re- write ASCII data extensions. Integrate APEX model tool helps the user to specify sub basins within the current SWAT.

3.4.6 SWAT simulation

This menu helps to run and simulate new conditions and then perform sensitivity analysis. Run SWAT command is used to run the modified input files in three SWAT input files such as the input control code file (.cod), the basin input file (.bsn), and the watershed water quality input file (.wwq). Read SWAT output command import the text file which has been written by SWAT into an Access database. Set default simulation command allows to reset the input files as active default simulation format. Manual calibration helper command provides a tool to make changes in the parameters in the specified HRUs during manual calibration.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 IDENTIFICATION OF SUITABLE CLIMATE MODEL

Physical processes in the atmosphere, ocean, land surface and cryosphere and their interactions are represented by General Circulation Models (GCMs). They are the most efficient tool for the representation of such natural nesting functions three dimensionally. GCMs are complex, numerical models which are governed by seven primitive physio – dynamic equations of nature. Most of the current GCMs are coupled climate system models having a horizontal resolution ranges between 250 and 600 Km, 10 to 20 vertical layers in atmosphere and sometimes as many as 30 layers in the oceans. These models can be used to conduct climate change studies from which climate change scenarios can be constructed. Scientists around the world are regularly working on the modelling and they develop different types of GCMs having specific goals. Using these models many weather file generators have been developed. MarkSim is one of such weather file generator developed by Climate Change, Agriculture and Food Security (CCAFS). New version of MarkSim was developed in 2013 which consists of 17 GCMs and four scenarios. These scenarios are referred as Representative Concentrated Pathways (RCPs) defined by IPCC Fifth Assessment Report.

Identification of best suitable climate model for this particular study area (Kurumali River basin) have been done by simple statistical analysis. Rainfall data for the period 2010-2015 generated by these 17 models have been downloaded from MarkSim and corresponding original data for the same period have collected from Agro meteorological observatory, Kerala Agricultural University, Thrissur. Then, Annual rainfall and monthly average rainfall for South West monsoon months have been computed. South west monsoon anomaly is tabulated as Table 6 and Annual Rainfall anomaly for each RCPs as Table 7.

Table 6: Anomaly for SW monsoon months (June, July, August and September) - Present climate

Model	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
BCC-CSM 1.1	-531.4	-508.9	-2126.9	-629.0
BCC-CSM 1.1(m)	-303.5	-487.6	-551.2	-728.7
CSIRO-Mk 3.6.0	-537.5	-585.3	-744.4	-946.9
FIO-ESM	-641.7	-302.1	-253	-392.0
GFDL-CM3	-416.6	-327.1	-533.1	-588.1
GFDL-ESM2G	-503.7	-838.7	-701.8	-678.9
GFDL-ESM2M	-295.6	-513	-338.8	-479.3
GISS-E2H	-743.1	-543	-684.2	-371.3
GISS-E2R	-270.9	-300	-377	-796.9
HadGEM2-ES	-411.4	-520	-674.1	-728.2
IPSL-CM5A-LR	-514.3	-620	-533.8	**-252.2**
IPSL-CM5A-MR	-647.2	-466.5	-450.2	-564.6
MIROC-ESM	**-246.5**	-359.5	-444.2	-417.3
MIROC-ESM-CHEM	-645.4	-581.4	-262.1	-735.2
MIROC5	-815.8	**-241.6**	**-247.7**	-443.6
MRI-CGCM3	-295.3	-373.5	-416.9	-577.5
NorESM1-M	-679.7	-529.4	-538.8	-623.3
Ensemble	-453.7	-583.5	-370.1	-547.1

Table 7: Annual rainfall anomaly- Present climate

Models	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
BCC-CSM 1.1	-561.5	-467.1	-2232.3	-759.6
BCC-CSM 1.1(m)	-212.3	-406.0	-654.6	-982.0
CSIRO-Mk 3.6.0	-479.6	-597.0	-715.5	-873.1
FIO-ESM	-587.6	-338.8	-352.7	-647.5
GFDL-CM3	-608.0	-429.6	-573.8	-626.1
GFDL-ESM2G	-671.5	-1061.5	-747.8	-676.4
GFDL-ESM2M	-338.4	-450.1	-431.4	-567.1
GISS-E2H	-605.0	-524.6	-652.9	-400.0
GISS-E2R	**-195.7**	-315.9	-383.1	-672.8
HadGEM2-ES	-516.1	-519.4	-634.6	-697.3
IPSL-CM5A-LR	-550.8	-640.0	-740.2	**-399.5**
IPSL-CM5A-MR	-885.8	-556.4	-501.7	-612.8
MIROC-ESM	-281.3	-497.4	-376.2	-429.8
MIROC-ESM-CHEM	-777.6	-705.4	-478.4	-725.2
MIROC5	-1033.1	**-295.5**	**-310.4**	-453.2
MRI-CGCM3	-318.7	-394.2	-482.8	-742.3
NorESM1-M	-772.0	-486.4	-512.7	-700.9
Ensemble	-470.9	-525.2	-373.9	-481.8

Difference between the original rainfall occurred and the simulated data is referred here as anomaly. Table 6 shows the anomaly computed for south west monsoon months. South west monsoon rainfall for the selected 30 year period (1983-2013) is averaged to 2030.2 mm. By comparing the anomaly values between the 17 General Circulation Models MIROC-ESM showed the least anomaly (difference) from the original received rainfall in RCP 2.6. According to RCP 4.5 and RCP 6.0, MIROC 5 model shows least anomaly. By using RCP 8.5, IPSL-CM5A-LR model was having least SW anomaly. These results are graphically represented as figures 4.1, 4.2, 4.3 and 4.4.

Annual rainfall recorded at the agro-meteorological observatory, for the 30 years period (1983-2013) is 2752.1 mm. According to RCP 2.6, GISS-E2R shows the least annual rainfall anomaly. As per RCP 4.5, MIROC5 has least anomaly output in present climate. According to RCP 6.0, similar result is observed as RCP 4.5. As per RCP 8.5 IPSL- CM5A-LR model is having least annual rainfall anomaly.

Based on these analysis only MIROC-ESM, MIROC 5 and IPSl-CM5A-LR models can be considered for this study. By considering the range of variation MIROC 5 is selected for the simulation of future climate in this study. Graphical representation of these analysis is given below as figure 4 and 5.

4.2 PRESENT CLIMATE OF KURUMALI RIVER BASIN

Daily weather data for the last 30 years (1983- 2013) has been collected from agro-meteorological observatory, Kerala Agricultural University, Thrissur for the identification of present climate of the study area. Weather data consists of daily rainfall, maximum and minimum temperature, relative humidity, evaporation and wind velocity.

4.2.1 Precipitation

Annual rainfall of Kerala is 3000 mm. it is distributed through mainly three seasons in Kerala. They are South West monsoon (June- September), North East monsoon (October-November) and summer monsoon (March- May). South West monsoon is the predominant distributor of major quantity of rainfall over Kerala. It is nearly 75 per cent of total annual rainfall. NE monsoon provides 20 per cent of rainfall and remaining is received during summer months. Monthly mean and annual average of rainfall is represented below in figures 4.1 and 4.2.

According to figure 4.1, maximum rainfall was recorded during monsoon months especially, June and July months. Sudden increase in rainfall is observed from May to June. Nearly, 2046.7 mm rainfall was received during South West monsoon months and 391.6 mm was observed during North East monsoon months. Annual average rainfall value is fluctuated between 2000 mm to 4000 mm. During the last 30 years, maximum rainfall was recorded in 2007 (3962.4 mm). This is higher than annual average of Kerala. Among this amount, 3243.6 mm was received during SW monsoon months. 1999 to 2005 is represented as the driest period for this location. Similarly, 2008, 2009 and 2012 also was the driest years. This long term average of rainfall data depicts that, Kurumali River basin receives above average quantity of rainfall annually which is contributed considerably by South West monsoon. North East monsoon is also severe in some years.

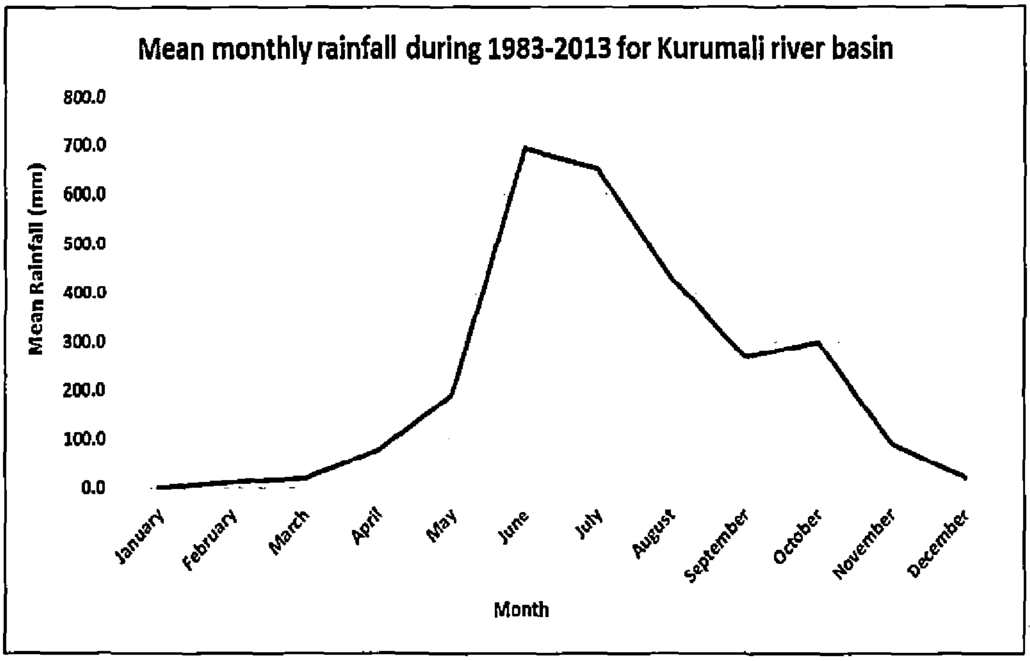

Fig. 4.1 Mean monthly rainfall during 1983 - 2013

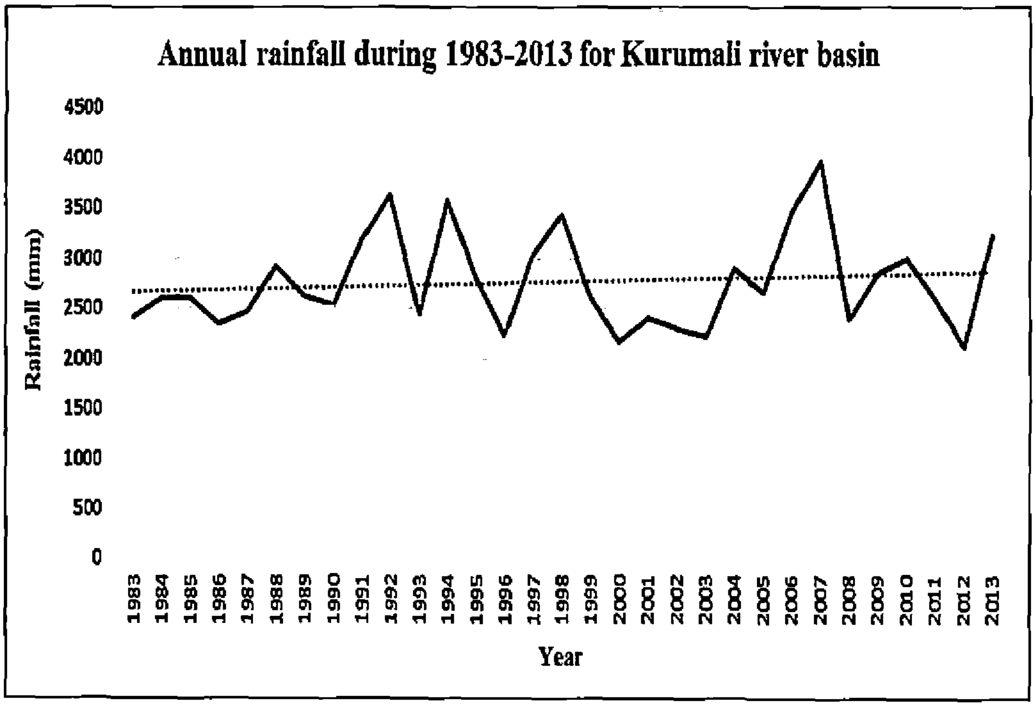

Fig. 4.2 Annual Rainfall during 1983 -2013

4.2.2 Maximum and Minimum Temperature

Temperature measurement can be done in two modes such as maximum temperature and minimum temperature. Maximum temperature is measured with the help of mercury thermometer and minimum temperature is measured using alcohol thermometer. Both these measurements are essential for defining certain physical and dynamical processes of atmosphere. They are very sensitive parameters. Temperature of any location is determined by its geographic features like latitude, altitude, coastal presence and orographic features and season, time of observation and wind speed. Maximum temperature plot is designated as fig 5.1 and 5.2. Minimum temperature plot is named as 6.1 and 6.2.

Monthly average maximum temperature ranges between 29°C to 36° C. The curve increases from January to March and reaches maximum in March (35.6° C) then, slight decrease happens in April and May. In June, July and August minimum values are observed. Again it increases afterwards. Maximum temperature parameter ranges between 31° C to 32° C in winter months. So, the least value is recorded during South West monsoon months. Monthly average minimum temperature reaches maximum during April and May (24.9°C and 24.8°C respectively). Then it decreases up to 23°C in July and remains more or less constant during August, September and October. Lowest average minimum temperature is observed in November and December months (winter season).

Annual average maximum temperature for Kurumali River basin area is showing a decreasing trend. But, the annual average minimum temperature curve is showing a slight increasing trend. 1995 is considered as the warmest year among this period of observation. Annual average of maximum temperature of this year is 33°C. But, the minimum temperature of corresponding year was 23.3°C. It is considerably lower than the mean value. Sudden hike in minimum temperature is happened in 1996 and 1997. Anyway, annual mean value of minimum temperature ranges between 23.2°C to 23.4°C and that of maximum temperature is between 31.8°C to 32.4°C. Reduction in maximum temperature from 34°C to 30°C and increase in minimum temperature by 1.04% have observed in the study conducted by George (2015).

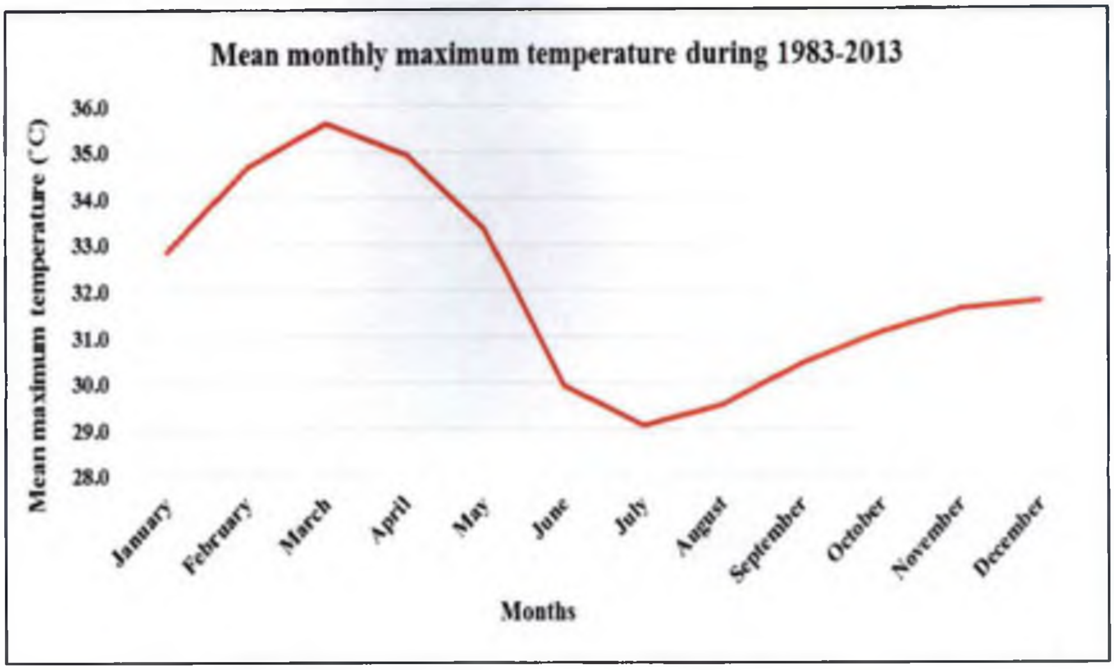

Fig. 5.1. Mean monthly maximum temperature during 1983-2013 for Kurumali river basin

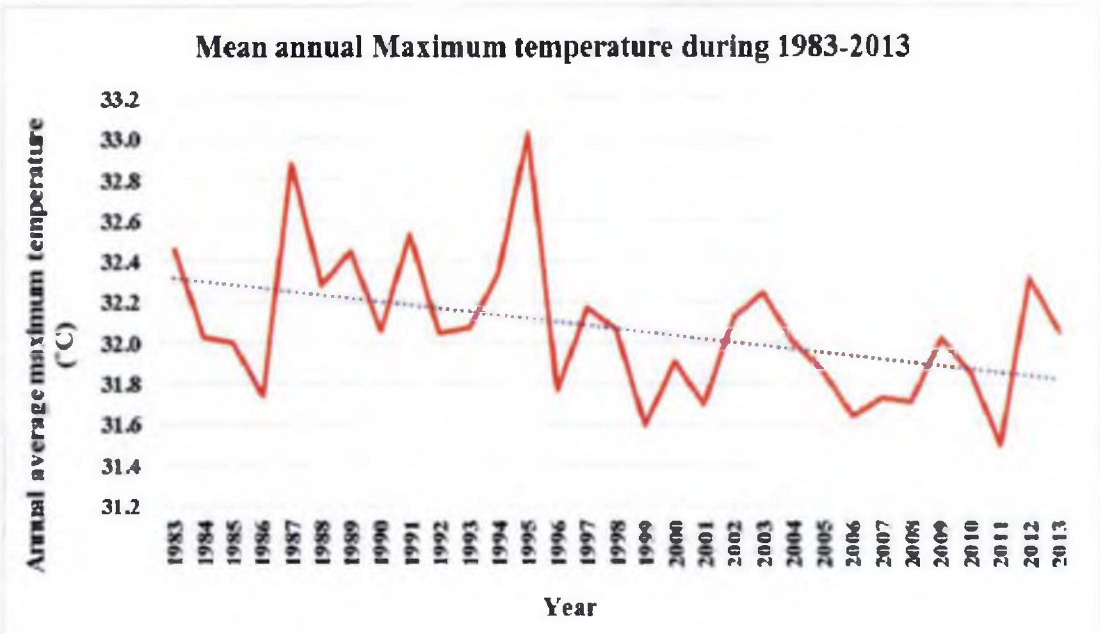

Fig. 5.2. Mean annual maximum temperature during 1983-2013 for Kurumali river basin

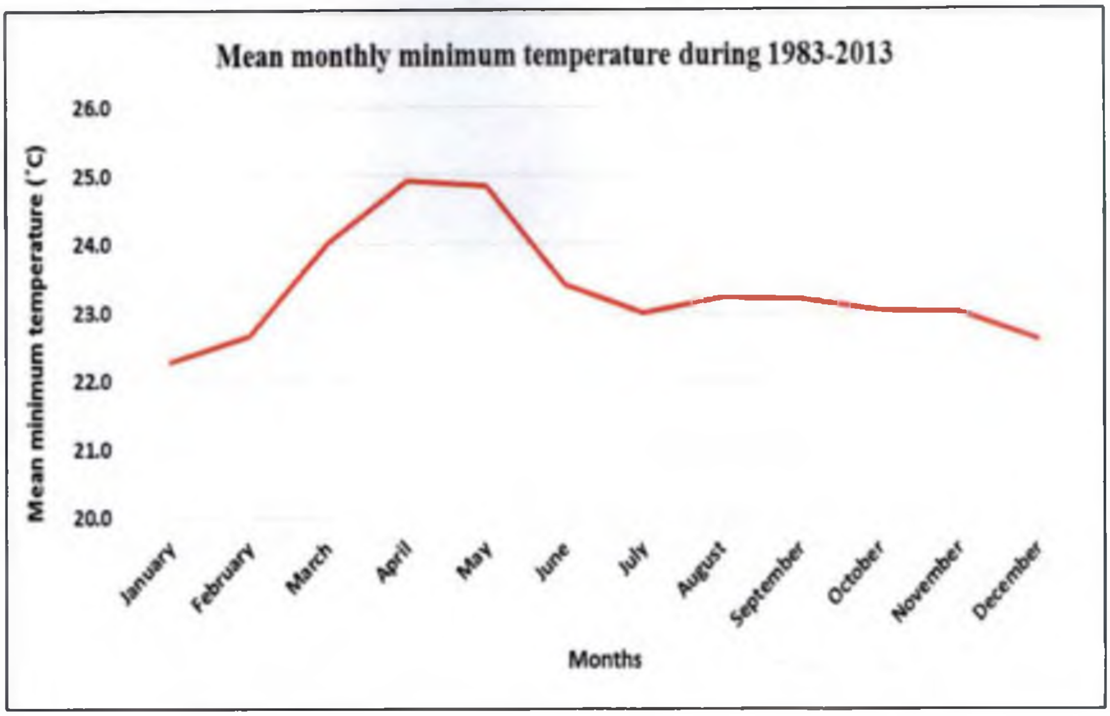

Fig. 6.1. Mean monthly minimum temperature during 1983-2013 for Kurumali river basin

