RECOMMENDATIONS TO REJUVENATE RIVER BHARATHAPUZHA USING GIS AND WATERSHED SIMULATION MODEL

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PROJECT REPORT

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DECLARATION

We here by declare that this project entitled **"RECOMMENDATIONS TO REJUVANATE RIVER BHARATHAPUZHA USING GIS AND WATERSHED SIMULATION MODEL"** is a bonafide record of project work done by us during the course of project and the report has not previously formed the basis for the award to us for any degree, diploma, associateship, fellowship or other similar title of any other university society.

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Aiswarya, K. P.
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Dedicated to

The Almighty,

Loving parents

and Teachers

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SYMBOLS AND ABBREVIATIONS

AGNPS	Agricultural Non-Point Source
AH	Autumn Harrowing
AP	Autumn Ploughing
ARS	Agricultural Research Service
ASCII	American Standard Code for Information Interchange
Aug	August
cm	centimeter(s)
CN	Curve Number
dBASE	Data base
Dec	December
DEM	Digital Elevation Model
D_RECH	Deep recharge
EIMU	Erosion Intensity Mapping Units
et al	and others
FCC	False Colour Composite
Feb	February
GIS	Geographic Information System
GIUH	Geomorphologic Instantaneous Unit Hydrograph
GPS	Global Positioning System
GW_Q	Ground Water Runoff
ha	hectare
ha m	hectare meter(s)
HRUs	Hydrologic Response Units
ILWIS	Integrated Land and Water Information System
IRS	Indian Remote Sensing
Jan	January
Jul	July

Jun	June
KAU	Kerala Agricultural University
KCAET	Kelappaji College Agricultural Engineering and Technology
Km	Kilometer(s)
Km^2	Square Kilometer(s)
Lat_Q	Lateral Flow
LISS	Linear Imaging Self Scanning
LUP	Land Use Planning
LWRCE	Land and Water Resources and Conservation Engineering
M ha m	million hector meter(s)
M km^3	million cubic kilometer(s)
Mar	March
MAX	Maximum
MIN	Minimum
mm	millimeter
MUSLE	Modified Universal Soil Loss Equation
NBSS	National Bureau of Soil Survey
Nov	November
NPS	Non Point Source
NRSA	National Remote Sensing Agency
NSE	Nash–Sutcliffe Simulation model Efficiency
Oct	October
PAN	Panchromatic
PET	Potential Evapotranspiration
PREC	Precipitation
rch	Main Channel Output File
SCS	Soil Conservation Service
Sep	September
SOI	Survey of India

SOL_AWC	Soil Available water capacity
SP	Spring Ploughing
SPOT	Systeme Pour l'Observation de la Terre
sub	Subbasin Output File
Sur_Q	Surface Runoff
SWAT	Soil and Water