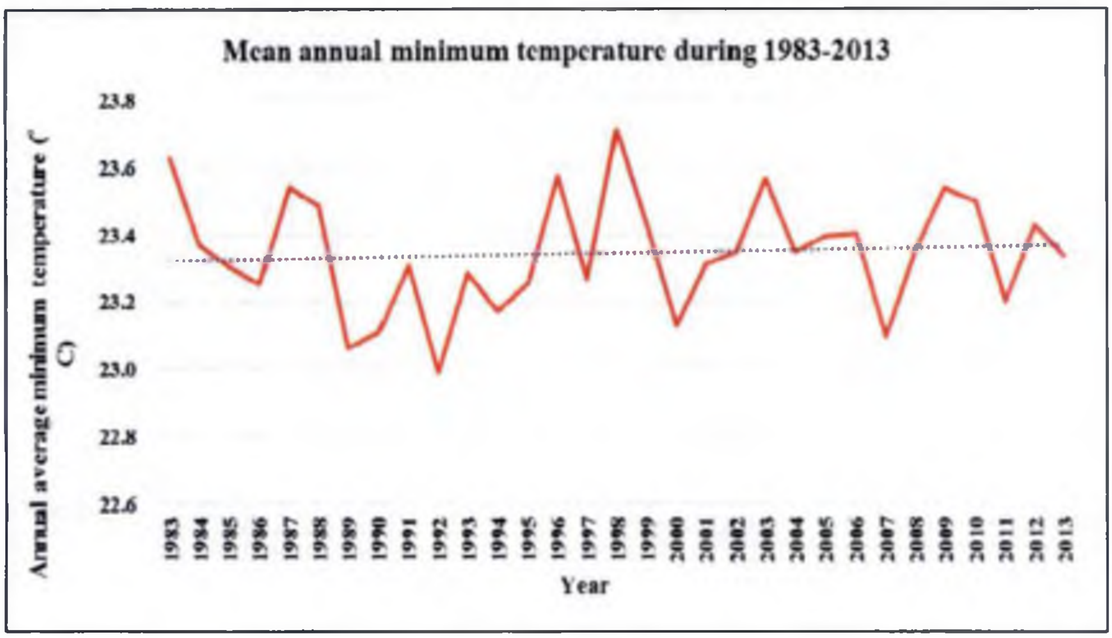

Fig. 6.2. Mean annual minimum temperature during 1983-2013 for Kurumali river basin

4.2.3 Evaporation

Evaporation is one of the major parameter of natural hydrologic cycle. It is a function of temperature, relative humidity and wind speed. Evaporation is measured by an equipment called Pan Evaporimeter. Maximum evaporation is observed in January (190.3 mm). Then, it decreases gradually. Minimum evaporation is recorded in July (92.2 mm). Annual average evaporation is showing a decreasing trend. Minimum evaporation is recorded in 2011 (1015.5 mm). Maximum is observed in 1987 (2092.5 mm) and followed by 2004 (1842 mm). Monthly and annual average of evaporation is depicted below (7.1 and 7.2 respectively).

4.2.4 Relative Humidity

Monthly average RH curve increases gradually from January to July and remains the same in August and decreases linearly. Maximum RH is observed in monsoon months especially in July and August (94%). Minimum RH is recorded in winter months (November, December and January). Annual average RH is showing an increasing trend .Maximum annual RH is recorded in 1998 and 2010 (89%). Minimum RH is observed in 2004. Fig. 8.1 and 8.2 depicts the monthly and annual average of RH.

4.2.5 Wind Velocity

Maximum wind velocity is observed during winter months (November, December and January). The effect of Mundakan wind (peculiar wind-blown only in Thrissur, Palghat districts) may enhance the wind strength during these season. Lowest wind velocity is recorded in October (3.1 km/h). During South West monsoon periods winds are generally from south west direction with an average velocity of 3.5 km/h. During North East monsoon season, wind strength is comparatively low. Figure 9.1 and 9.2 shows the graphical representations of monthly and annual average of wind velocity.

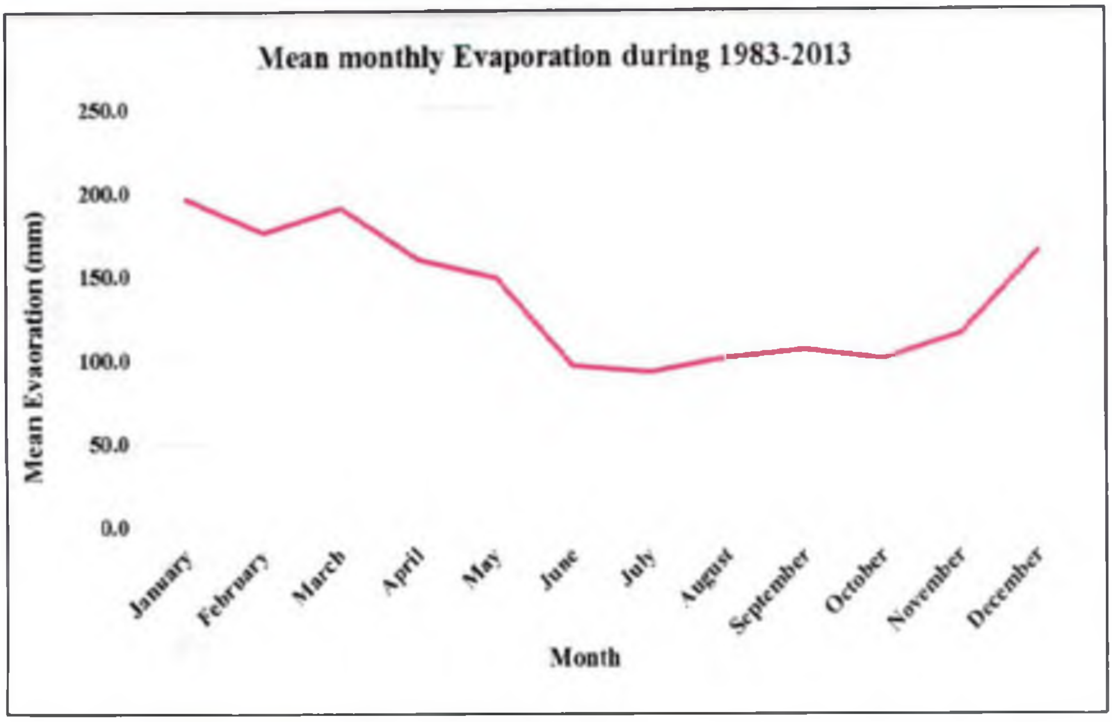

Fig. 7.1. Mean monthly evaporation during 1983-2013 for Kurumali river basin

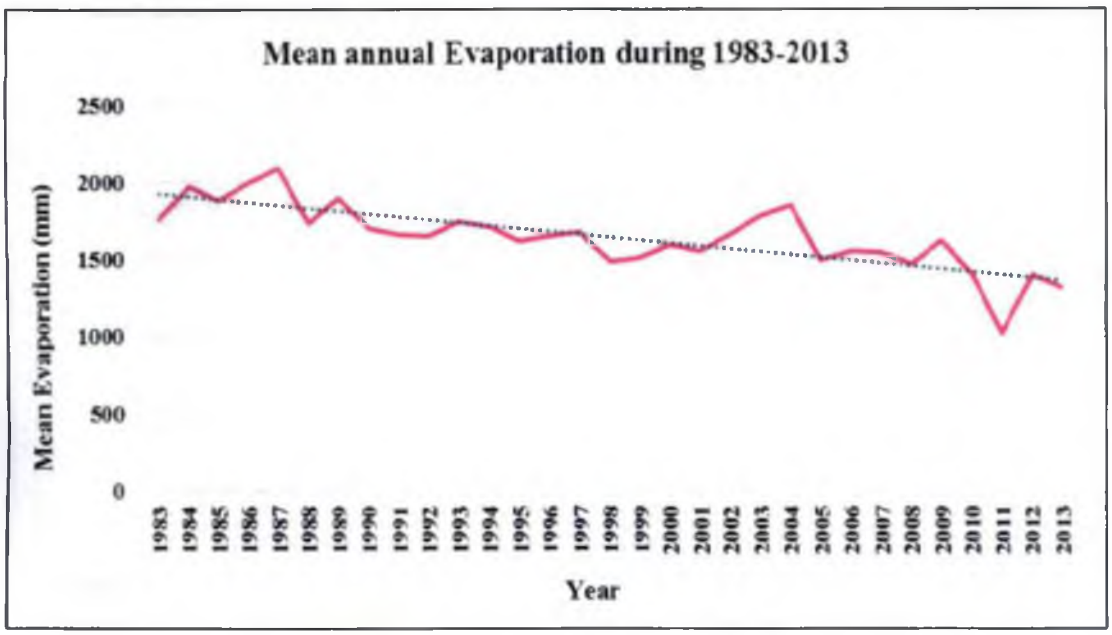

Fig. 7.2. Mean annual evaporation during 1983-2013 for Kurumali river basin

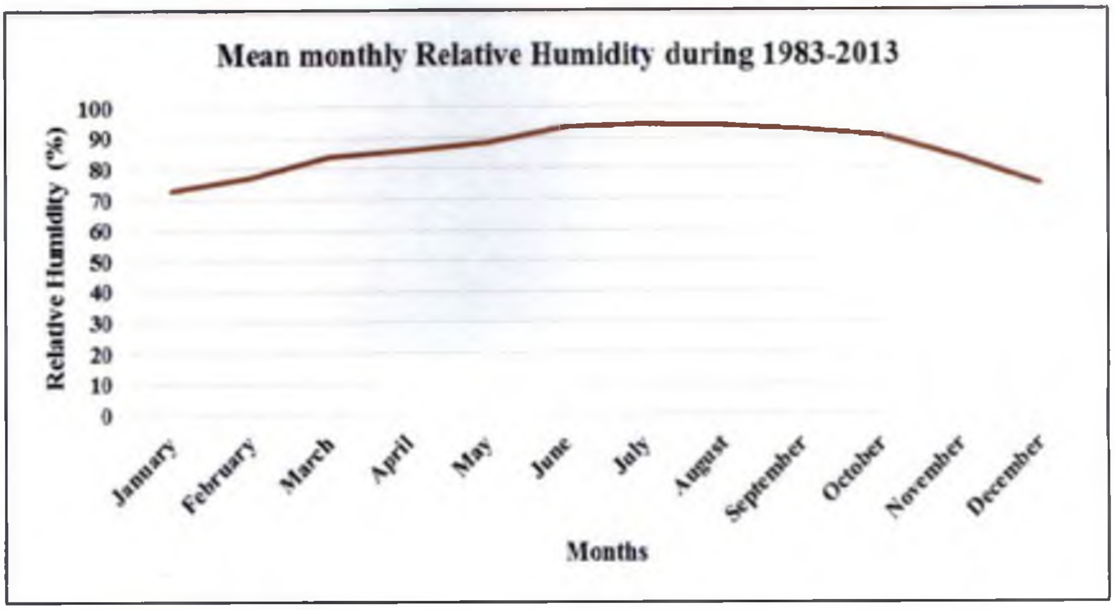

Fig. 8.1. Mean monthly relative humidity during 1983-2013 for Kurumali river basin

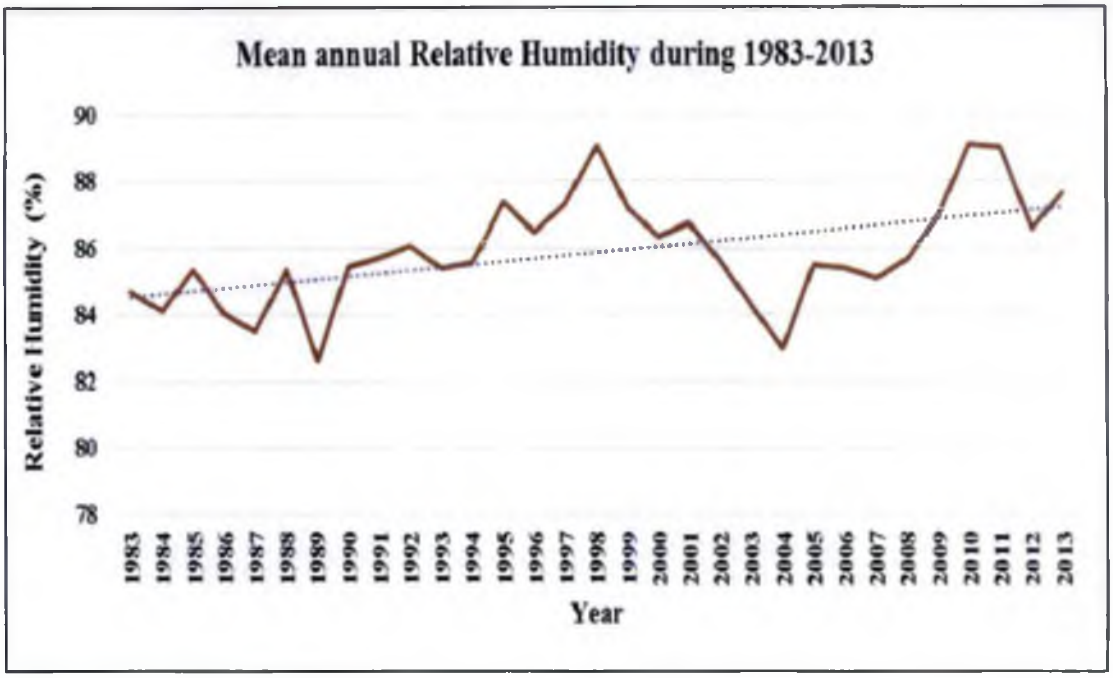

Fig. 8.2 Mean annual relative humidity during 1983-2013 for Kurumali river basin

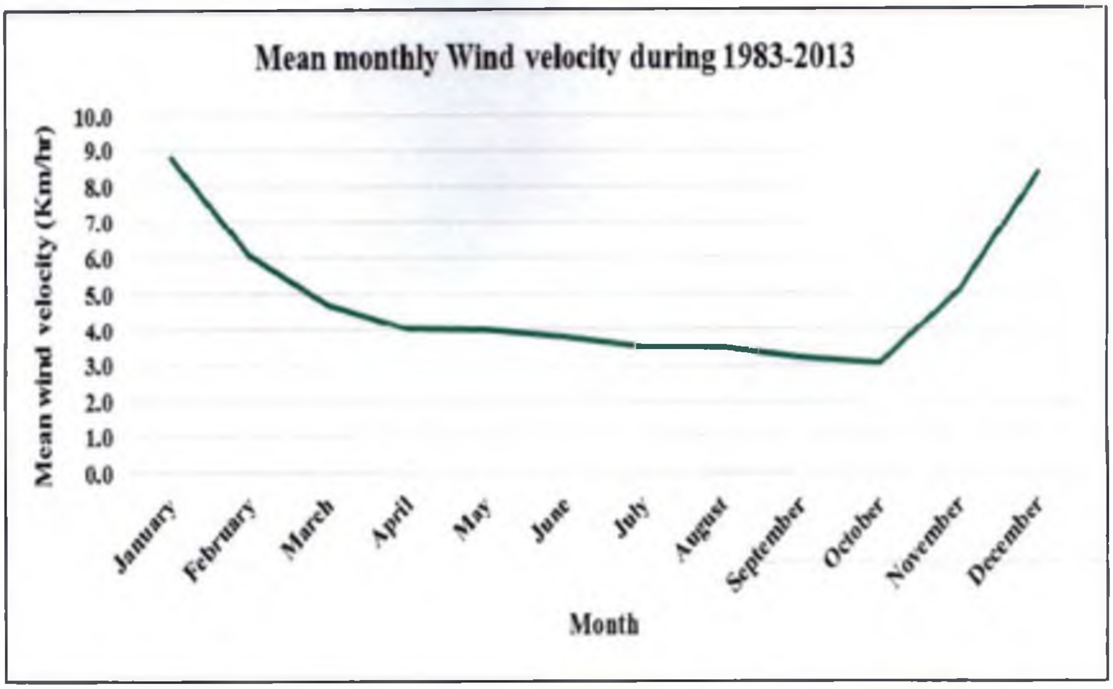

Fig. 9.1. Mean monthly wind velocity during 1983-2013 for Kurumali river basin

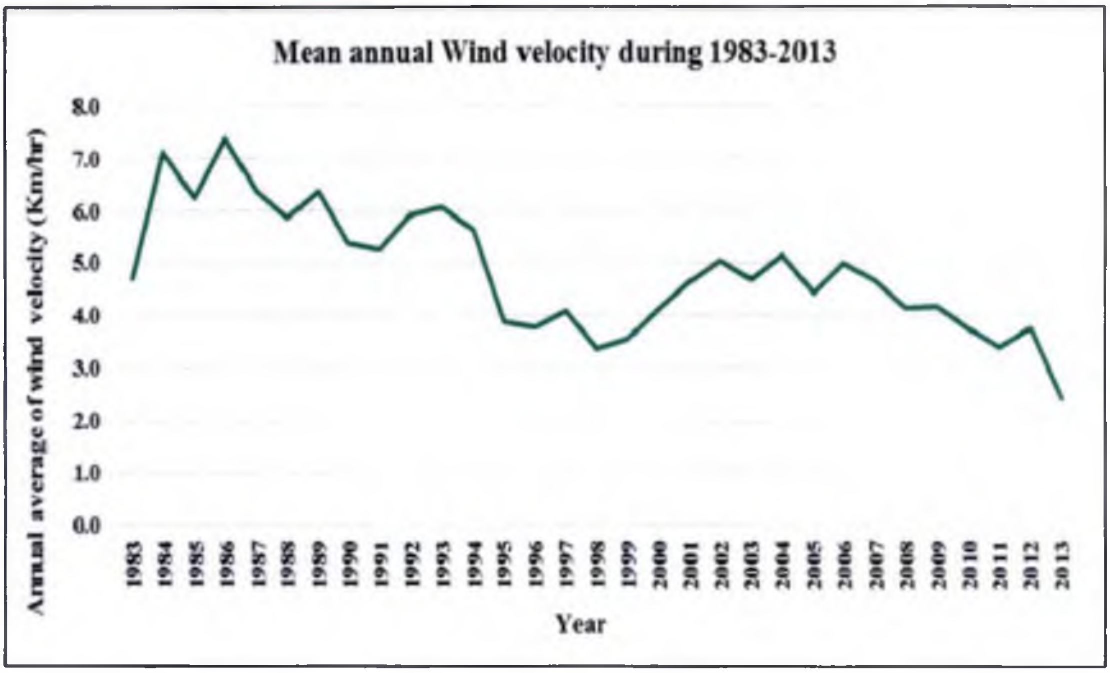

Fig. 9.2. Mean annual wind velocity during 1983-2013 for Kurumali river basin

4.3 PHYSIOGRAPHIC FEATURES OF THE WATERSHED

Kurumali River is located at latitude 10°15' N to 10°40'N and longitude of 76° 00' E to 76°35'E in Thrissur district of Kerala State. Major river flow and their tributaries are combined to form a drainage network. The drainage network map has prepared using ArcGIS 10.2.2 software. It is given below as figure 10. Watershed delineation has been done using Soil and Water Assessment Tool model.

First step of watershed delineation is that the identification of outlet. Because delineation begins from the outlet point. In this study, watershed outlet is identified at 10° 24'4'' N and 76°16'56'' E. Delineation is done using the SRTM DEM data which is having 30m resolution. All the input map layers are provided with the Datum and Projection of WGS_1984 AND UTM_ Zone 43 respectively. Delineated watershed with its sub basins is depicted below in figure 12. Threshold area selected for the stream line generation is 1000 ha. Twenty Five sub watersheds have been identified and delineated in the main watershed. Maximum length and width are calculated as 32.35 km and 20.37 km with a length width ratio as 32:20. Total area of the watershed is estimated as 422.57 km^2.

4.4 TOPOGRAPHIC CHARACTERISTICS OF WATERSHED

As per the figure 12, elevation of the watershed ranges from 2 to 1149m. A hypsometric curve is obtained (figure.13) as one of the SWAT output which shows the area elevation details of the watershed. A hypsometric curve is showing the relationship between area and elevation for a particular terrain. 'X' axis of such graph represents elevation (m) and 'Y' axis represents area in percentage above that elevation. Topographical details of 25 sub watersheds generated by SWAT is given in table 8. It includes mean elevation, standard deviation of elevation and area of each watershed. Sub watershed number 24 is having maximum area (52.21 km^2) followed by sub watershed 13 (41.19 km^2) and sub watershed 16 (38.12 km^2). Least area is observed in sub watershed 6 (0.14 km^2).

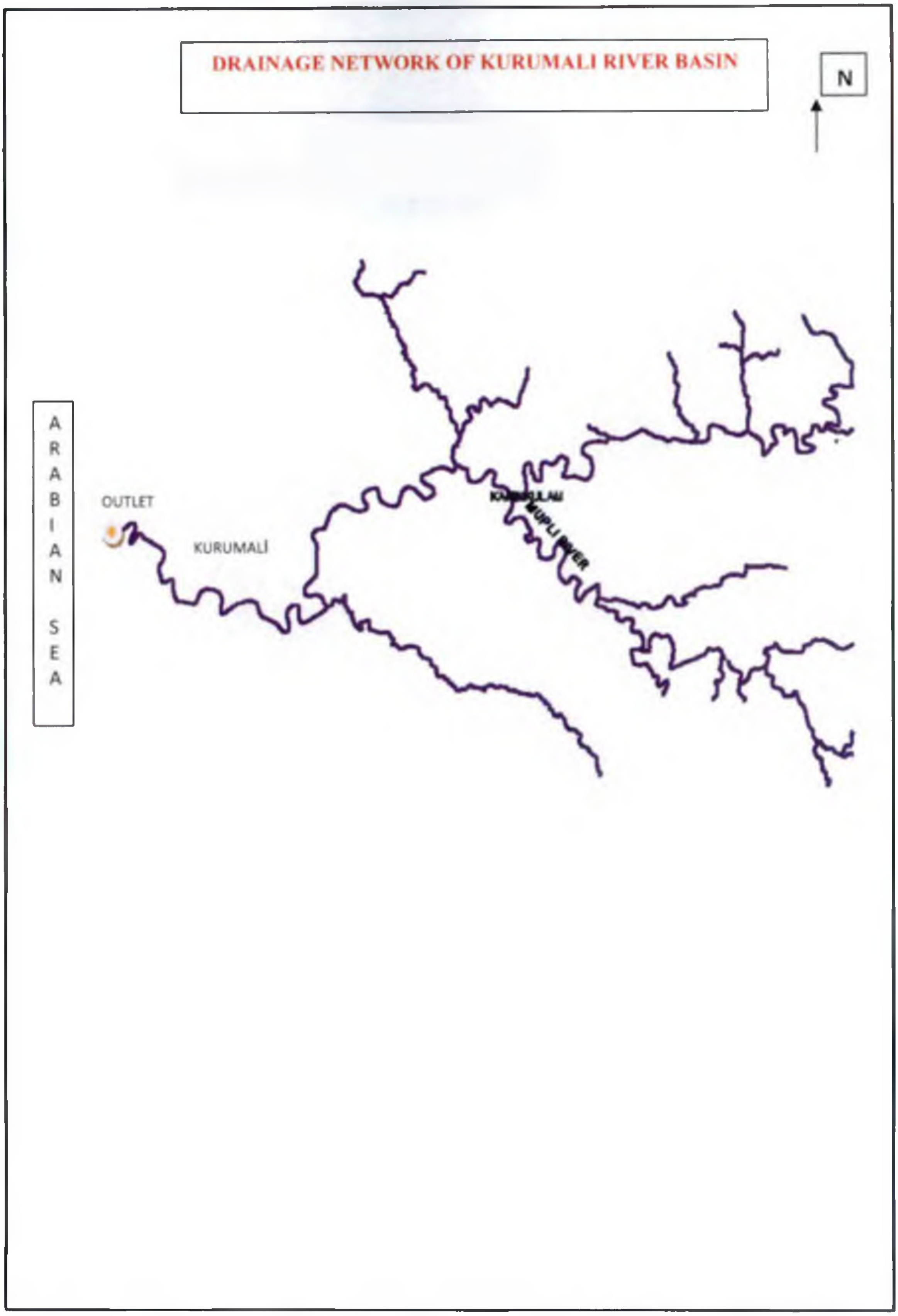

Fig. 10. Drainage network map prepared using ArcGIS 10.2.2

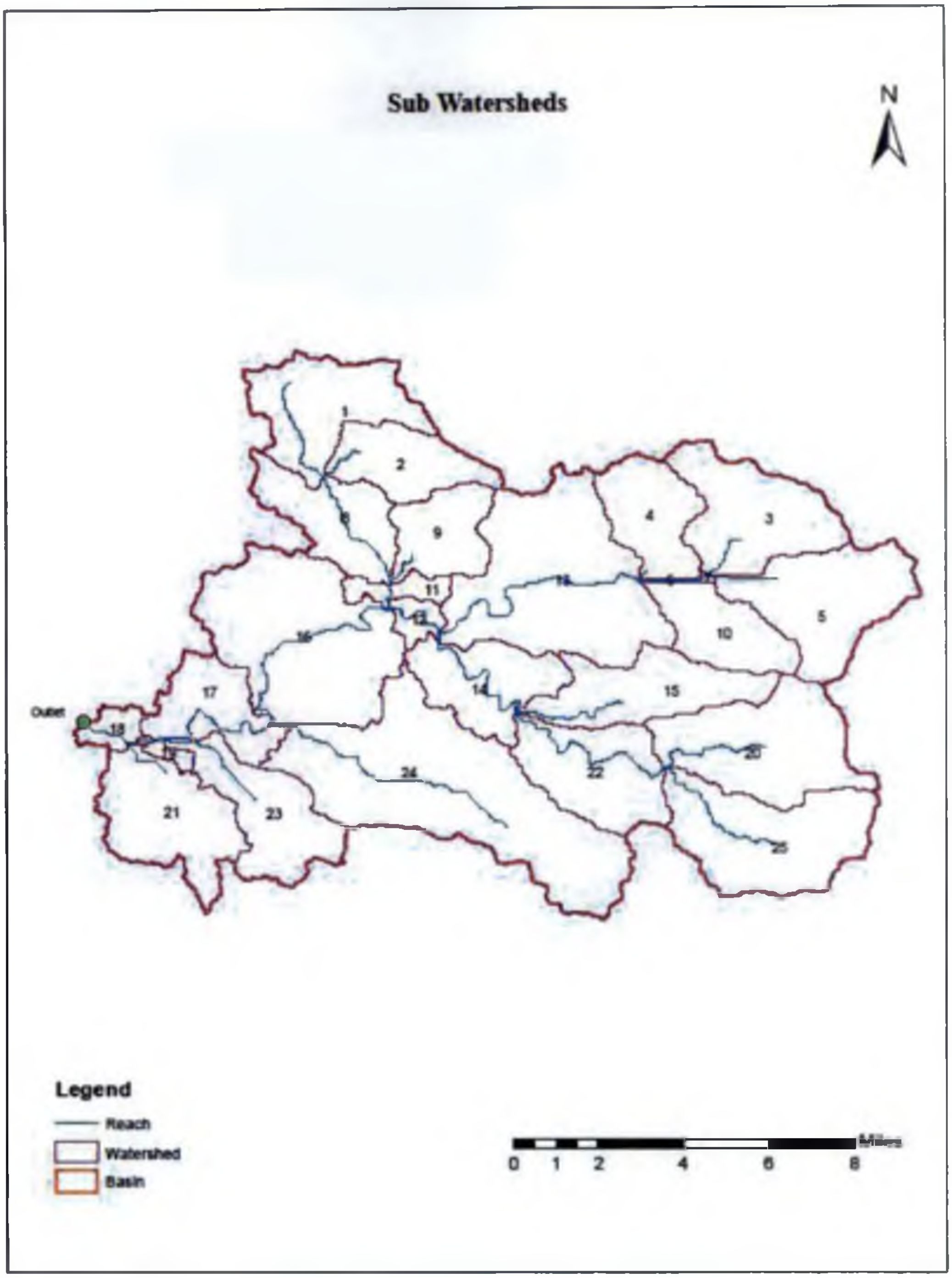

Fig. 11 Delineated Watershed

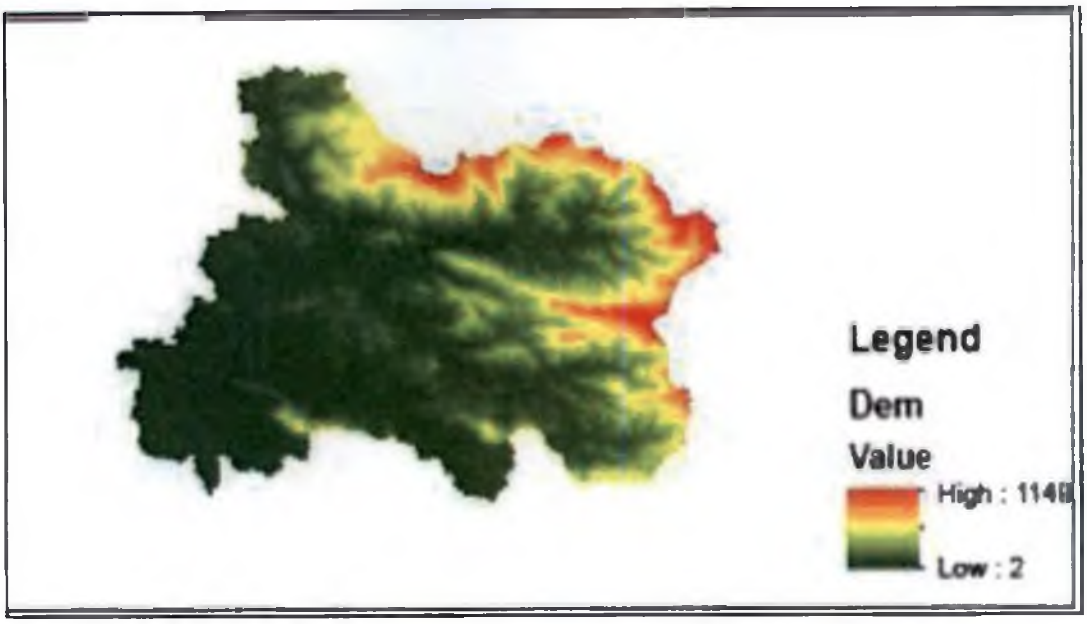

Fig. 12 Digital Elevation Model for Kurumali River basin

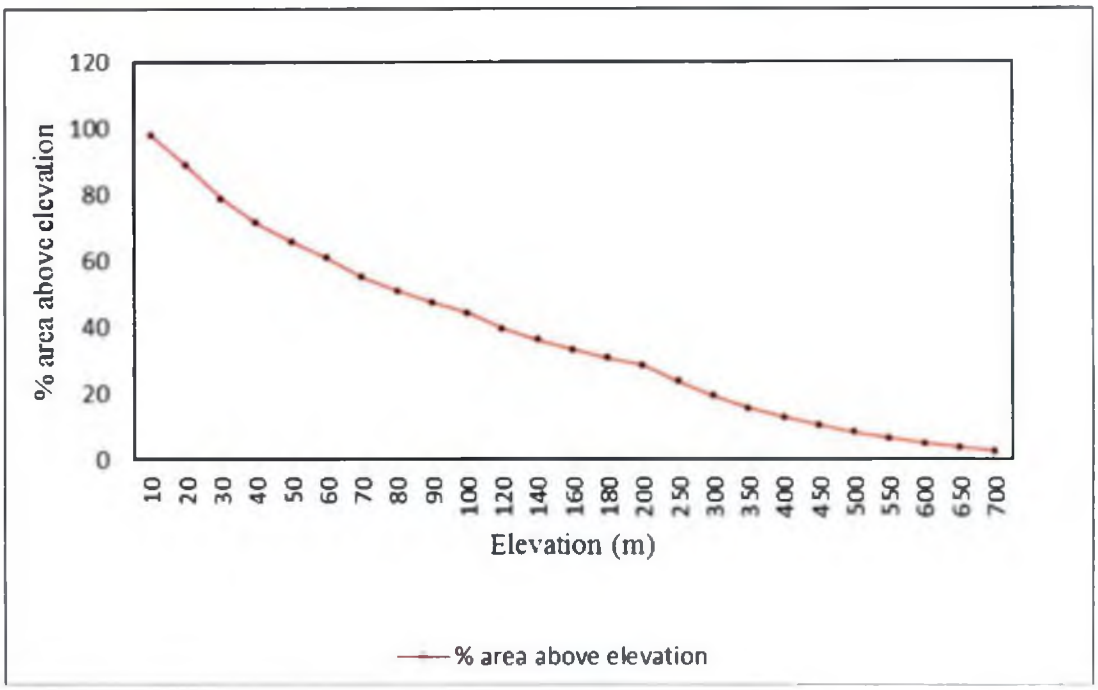

Fig.13 Hypsometric curve of Kurumali River basin generated by SWAT

Table 8. Topographic details of sub watersheds generated by SWAT model

Sub watershed No.	Mean Elevation (m)	Standard Deviation of Elevation	Area (km^2)
1	123.94	95.56	19.34
2	355.46	158.19	12.74
3	101.3	16.24	0.23
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

4.5 SOIL TYPES

Soil map was digitized for this study (fig.14) and the area is tabulated fo different soil types (Table 9). As per Soil Plant Air Water (SPAW) model outpu (Table 10) there are eight soil series that falls in this specific study area. Soil serie types are named as Ayyanthole, Mulayam, Maraickal, Vellappaya, Koottala Vaniampara, Painkulam and Kulamavu. They are mainly sandy or clayey soils. Sil content is very much low in such soil types.

Table 9. 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	174.13	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

Majority of area is coming under Koottala soil series (174.13 km^2) which is around 41.45 per cent of the total watershed area. It is followed by Vaniampara series (94.84 km^2). Least area is covered by Maraickal series (3.83 km^2, 0.91per cent).

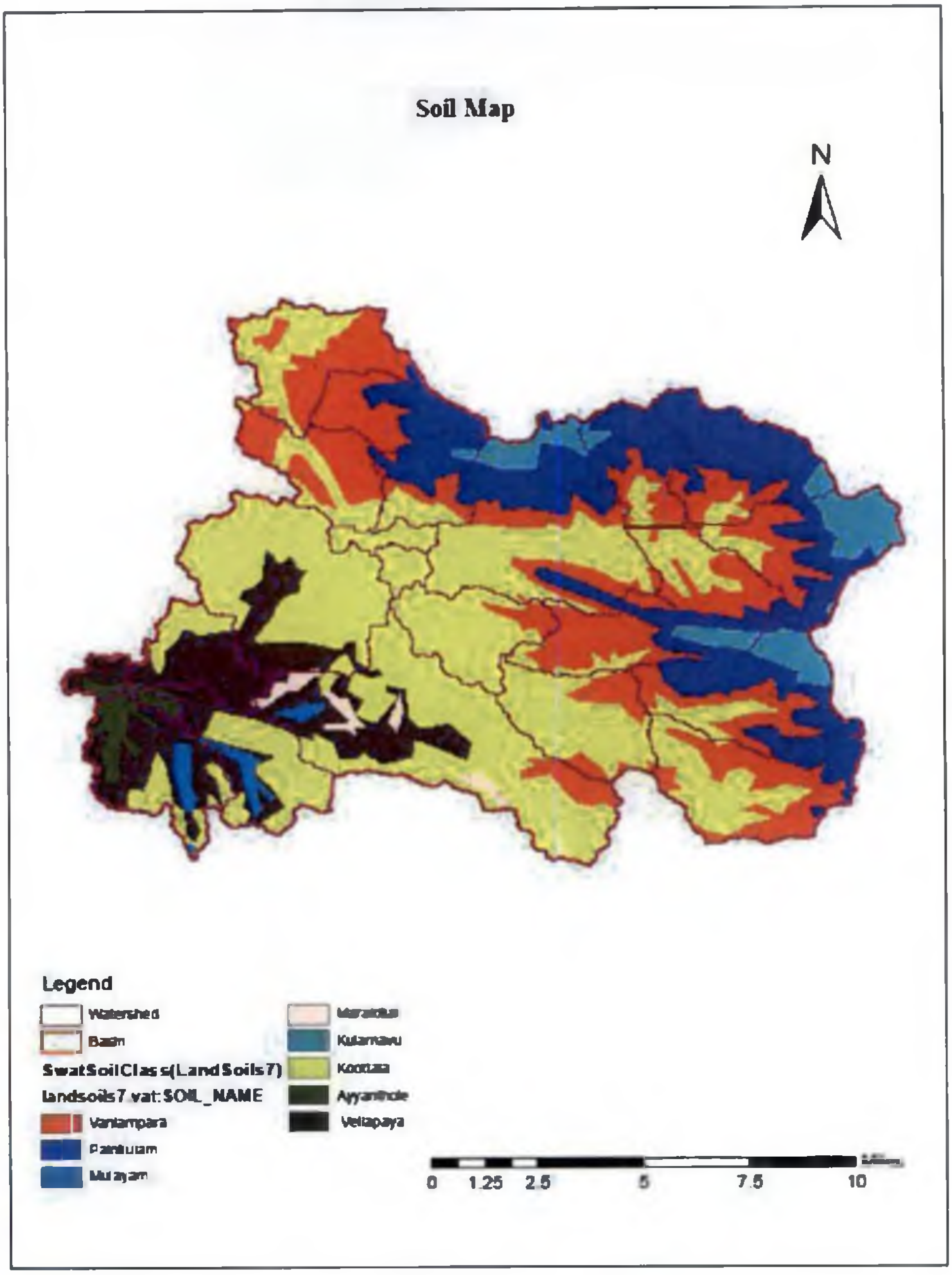

Fig. 14. Soil map of Kurumali sub basin generated by SWAT model

Table 10. Physical properties of soil generated by SPAW model

Soil Code	Soil Series	O.M (per cent)	Rock Weight (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

Most of these soil types are containing considerable quantity of sand and clay as the major constituent. Organic matter rich soil is Painkulam soil (7.26 per cent) with bulk density of 1.27 g/cm^3. It is followed by Kulamavu (4.52 per cent) and Vaniampara soil (4.27 per cent). Mulayam soil has least quantity of organic matter (0.50 per cent). Vaniampara soil has considerable quantity of rocky materials (41.03 per cent). Maximum bulk density is observed in Mulayam soil type (1.55 g/cm^3). Bulk density is least in Vaniampara soil. Available Water Content (AWC) is maximum in Ayyanthole, Vellapaya and Koottala soil series (0.12 mm/mm). Vaniampara soil has very least AWC value (0.06 mm/mm).

4.6 LAND USE/ LAND COVER

LISS III data is downloaded from USGS earth explorer archive. Satellite imagery is processed using the supervised classification and generated land use/ land cover map of the watershed (fig 15). Table 11 describes the identified land use classes in the area. There are five classes such as mixed crop, rice, rubber, forest and water bodies.

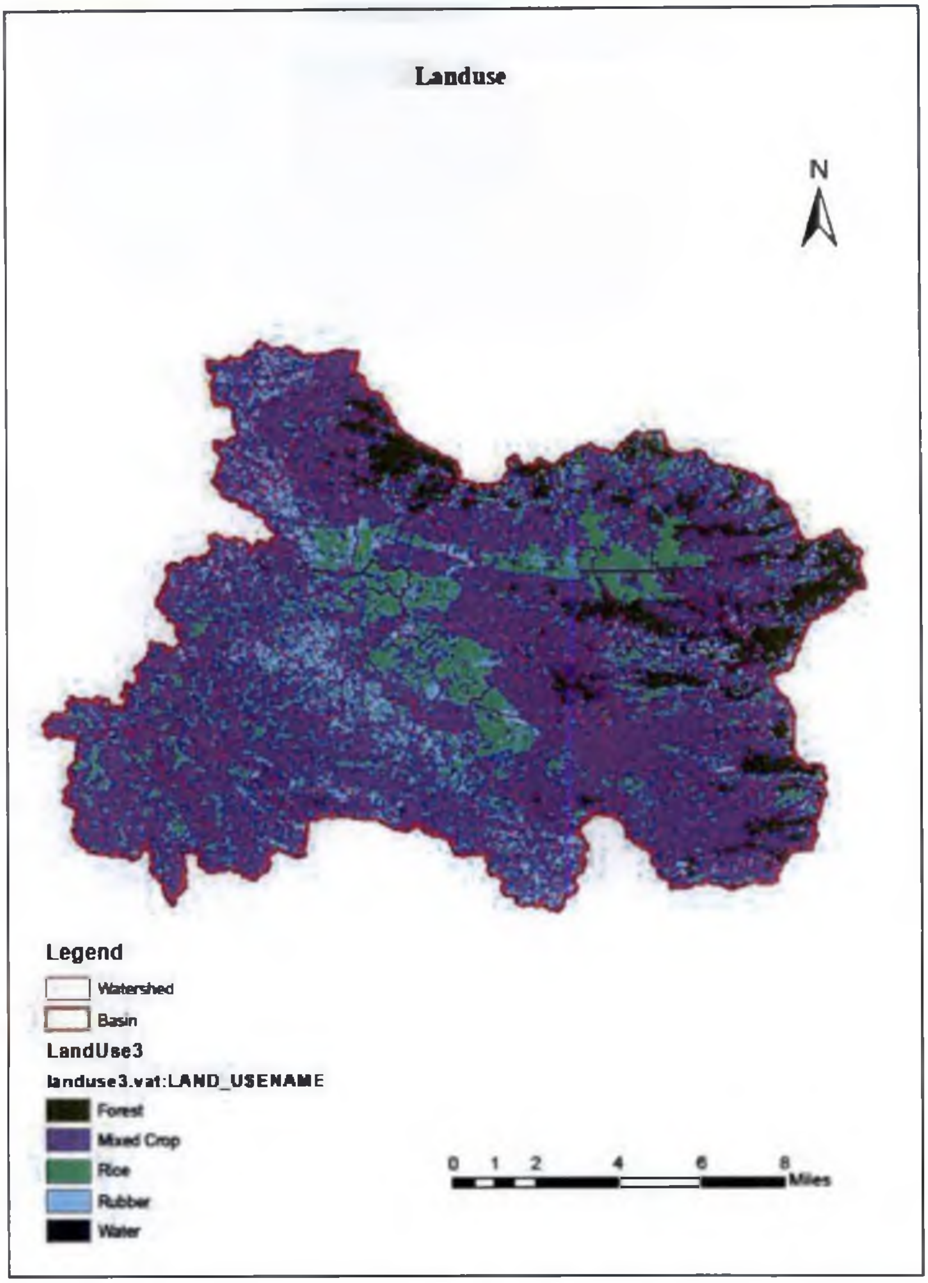

Fig.15 Land use map of Kurumali River basin generated by SWAT model

Table 11. Land use pattern and distributions generated by SWAT model

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

Table 12. Land slope distribution generated by SWAT model

SLOPE		
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

About 64.52 per cent area of total watershed is covered by mixed crop cultivation. It accounts 272.64 km^2 area. Since clay content is high in these location, rice cultivation accounts for 71.82 km^2 area. It is nearly 17 per cent of total area. Approximately 10.28 per cent area (43.44 km^2) is forest land. Rubber is the next class. It is nearly 8.19 per cent. Smallest area is water body. It uses only 0.01 per cent (0.06 km^2) area.

4.7 SLOPE MAP

Slope is one of the major factor determining river flow and consequent land use pattern. Slope map for entire Kurumali watershed is constructed in ArcSWAT (figure 16) and the details are given in table 12. The area has been classified into three slope classes for the division of Hydrological Response Units (HRUs). 0-5 slope class occupies an area of 62.13 km^2 (14.70 per cent). 5-10 class consists of 74.96 km^2 (17.74 per cent) and >10 slope class contains largest area 285.47 km^2 (67.56 per cent).

4.8 CHANNEL REACHES

Entire watershed is divided into 25 sub watersheds. Among these, sub watershed number 24 has longest and widest tributary channel (17.50 Km and 13.84 Km respectively). Average slope of this channel is 0.020. It is followed by sub watershed number 13. Length and width of this channel is 14.844 Km and 12.009 Km respectively. Its slope is 0.05. Shortest channel is observed in sub watershed number 6. The length of this tributary is only 2.37 Km and the width is 0.41 Km. Average slope of this tributary channel is 0.008.

This 25 sub watersheds are further divided into 816 Hydrological Response Units (HRUs). These are the representative of hydrological processes. So, water balance study is based on these HRU analysis. Details of these HRU units are given in table 14.

Forest land is present in HRU numbers 53,100,193,326 and 383. Rice cultivation is done in HRUs 201, 204, 211, 212, 328 and 341. Rest of the HRUs consists of mixed cropping.

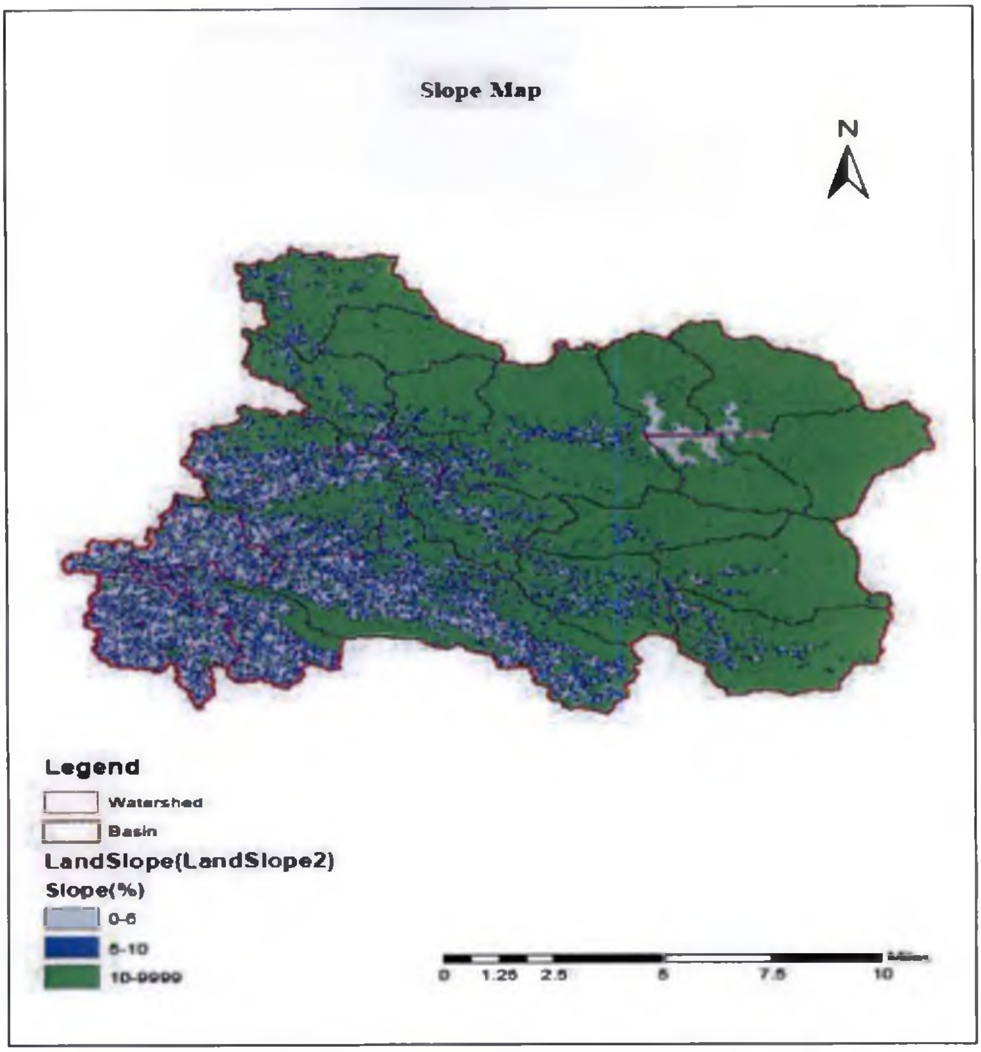

Fig. 16 Slope map generated by SWAT for Kurumali river basin

Table 13. 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 14. Physical properties of HRUs generated by SWAT model

Sub basin No.	HRU No.	Land use	Soil	Slope	Area (ha)	Per cent watershed Area	Per cent sub area
1	24	Mixed crop	Vaniaampara	>10	679.03	1.61	34.10
	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	4.18	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 crop	Vellapaya	5-10	280.28	0.66	22.02
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

4.9 OBSERVED RIVER FLOWS

Water Resources Department of Kerala has a river flow gauging station at Kurumali. Mean monthly discharge at the gauging station is shown graphically in figure 17. It depicts that, river flow is available only during rainy months. June to September is considered as South West monsoon months and October to November receives rainfall through North East monsoon. Influence of ground water is negligible in the summer months. It shows that, the surface water and ground water get discharge very quickly. There is no sufficient time for aquifer recharge or in other words, time lag between rainfall occurrence and recharge is very low.

4.10 MODEL CALIBRATION AND VALIDATION

Calibration is an important step in any physical condition based estimations and measurements. It helps to reduce the uncertainty during the simulation and projections. Comparison of model simulated data with the original observed data is the procedure for calibration technique. In this case, SWAT model is a physical model which is calibrated with 4 years (1996-1999) of observed discharge data collected from Department of Water resources. Validation is the technique used to verify the goodness of calibrated model. Here, two years of data (2000 and 2001) are being used for validation. River discharge simulation using default parameters in SWAT model are shown in figure 18. Corresponding simulation results are graphically represented as figure 19. Calibration and validation plots are given in figure 20 and 21 respectively.

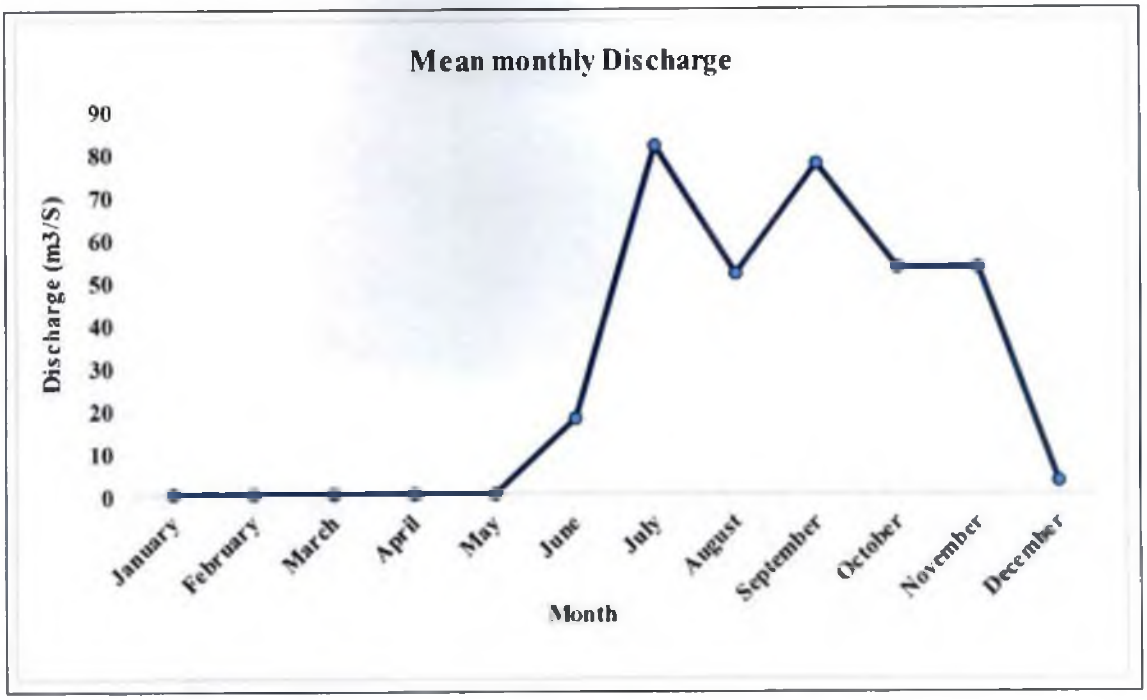

Fig. 17. Mean monthly river flow for Kurumali river basin

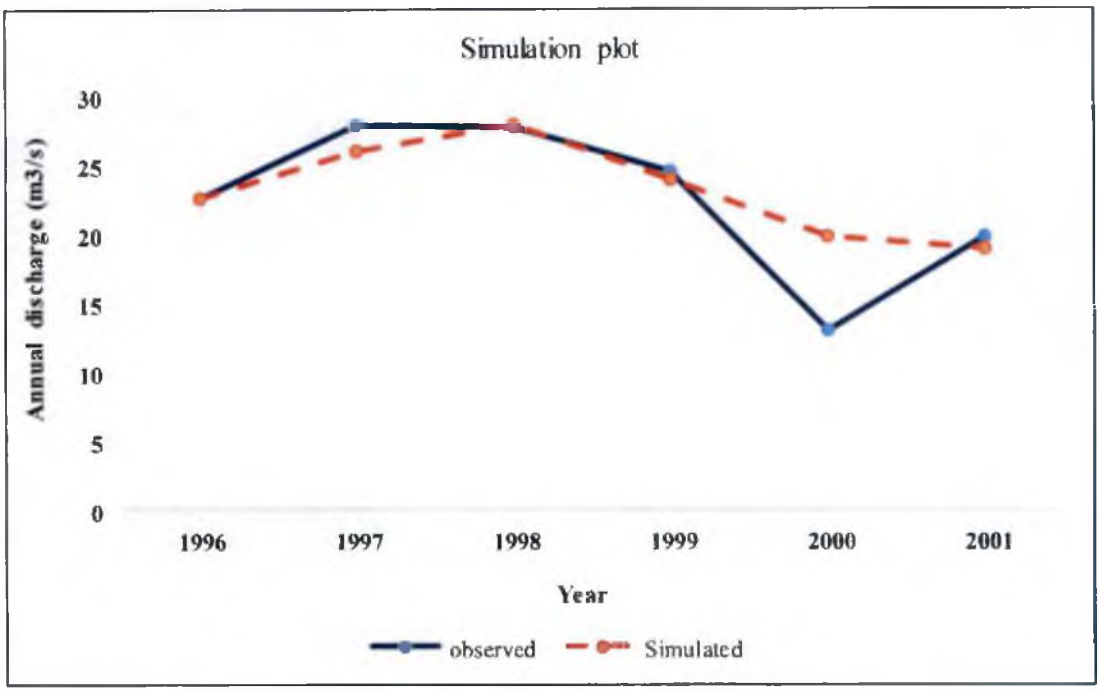

Fig.18 Annual river flow: Observed Vs Simulated

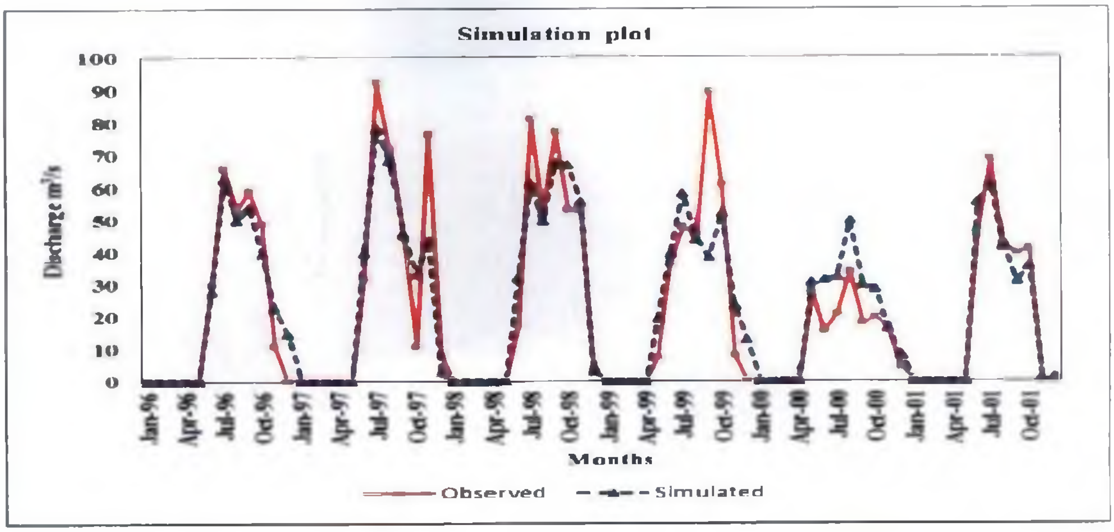

Fig. 19 Monthly river flow- Observed vs Simulated

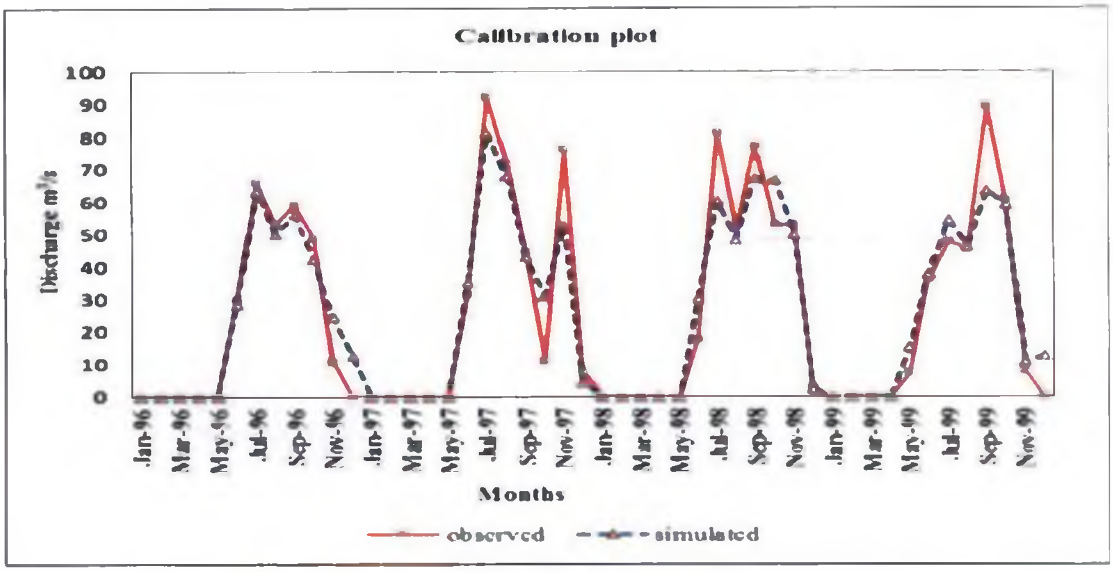

Fig.20 Monthly average river discharge during calibration period

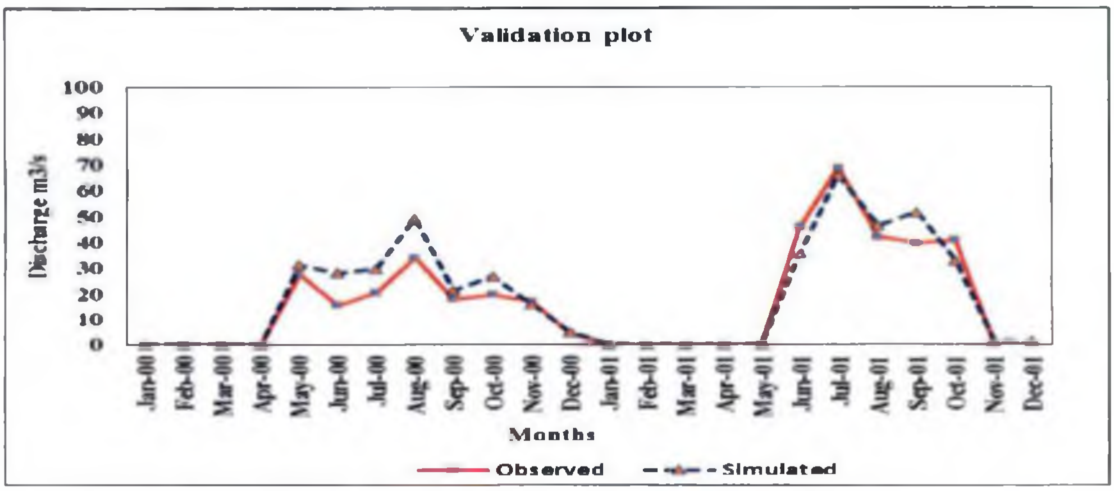

Fig. 21 Monthly average River discharge during Validation Period

Nash Sutcliffe Efficiency (NSE) and Coefficient of Determination (COD) are considered as the best indicators to determine the goodness of the result for this study. According to Sathian (2009), goodness of the prediction accuracy of any physical model is indicated by NSE, R^2 and time series. In this case, NSE and COD values are obtained as 0.88 and 0.96 respectively. Such higher values of NSE and COD explained that, the selected model is good for this study.

4.11 WATER BALANCE OF THE BASIN FOR EXISTING PERIOD

Important water balance components considered for this study are surface runoff (SUR_Q), lateral flow (LAT_Q), groundwater flow (GW_Q) and evapotranspiration (ET). Results are given as figure 22 in percentage of annual rainfall. Analysis shows that, major share of the water balance is contributed by groundwater component GW_Q. It ranges between 63 per cent (1998) to 66 per cent (2001). Groundwater contribution has increased from 1998 to 2001. Surface runoff is estimated in 1998 as 14 per cent. But, it gradually decreases year by year. When we look into 2001, it is reduced by 9 per cent. Share of lateral flow in 1998 was 12 per cent. It remains more or less constant in these 4 years. Evapotranspiration component shows high value in 2000 (15 per cent). Generally it ranges between 11 per cent and 15 per cent. Surface runoff, lateral flow, base flow and evapo-transpiration of the basin were estimated as 306.59mm, 339.23mm, 1649.68mm and 337.46mm respectively. Percentage rainfall contributions with respect to all other watershed components are tabulated in table 15.

Table 15. 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	14	400.52	12	1933.95	63	364.77	11
1999	311.30	11	346.65	13	1732.09	64	343.70	12
2000	208.63	9	277.14	12	1339.50	64	323.34	15
2001	230.59	9	332.59	13	1593.17	66	318.06	12

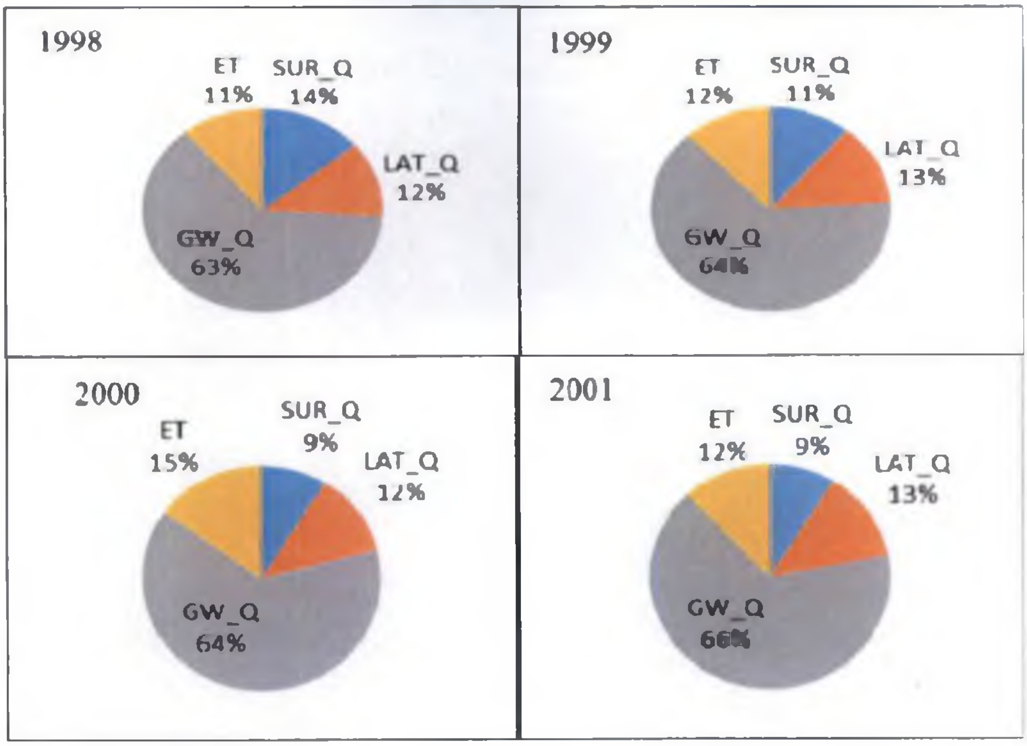

Fig.22 Water balance for Kurumali River basin for the existing conditions

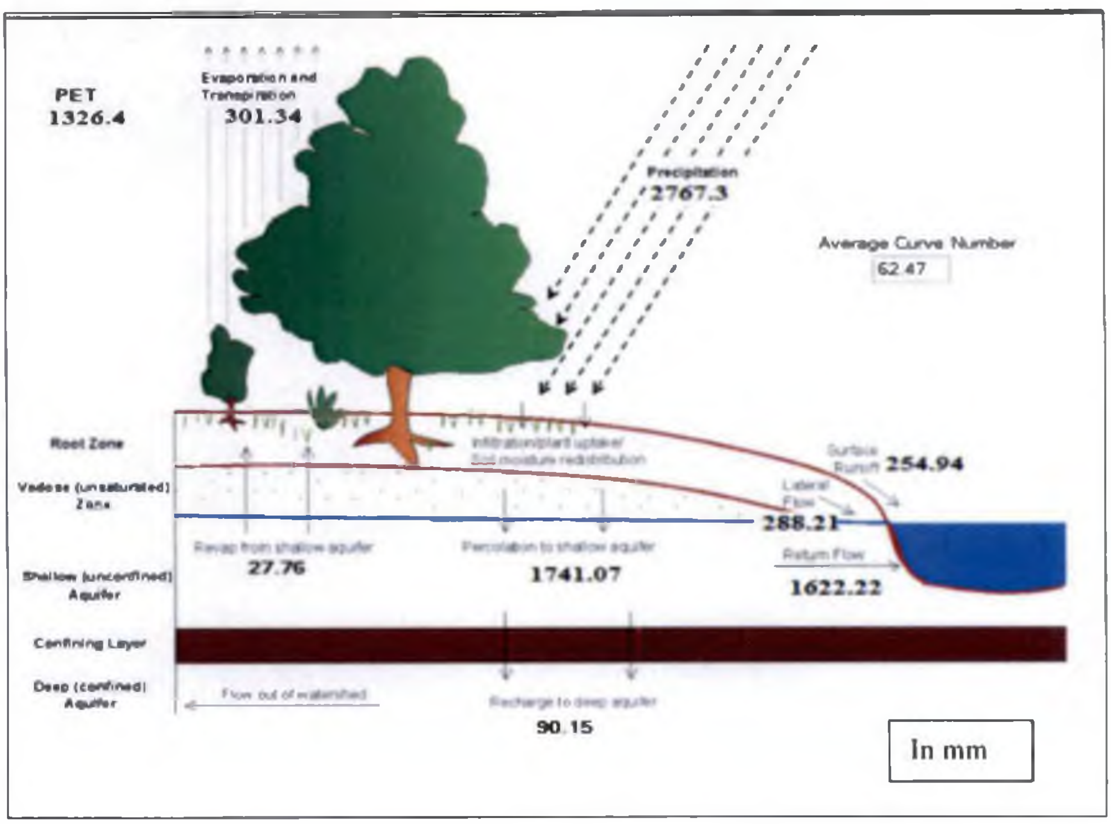

Fig.23 Schematic representation of Hydrologic cycle for the existing period generated by SWAT model

The average annual rainfall during the period 1983-2013 is estimated as 2767.3mm. Different water balance components are estimated using corresponding equations.

4.12 CLIMATE CHANGE

Future climate data is downloaded from MarkSim weather file generator using GFDL-ESM 2M model in four different Representative Concentrated Pathway (RCP) scenarios for the period of 2020 to 2050. Long 30 year average of rainfall is represented as figure 24.1, 24.2, 24.3 and 24.4.

Annual predicted mean rainfall will increase from existing condition in all four RCPs. But the trend is different in each RCPs. In RCP 2.6, a linear trend is observed and it remains constant between 3000mm and 3500mm range. Predicted annual average rainfall is expected to increase in RCP 2.6, 4.5, 6.0 and 8.5 are by 18 per cent, 28 per cent, 17 per cent and 22 per cent respectively. In all the four cases, south west monsoon rainfall is predicted to have a drastic increase. But, north east monsoon will get weaken in this locality. Similar results have been obtained in the Indian monsoon study conducted by Goswami *et al.*, (2006). They have shown a significant increasing trend in SW monsoon magnitude by the end of this century. Rainfall trend analysis studies conducted by Guhathakurtha *et al.* (2011) revealed that monthly shift in the magnitude of rainfall during monsoon. June, July rainfall is showing a decreasing trend in their study.

Predicted annual and monthly discharges are given below as figure 26.1, 26.2, 26.3 and 26.4.

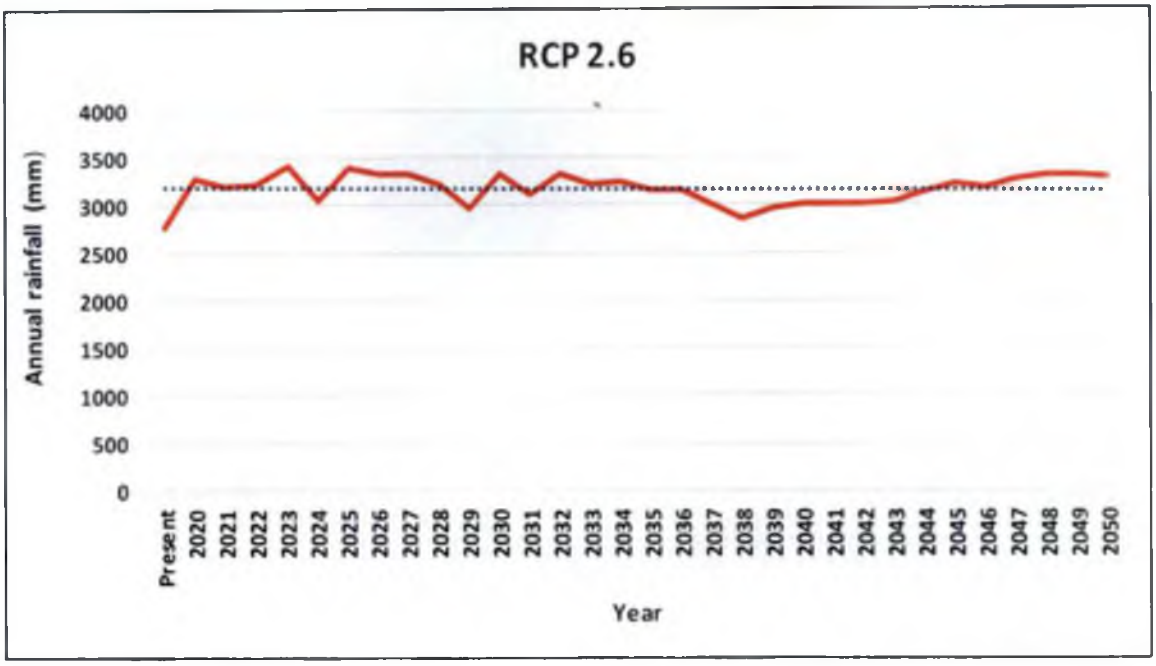

Fig. 24.1. Predicted annual rainfall for Kurumali River basin during 2020-2050 using RCP 2.6

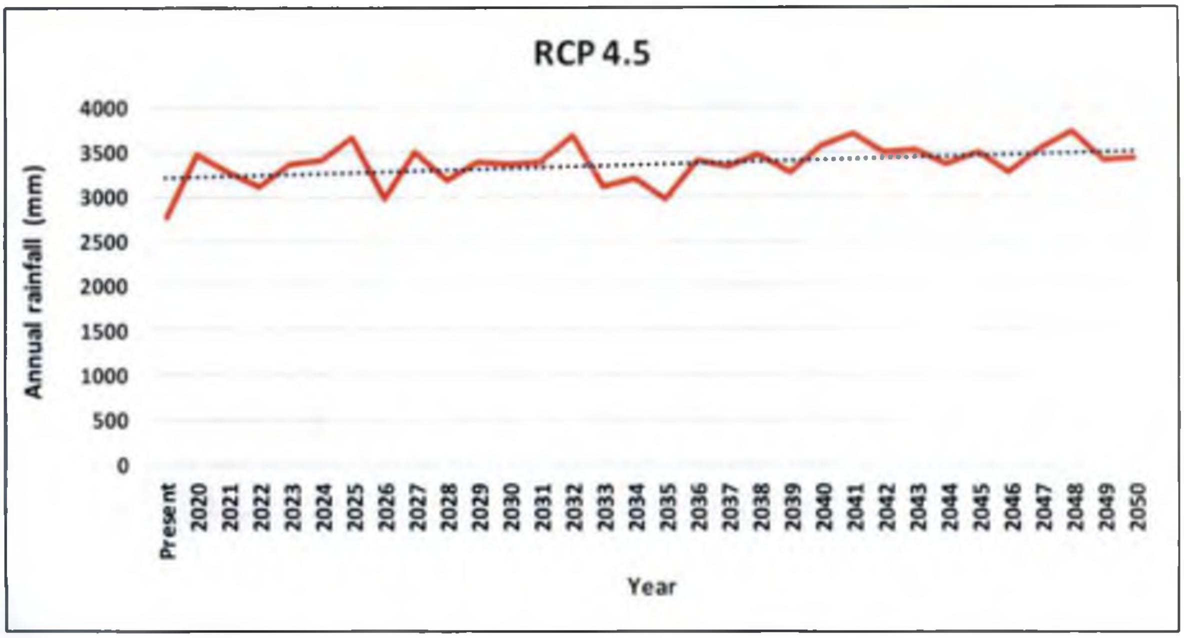

Fig. 24.2. Predicted annual rainfall for Kurumali River basin during 2020-2050 using RCP 4.5

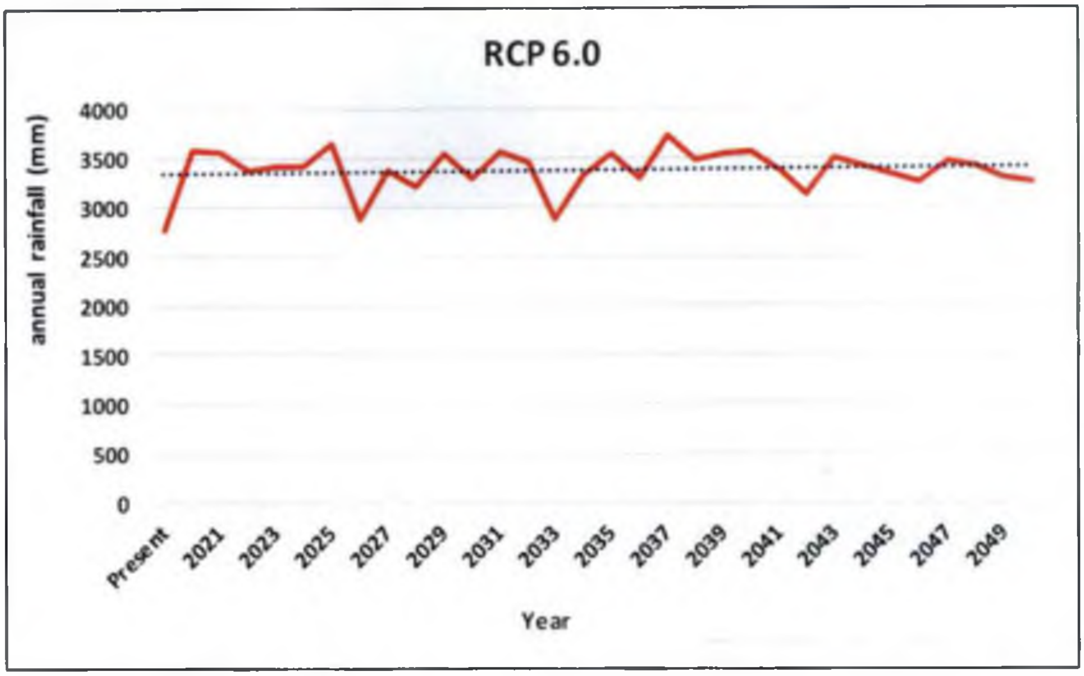

Fig. 24.3. Predicted annual rainfall for Kurumali River basin during 2020-2050 using RCP 6.0

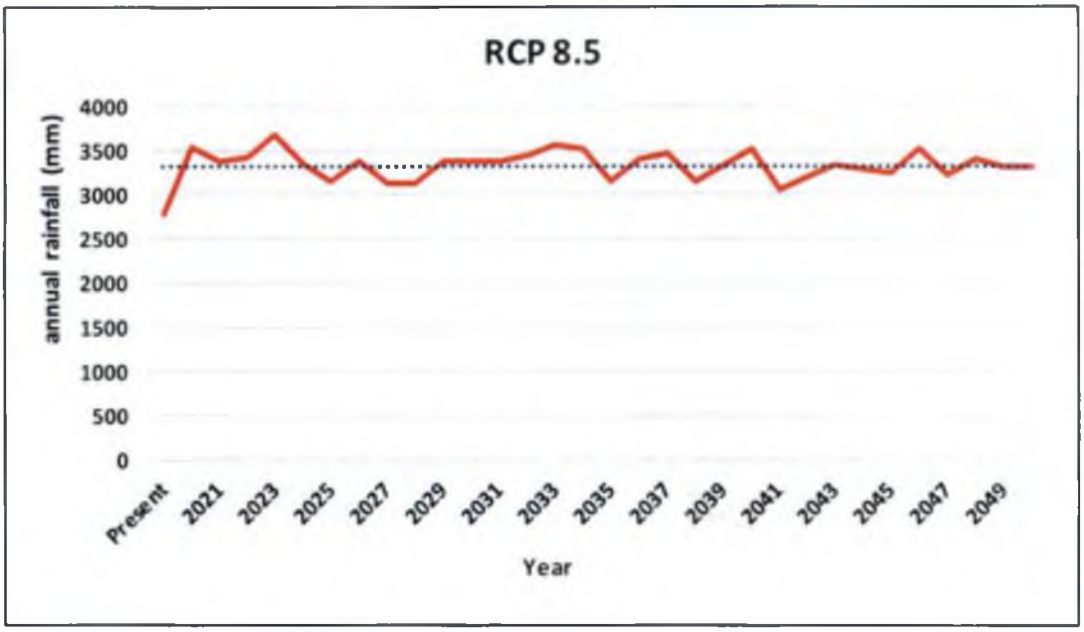

Fig. 24.4. Predicted annual rainfall for Kurumali River basin during 2020-2050 using RCP 8.5

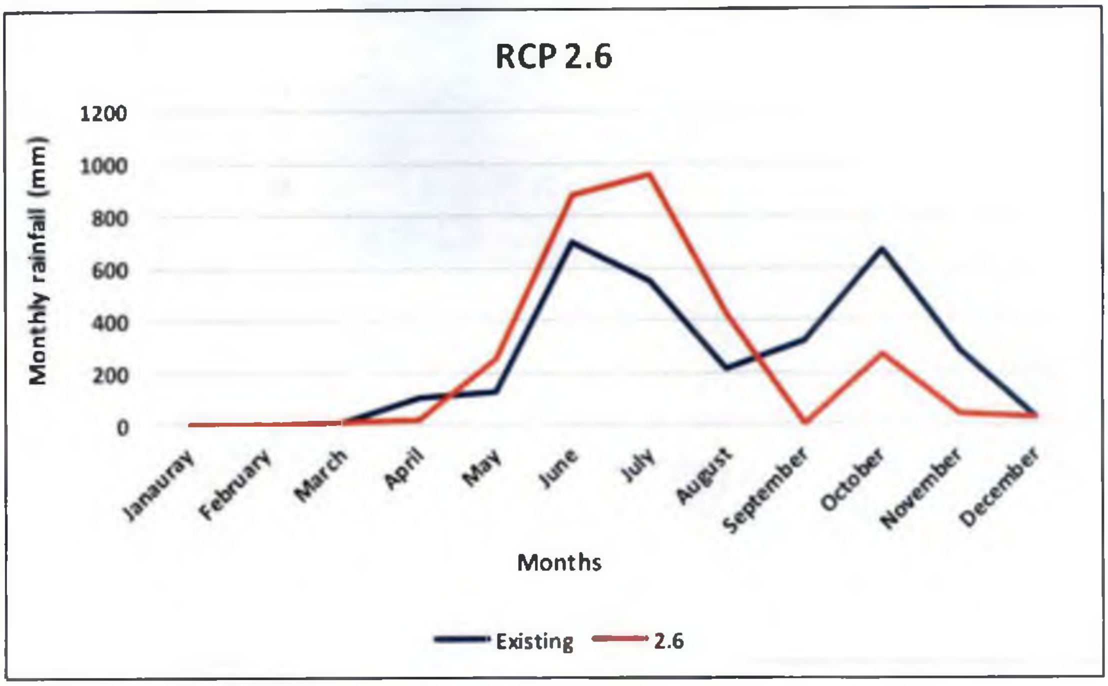

Fig.25.1. Predicted mean monthly rainfall for Kurumali river basin during 2020-2050 using RCP 2.6

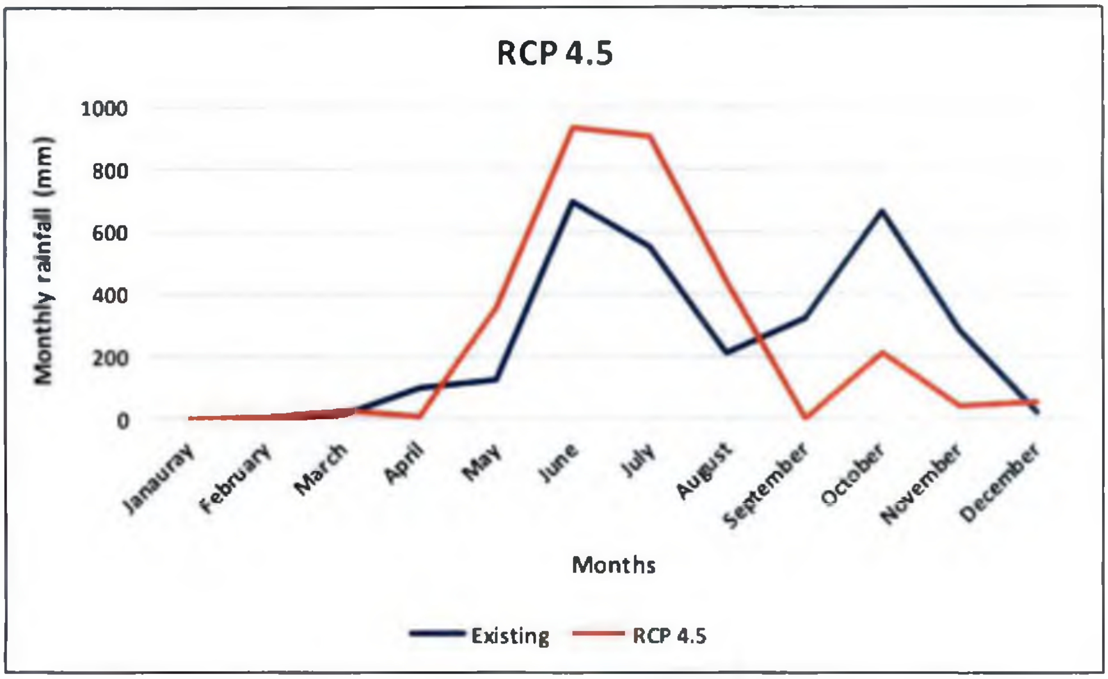

Fig.25.2. Predicted mean monthly rainfall for Kurumali river basin during 2020-2050 using RCP 4.5

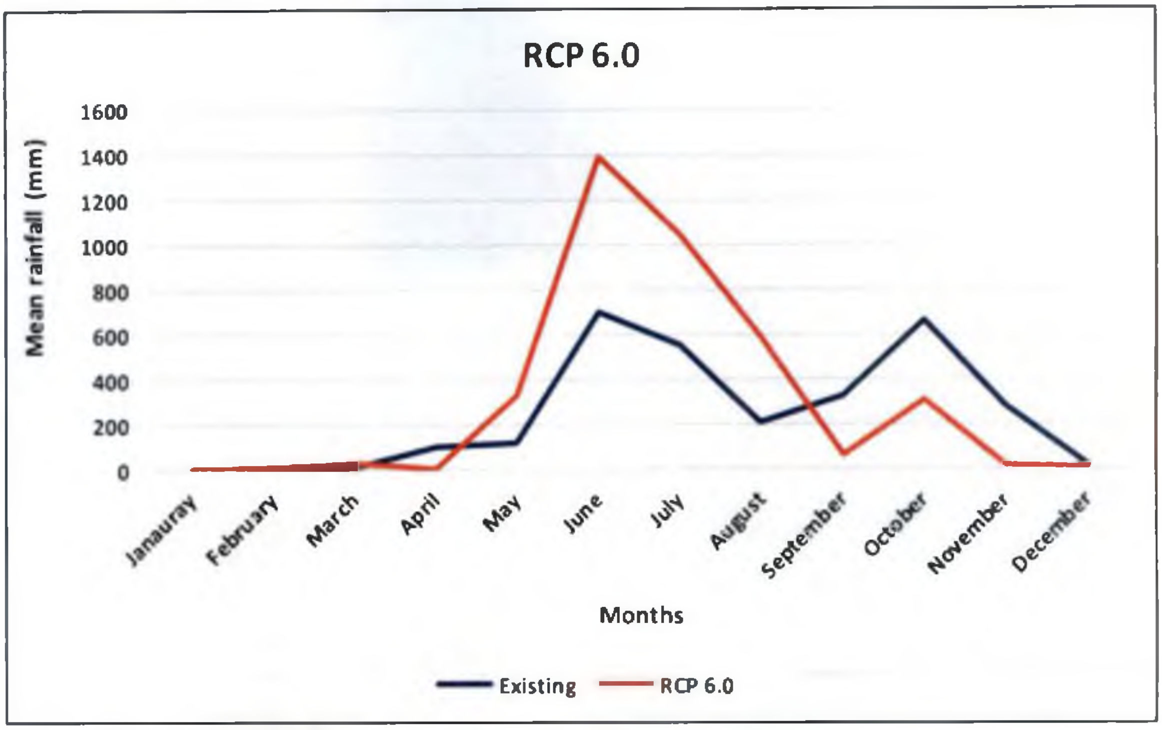

Fig.25.3. Predicted mean monthly rainfall for Kurumali river basin during 2020-2050 using RCP 6.0

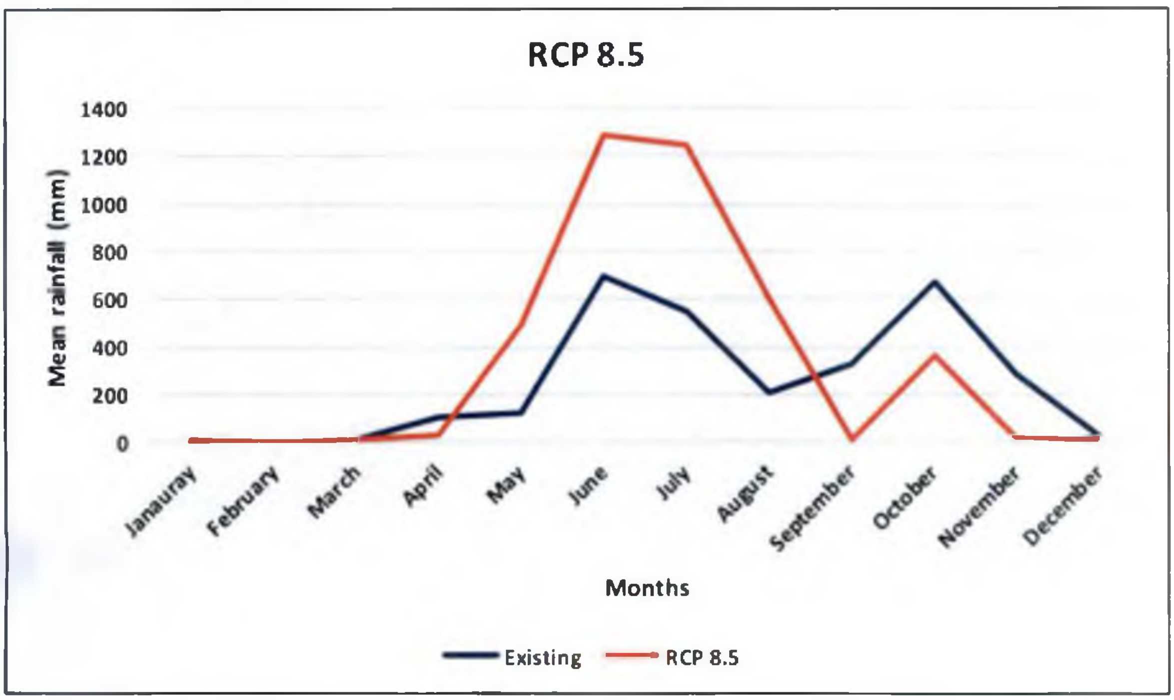

Fig.25.4. Predicted mean monthly rainfall for Kurumali river basin during 2020-2050 using RCP 8.5

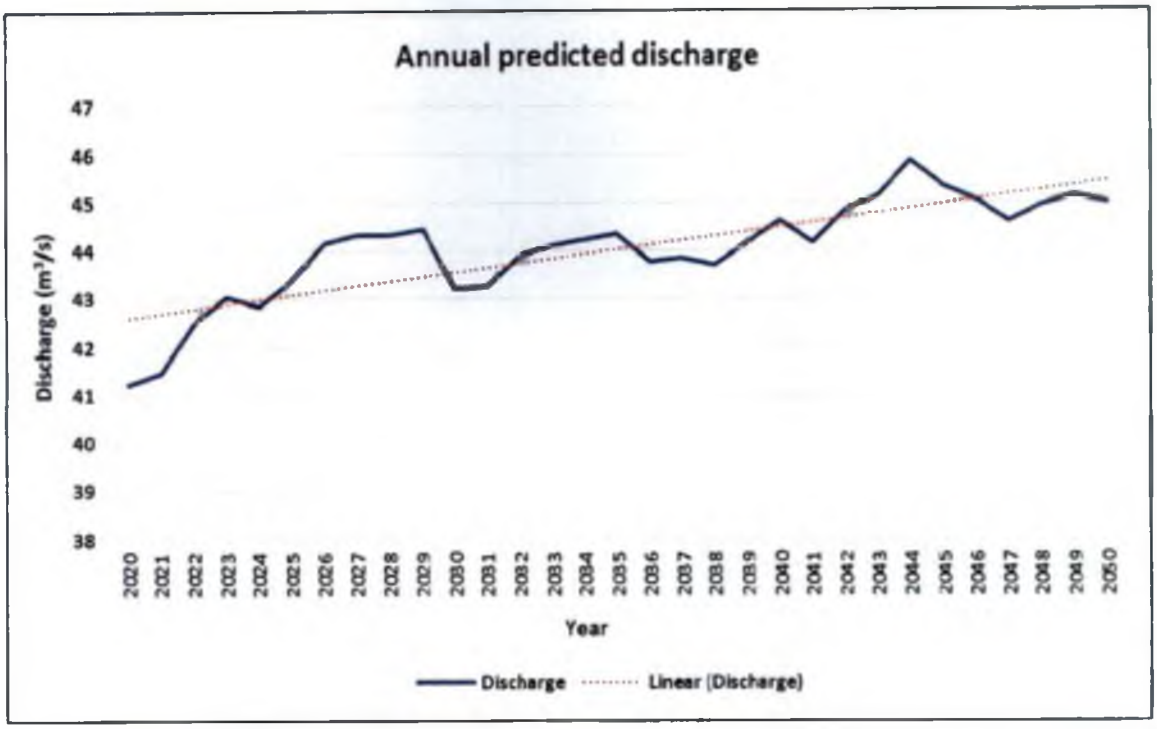

Fig.26.1 Predicted mean annual discharge of Kurumali river basin during 2020 to 2050 –RCP 2.6

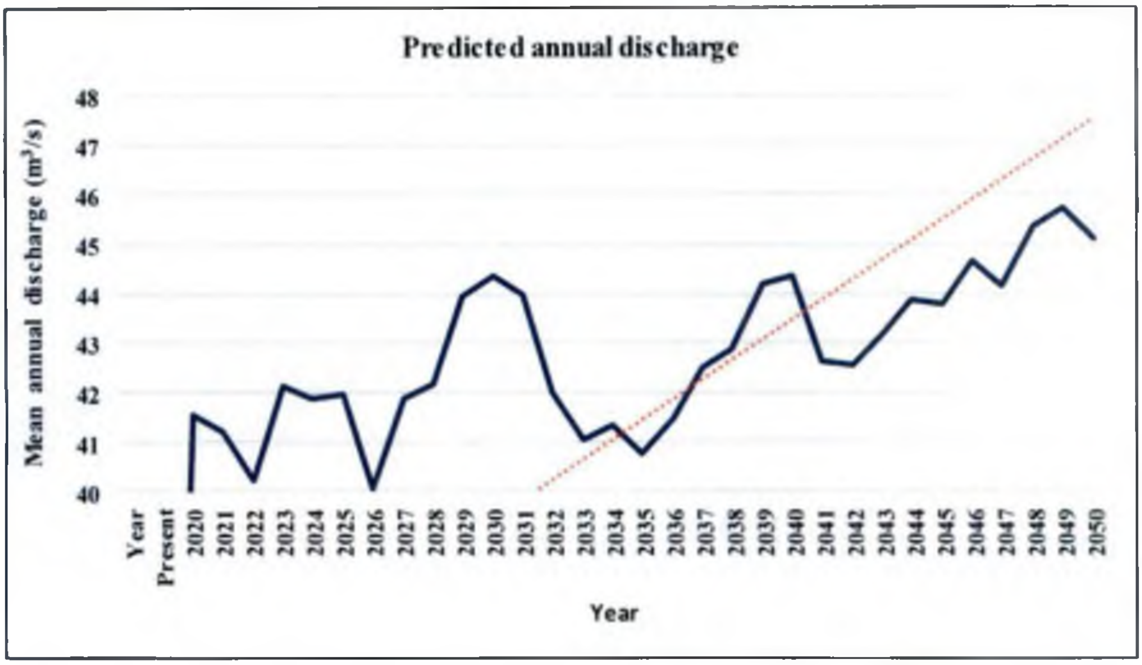

Fig.26.2. Predicted mean annual discharge of Kurumali river basin during 2020 to 2050 –RCP 4.5

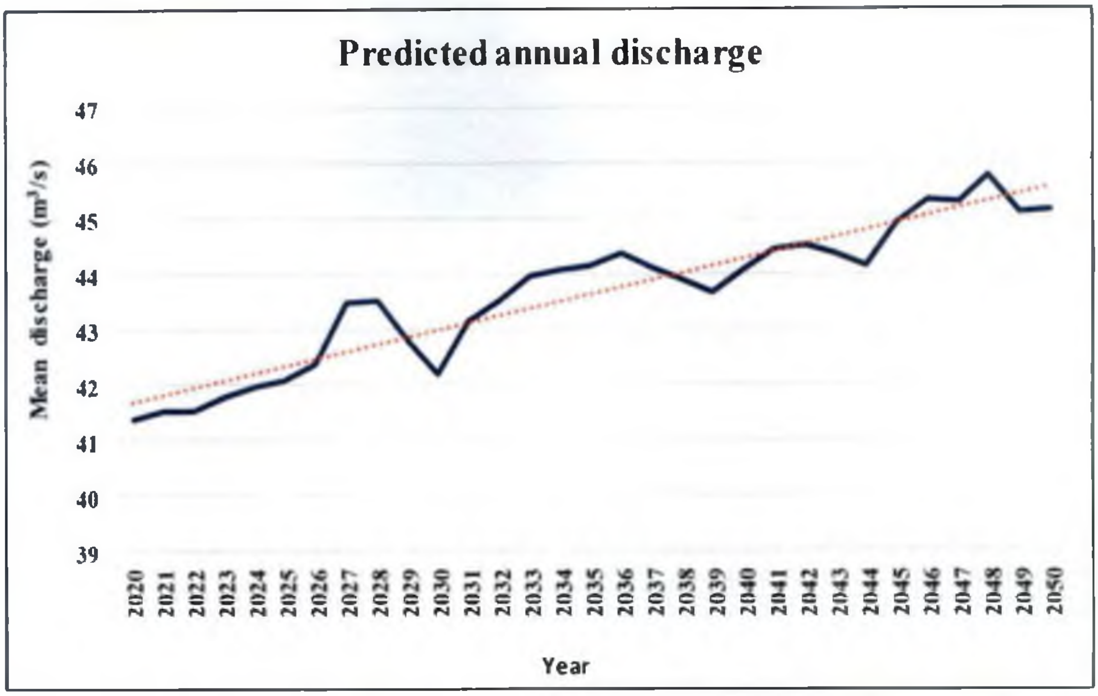

Fig.26.3. Predicted mean annual discharge of Kurumali river basin during 2020 to 2050 –RCP 6.0

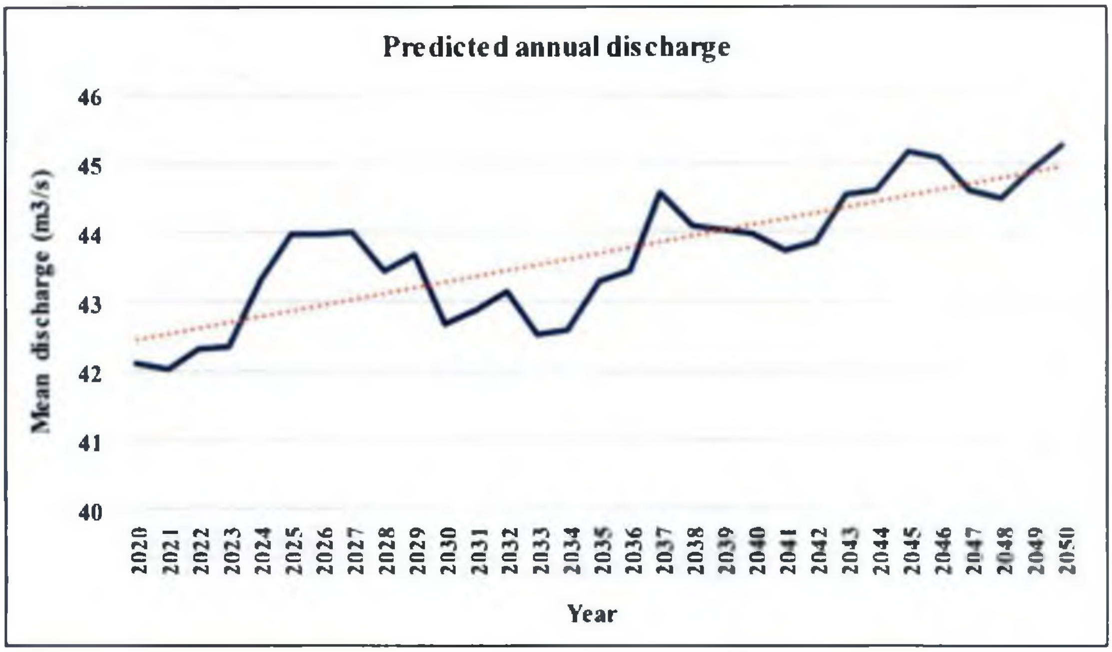

Fig.26.4. Predicted mean annual discharge of Kurumali river basin during 2020 to 2050 –RCP 8.5

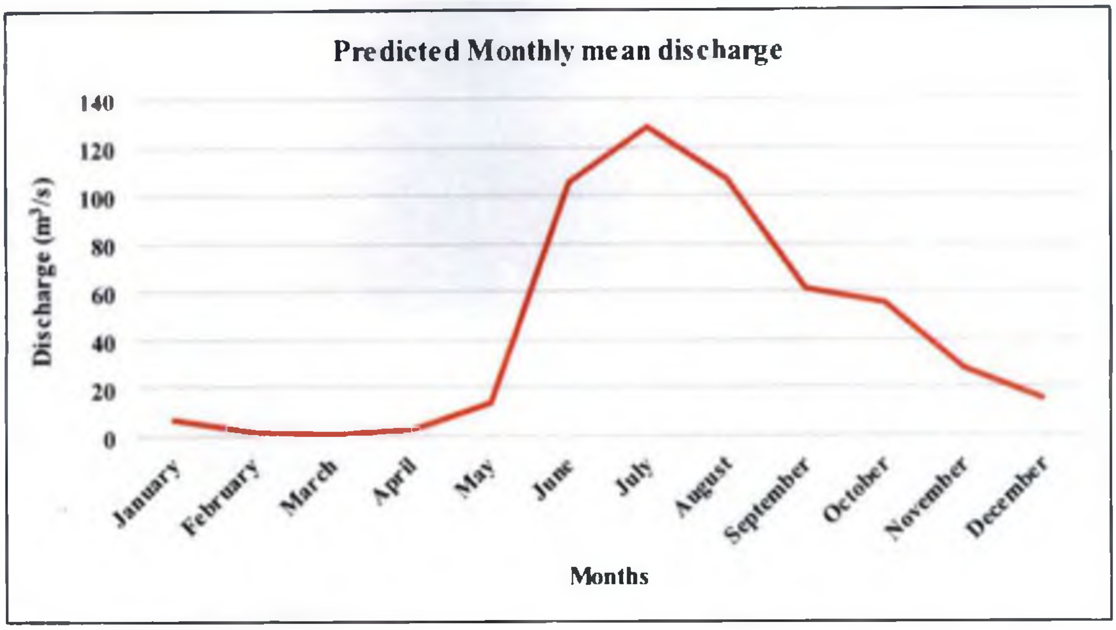

Fig. 27.1 Predicted mean monthly discharge for Kurumali river basin using RCP 2.6 during 2020 -2050

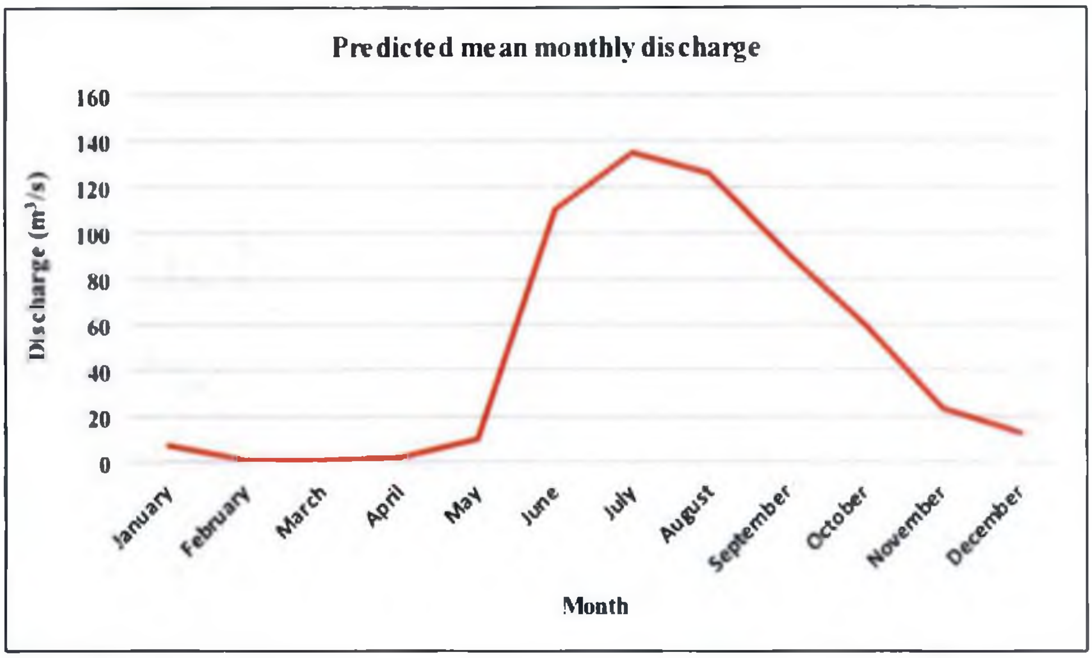

Fig. 27.2 Predicted mean monthly discharge for Kurumali river basin using RCP 4.5 during 2020 -2050

Fig. 27.3 Predicted mean monthly discharge for Kurumali river basin using RCP 6.0 during 2020 -2050

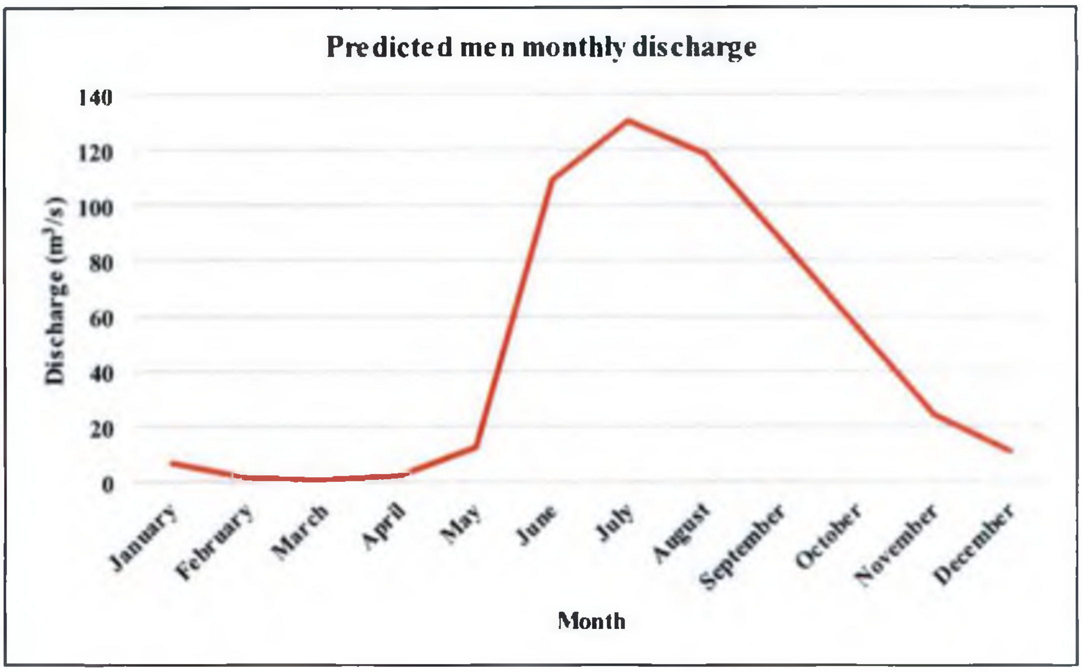

Fig. 27.4 Predicted mean monthly discharge for Kurumali river basin using RCP 8.5 during 2020 -2050

Annual discharge also shows an increasing trend in each case. It could expected to increase up to 45.76 m^3/s from the existing annual discharge. Average value of present annual discharge is only 23.2m^3/s. Monthly discharge is predicted maximum during monsoon months. Summer months are predicted to be dry. River flow will be observed only in June to December.

4.13 WATER BALANCE FOR THE PREDICTED CLIMATES

Water balance is computed for 2050 using SWAT model. Climate prediction has been done in different RCPs. Water balance calculation has done for them separately. Water balance components are surface runoff (SUR_Q), lateral flow (LAT_Q), ground water flow (GW_Q) and evapotranspiration (ET). All these components are varying in different conditions. Observed results are tabulated in table 16, which shows the percentage contribution of rainfall with respect to water balance components.

Table 16. Water balance components generated from SWAT model for different RCPs

RCP	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)
2.6	885.33	27	459.06	14	1639.5	50	491.85	15
4.5	852.54	26	491.85	15	1672.29	51	491.86	15
6.0	885.33	27	459.06	14	1705.08	52	524.64	16
8.0	918.12	28	459.06	14	1672.29	51	524.64	16

Groundwater will be the major contributor in all four cases. According to RCP 2.6, 50 per cent share will be given by GW_Q, 27 per cent by SUR_Q, 15 per cent by ET and 14 per cent by LAT_Q. According to RCP 4.5, 51 per cent will be given by GW_Q, 26 per cent by SUR_Q, 15 per cent each by LAT_Q and ET. In the case of RCP 6.0, 52 per cent will shared by GW_Q, 27 per cent by SUR_Q, 16 per cent by ET, 14 per cent by LAT_Q. In the case of RCP 8.5, 51 per cent will contributed by GW_Q, 28 per cent by SUR_Q, 16 per cent by ET and 14 per cent by LAT_Q.

Though groundwater component will be the major contributor in future, then the percentage contribution will decrease from 63 per cent to 51 per cent. But, the surface runoff percentage contribution will increase from 14 per cent (current value) to 27 per cent in 2050. Lateral flow will not showing any drastic change. It will fluctuate between 14 per cent and 15 per cent. Evapotranspiration component shows a slight increase from 11 per cent to 16 per cent.

George (2015) analyses the water balance components of Kurumali watershed described as 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.

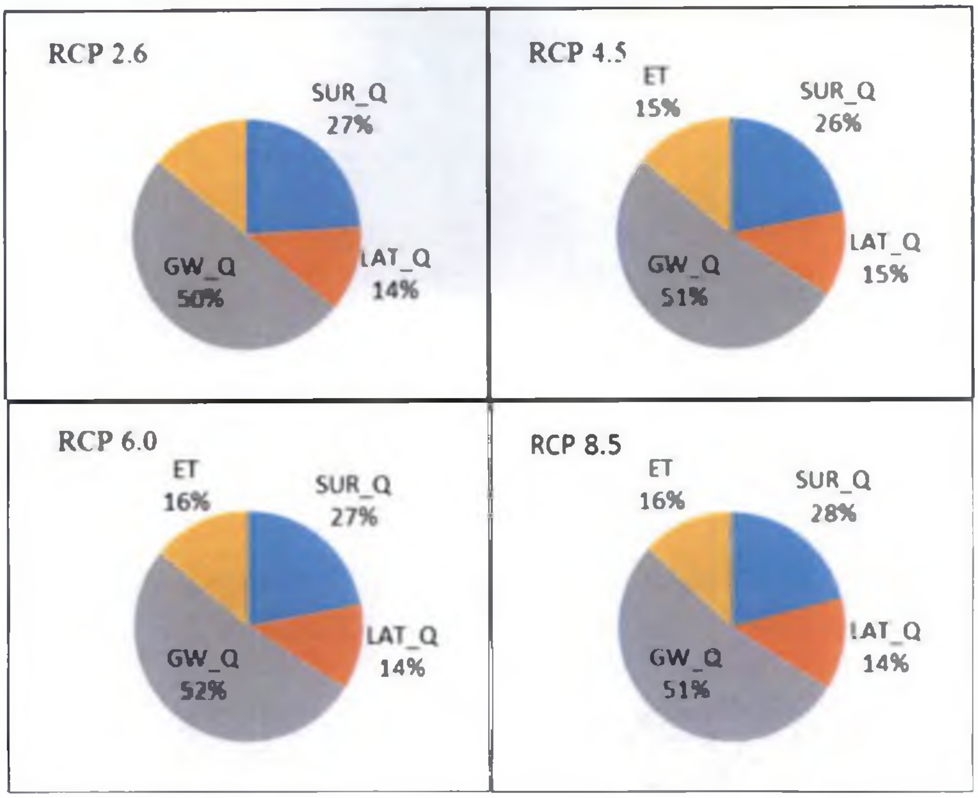

Fig. 28. Water balance of Kurumali sub basin for different RCPs expressed as a percentage of annual rainfall for 2050

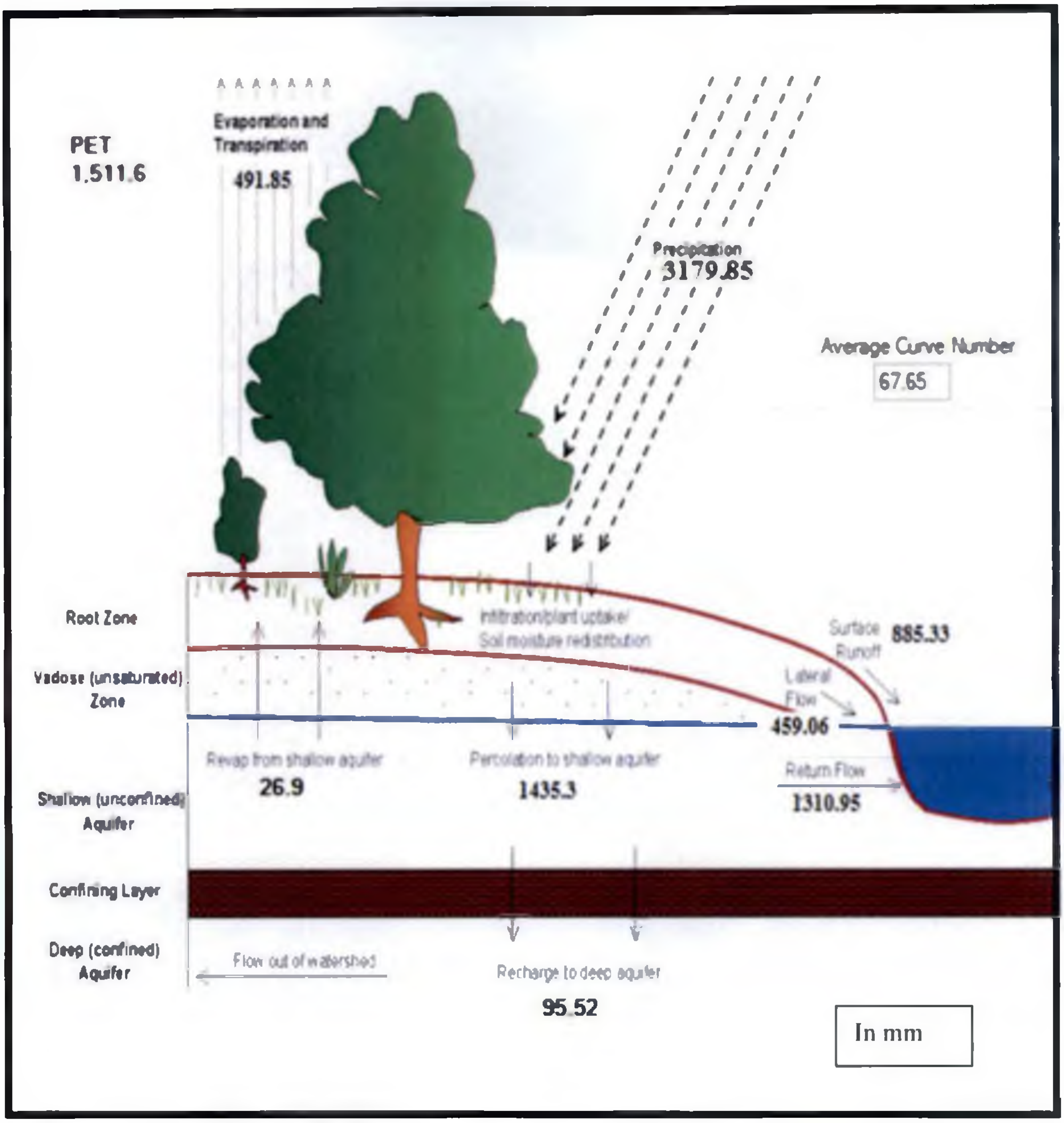

Fig. 29.1. Schematic representation of water balance for 2050 (RCP 2.6) generated by SWAT model

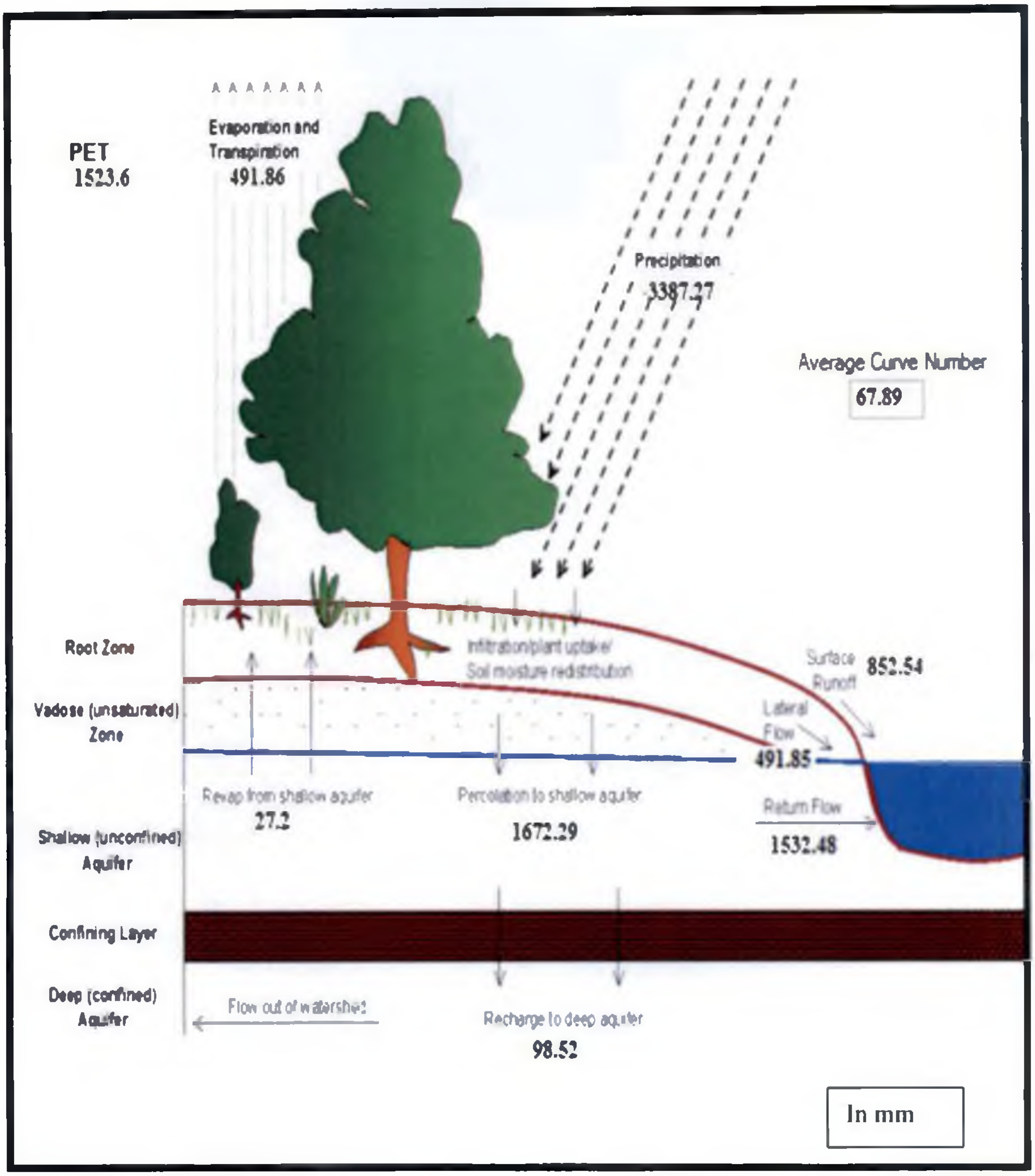

Fig. 29.2. Schematic representation of water balance for 2050 (RCP 4.5) generated by SWAT model

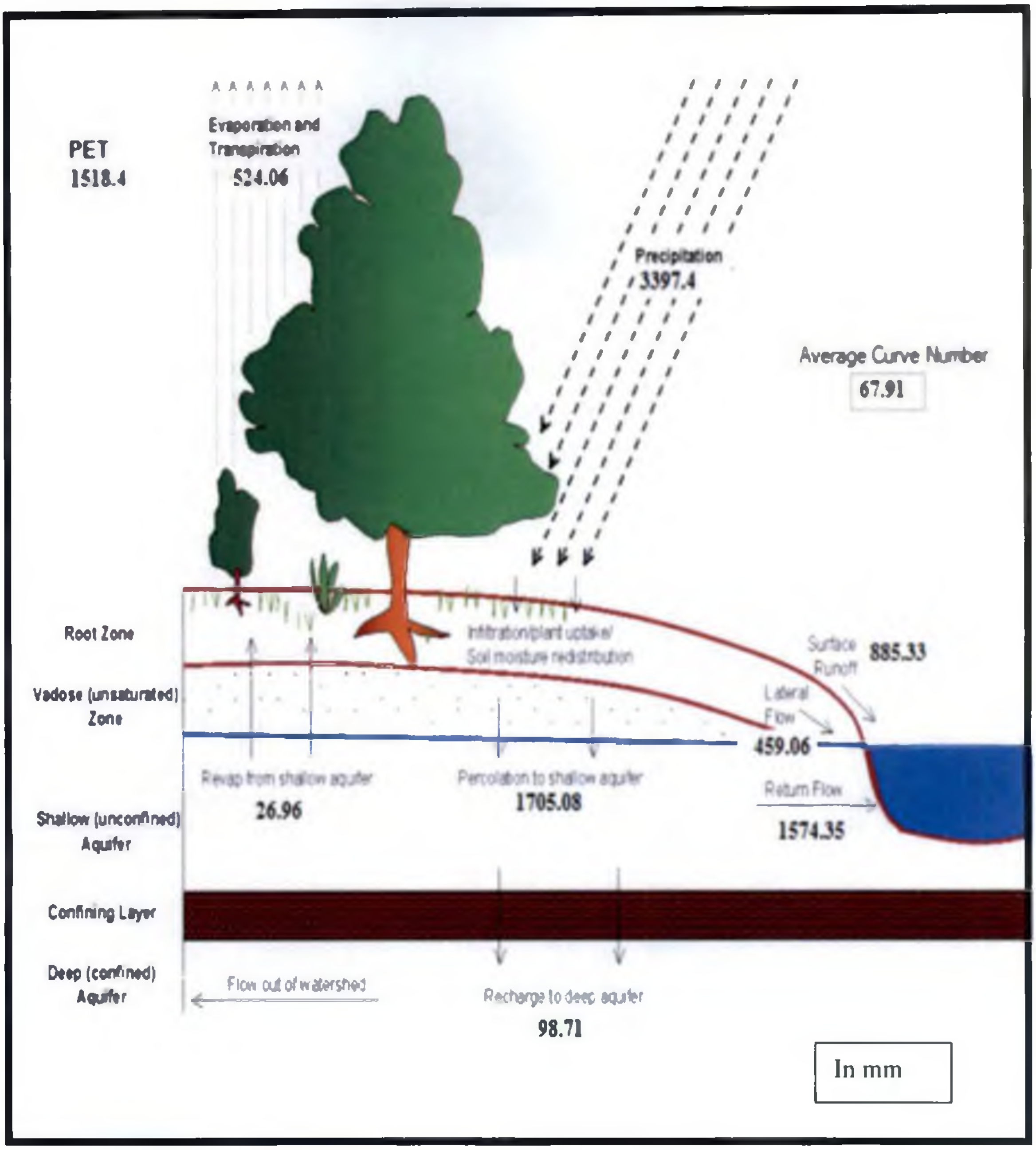

Fig. 29.3. Schematic representation of water balance for 2050 (RCP 6.0) generated by SWAT model

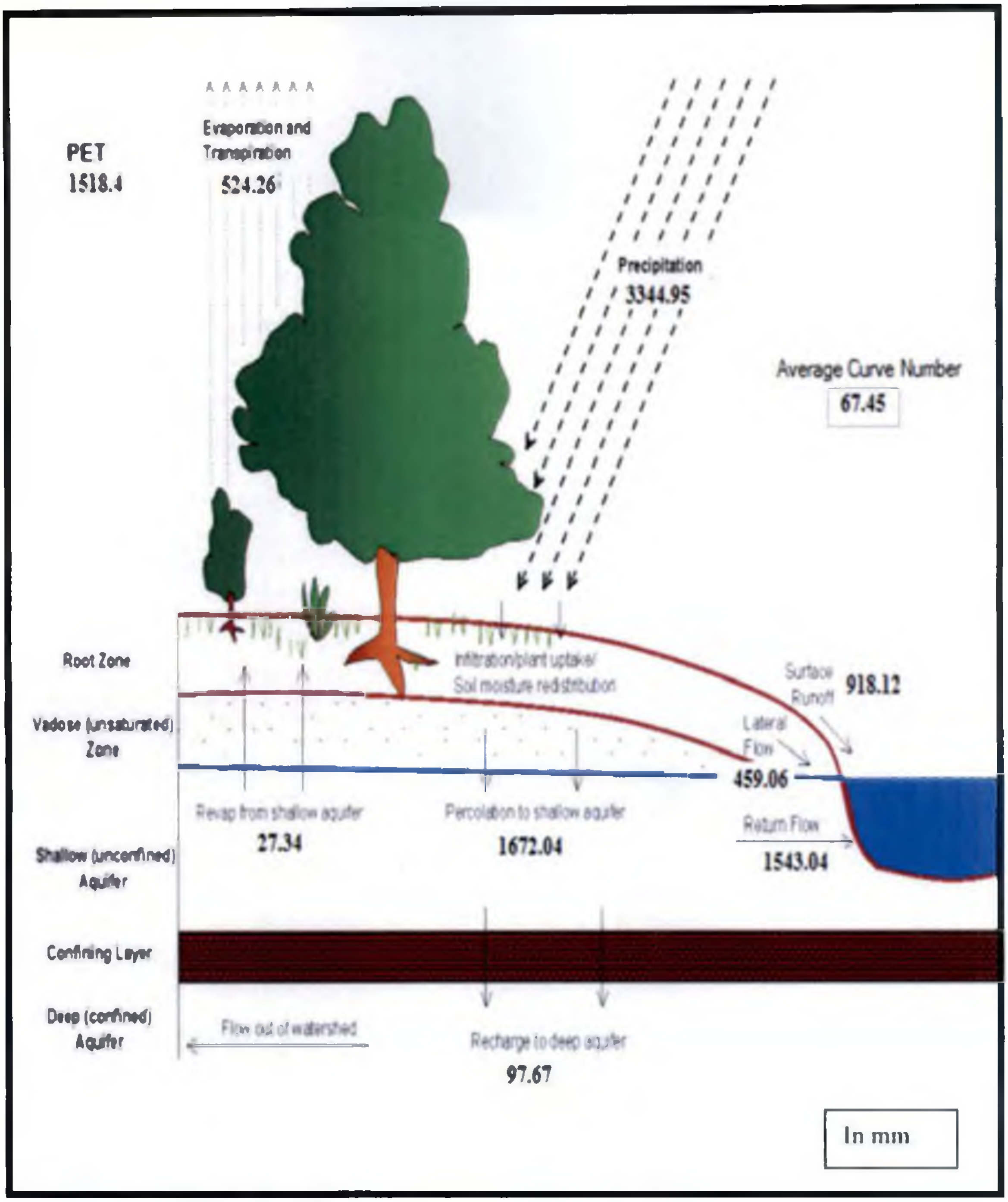

Fig. 29.4. Schematic representation of water balance for 2050 (RCP 8.5) generated by SWAT model

Using RCP 2.6, annual precipitation is projected as 3179.85mm. Surface runoff will shared by 885.33mm and lateral flow by 459.06mm. Percolation has been quantified as 1435.3mm. From this quantity, 1310.95mm will be lossed as return flow. Only 95.52mm will help to recharge aquifers.

According to RCP 4.5, expected rainfall is 3387.27mm. Around 852.54mm will contribute directly as surface runoff. Lateral flow will be 491.85mm. Among the 1672.29mm percolated flow, 1532.48mm will transferred as return flow. Aquifer recharge will be done by 98.52mm only.

3397.4mm rainfall is expected in 2050 using RCP 6.0. Surface runoff will be contributed by 885.33mm and lateral flow by 459.06mm. Around 1705.08mm will be percolated down and will recharge deep aquifer only by 98.71mm. Rest of percolated water (1574.35mm) will move as return flow.

Annual precipitation using RCP 8.5 is projected as 3,344.95mm. Around 918.12mm is shared by surface runoff. Lateral flow will be 459.06mm. Around 1672.04mm will percolate down. Among this quantity 1,543.04mm is washed out as return flow. Only 97.67mm will utilised for aquifer recharge.

4.14. EXISTING MANAGEMENT PRACTICES

Soil erosion and water depletion are the major identified threats in every watershed. Adoption of suitable management practices are very much essential for the conservation of such natural resources. Soil Survey Department of Kerala had conducted a survey relate with the implementation of management practices across various watersheds of Kerala. It indicates that the most adopted soil conservation practice is stone pitched contour bunds. They constructed across the slope in steep sloppy lands ranges between 2 and 40 per cent. For the land having slope between 5 and 20 per cent contour bunds are good. Staggered trenches are good for plantation crops cultivated land.

Current existing management practices conducted in Kurumali River basin are picturised as plate 1 and 2. Mainly engineering measures are utilised in the entire River basin. Stone pitched contour bunds are present in around 5.3 ha of land. Moisture conservation pits or trenches are present in some areas especially in central region. Contour trenches are seen in north eastern part of basin. Loose bund check dams are present in cropping lands.

4.15 FUTURE MANAGEMENT PRACTICES

Predicted mean annual rainfall is very high in all four RCP conditions compared to the existing mean value (2767.3mm). As per RCP 2.6, 4.5, 6.0 and 8.5 average rainfall will increased to 3179.85mm, 3387.27mm, 3397.4mm and 3344.95mm respectively. Around 80 per cent of annual rainfall will be received during South West monsoon months. North East monsoon rainfall is projected to decrease in this area. Accordingly surface runoff is projected to increase up to 885.33mm, 852.54mm, 885.33mm and 918.12mm respectively in RCP 2.6, 4.5, 6.0 and 8.5. The increased rainfall and surface runoff will induce the soil erosion by water. Soil conservation practices are different for different topographical locations. Proposal of management practices for entire watershed is a difficult task. So, for proposing efficient, suitable management strategies select three locations from geographically different regions of the watershed.

One location is Nandikkara which is situated in south west region of the Kurumali River basin. Mixed crop cultivation is the major land use. Major component of soil is sand and silt. Land slope of this location is comparatively low. Hence, water harvesting techniques can efficiently be practiced here. Engineering measures includes construction of rainfall pits, alternate bunds and trenches. Agronomic measures such as cover cropping and mulching can be effectively utilise here. Crops with different heights can be used for mixed cultivation. It will help to increase the interception storage. If crop cultivation could be done in small basins, then it will collect the water within the plant root area. It also prevents soil moisture loss as evaporation. Pueretorican terraces can be used as an erosion control measure in low sloping lands.

Second location selected is Vellarampadam where rice cultivation is the major agricultural practice. Soil is mainly composed of clay. Bunds can be constructed along the boundary of each cropping land. It will prevent runoff and thereby erosion. Cover crops can be cultivated over such bunds. Staggered trenches will be a good substitute for moisture conservation pits. Small check dams can construct between two crop lands. Coconut plantations are also seen in some part of this area. Coconut seedlings can be planted within a moon shaped basin which is having boundary with bunds. Crops like pineapple or other small crops can cultivate over this bund. This will be a very good measure for moisture conservation.

Third location is at North Eastern part of the basin called Karikkulam. Most of the nearby areas are either forest land or rubber plantations. Since the slope of this area is high surface runoff need to be reduced effectively. Instead of constructing contour bunds, adoption of graded bunds would be better. Because it will help in preventing the damage of bunds due to the impounding of runoff water by safe disposal of water towards the low sloping land. Inward terraces can be used for reducing runoff velocity. Moon shaped terrace can be constructed. Boundary of such terrace could be secured with bunds.

Proper maintenance and management of existing conservation interventions are very much essential for effective soil and water conservation.

Plate 1 Stone pitched bund

Plate 2 Moisture conservation trenches

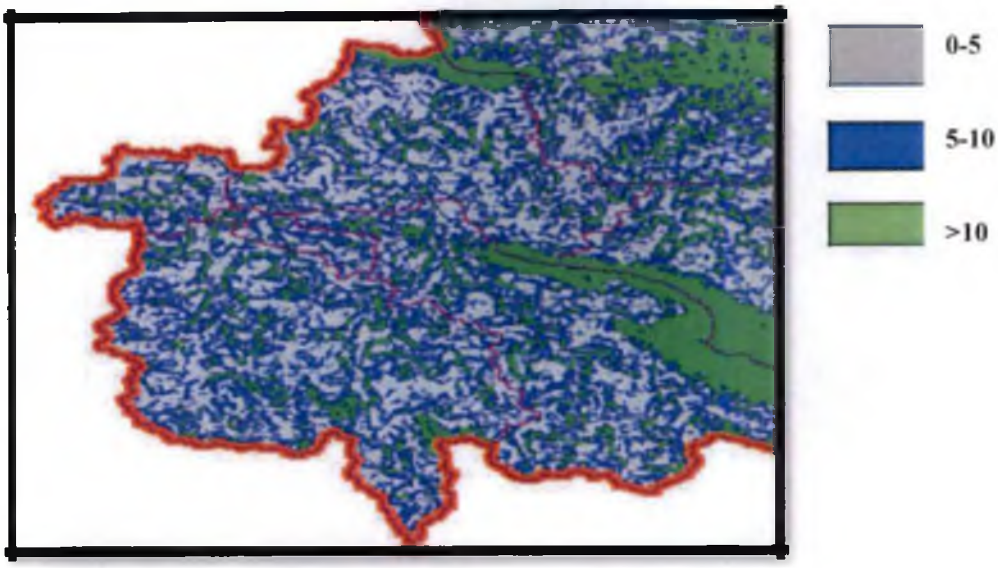

Fig.30.Land slope of Nandikkara locality

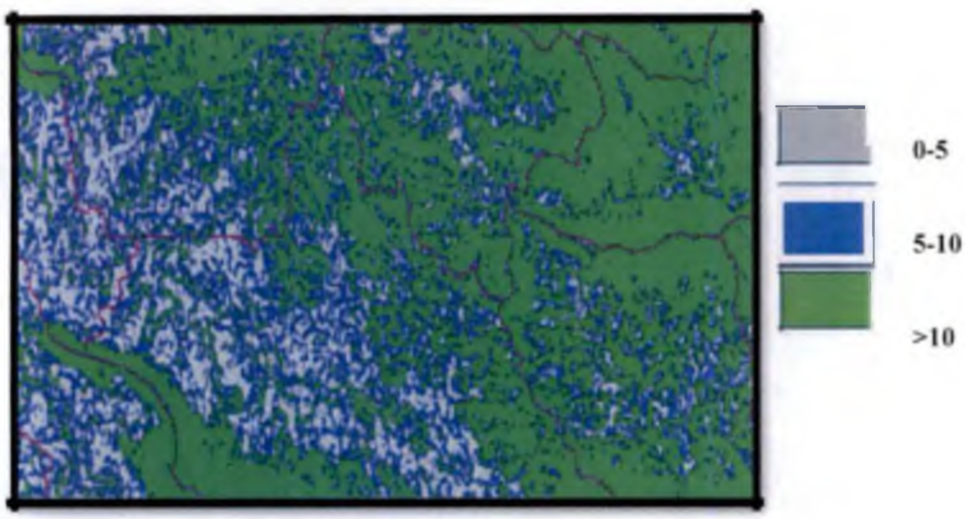

Fig.31.Land slope of Vellarampadam locality

Fig.32. Land slope of Karikulam locality

Fig.33.1. Areal extent of Nandikkara

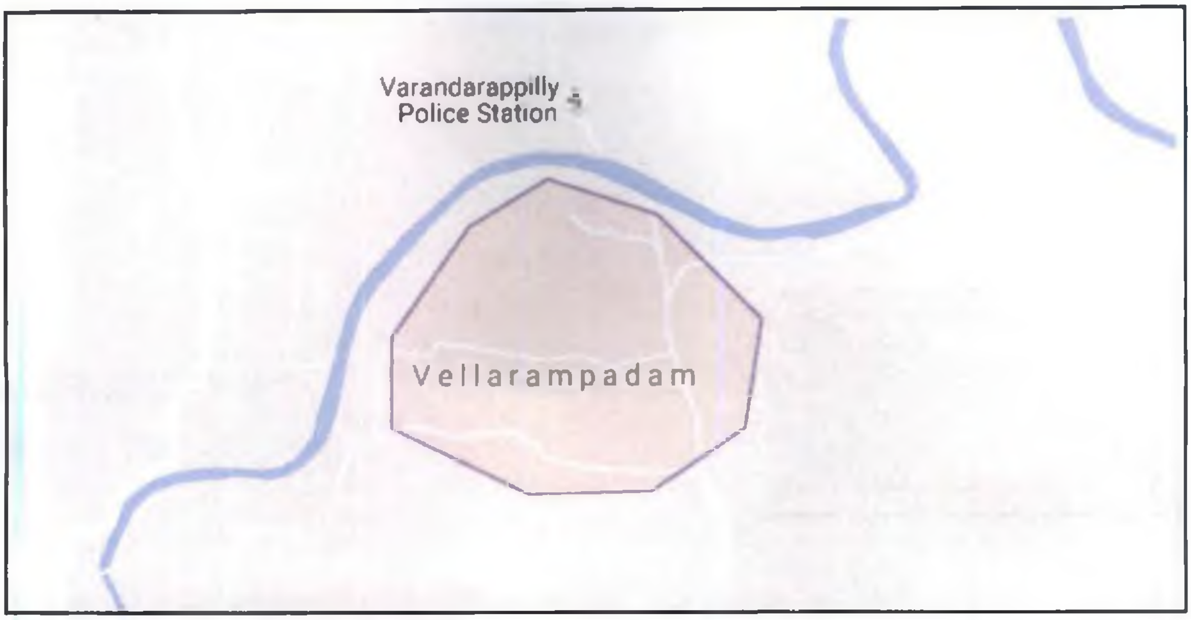

Fig.33.2. Areal extent of Vellarampadam

Fig.33.3. Areal extent of Karikulam

CHAPTER 5

SUMMARY AND CONCLUSIONS

Long term average changes in the physical interactions between the components of the climate system is referred as climate change. Climate system comprises of hydrosphere, atmosphere, cryosphere, lithosphere and biosphere. Any variability at any point of this linkage definitely will alter the entire system. Such interactions could be explained by causative radiative forcing mechanisms and response feedback mechanisms. So, climate change becomes the major threat for the biotic nature of the earth and its natural resources. Hydrologic cycle is the most fundamental physical interaction which is the primitive regulator of the life. Climate change has direct effects on the hydrologic cycle and water balance. Water is the most important resource for day to day life. Proper availability and accessibility of the water is required by humanity and other life forms. Climate change impact studies have significant role in current world. So, a study has been taken up to assess the impact of climate change on water resources, as Kurumali river basin as the study area, using the SWAT model. The specific objectives of this study are:

1. To identify the best suitable GCM for analyzing climate change in the location of study
2. To assess the impact of climate change on the hydrologic regime of *Kurumali* sub Basin of *Karuvannur* River and thereby to evaluate the water resources availability of the basin
3. To suggest soil and water conservation practices for the watershed on a pilot scale.

Soil and Water Assessment Tool (SWAT) is a widely accepted model for the river flow calculation, sediment transport estimation and nutrient availability computations. Climatological parameters, soil and land use features are the inputs for this model. Existing weather data have been collected from agro-meteorological observatory, Kerala Agricultural University. Future projected data have been generated by MarkSim weather file generator tool. Geographical details such as Digital Elevation Models and LISS III satellite imagery have been collected from USGS portal and NRSA site respectively.

For identifying best suitable model, original rainfall for the period 2010-2015 have been compared with simulated rainfall data by different IPCC models. There are 17 models in MarkSim weather file generator. Model simulations have done for different RCPs such as RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. Classified the daily rainfall data into total annual average and South West monsoon average. Lowest difference between original averages rainfall is selected in each category. Anomaly during South West monsoon as well as annual average condition shows that, MIROC-ESM is having lowest anomaly in most of the continuous years as per RCP 2.6 and RCP 6.0. According to other two RCPs no unique majority is observed. So, MIROC-ESM is selected for the future climate simulation for 2050. Watershed simulations have been done for 2050 in four RCPs.

Current annual average rainfall (1983-2013) for Kurumali River basin is computed as 2767.3mm. Using this model in RCP 2.6, 4.5, 6.0 and 8.5 projected 30 year annual average rainfall is 3179.85mm, 3387.27mm, 3397.4mm and 3344.95mm respectively. This study reveals that, annual average will increase but, duration of rainfall months may decrease. Amount of SW monsoon rainfall will increase but the amount of NE monsoon will decrease.

Using this projected annual rainfall, water balance has been computed using SWAT model for 4 RCPs independently. SWAT, a continuous watershed scale model, estimates surface runoff, lateral flow, groundwater flow and evapotranspiration. These are the components of hydrologic cycle. Difficulties during watershed simulations are minimised by dividing the large watershed into small comparable units called hydrological response units. Before the simulation step, the model needs to be calibrated and validated. For calibration of the model, four years discharge data was utilised and obtained higher NSE and Coefficient of Determination. High value of NSE and COD infer the good predictive capability of the model.

Water balance for different RCPs have been computed. Surface runoff has been increased from 254.9mm to 885.3 mm in RCP 2.6; 852.5mm in RCP

4.5;885.33mm in RCP 6.0 and 918.1mm in RCP 8.5. Lateral flow also increased from 288.2mm to 459.1 in RCP 2.6; 491.9mm in RCP 4.5; 459.06mm in RCP 6.0 and in RCP 8.5. But, the groundwater flow will reduce from 1622.2mm to 1310.95mm in RCP 2.6; 1532.5mm in RCP 4.5; 1574.4mm in RCP 6.0 and 1543.0mm in RCP 8.5. Thereby, aquifer recharge is likely to reduce considerably. So, the water availability of the area will likely to be affected. Share of groundwater in water balance will decrease considerably as rainfall increases.

The study concludes that annual rainfall of the Kurumali river basin will increase in future, however, the monthly distribution of rainfall may get more skewed. Surface runoff and lateral flow will increase and as a consequent base flow will decrease. This will lead to more water scarcity in the region. Therefore, more attention has to be given for soil and water conservation measures to overcome the ill effects of high rainfall events and water scarcity during summer.

Future scope of study:

1. Study can include quantification of soil erosion and sediment yield at each micro watershed and thereby, prioritisation of different micro watersheds for soil and water interventions.
2. Impact of watershed management practices may be assessed.

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IMPACT OF CLIMATE CHANGE ON WATER RESOURCES OF KURUMALI RIVER BASIN

by

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ABSTRACT OF THE THESIS

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ABSTRACT

Soil, water and air are the primary requirements for the existence of life on earth. Efficient distribution and sustainable use of water resources has to be managed on watershed basis. A watershed is a geographical area which receives water through precipitation and drains out to a common outlet. Watershed scale hydrological studies consider the weather conditions and physiographic features of the watershed as input factors. Changes in any of these parameter definitely will influence the watershed hydrology.

Climate models are the most important tool for making climate predictions on temporal and spatial scales and making projections of future climate for the coming century. In the present study, Kurumali sub basin of Karuvannur river was selected as the study region. Future projected climate data was obtained from MarkSim DSSAT weather file generator for the future 30 years (2020-2050) using MIROC-ESM general circulation model in four RCPs(2.6,4.5,6.0 and 8.5).Present annual rainfall for Kurumali sub basin is 2767.3mm. The model predicted annual rainfall for 2050 are 3179.8mm, 3387.2mm, 3397.4mm and 3344.9mm in RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 respectively. This data was used as weather input for predicting the future watershed processes and water resource availability using SWAT model. The model predicted an increase in annual rainfall and a decrease in duration of individual storms. An increase in the amount of SW monsoon rainfall and a decrease in the amount of NE monsoon was predicted.

Soil and Water Assessment Tool (SWAT) is a widely accepted model for the river flow calculation, sediment transport estimation and nutrient availability computations. SWAT wasused for the water balance computation. Surface runoff was found to increase from 254.9mm to 885.3mm in RCP 2.6; 852.5mm in RCP4.5; 885.3mm in RCP 6.0 and 918.1mm in RCP 8.5. Lateral flow also showed an increase from 288.2mm to 459.1mm RCP 2.6; 491.9 mm in RCP 4.5; 459.06mm in RCP 6.0 and 459.06mm in RCP 8.5.The groundwater flow was found to reduce from 1622.2mm to 1310.9mm in RCP 2.6; 1532.5mm in RCP 4.5; 1574.4mm in RCP 6.0 and 1543mm in RCP 8.5.

Predicted high intensity short duration rainfall will enhance runoff. Evaporation losses were also found to increase and this in turn will reduce the water

availability of the Kurumali sub basin.The reduced aquifer recharge consequent to high runoff and evaporation losses will disturb the demand supply balance of water within the watershed. Adoption of suitable soil and water conservation measures are recommended to overcome the water scarcity expected in future years.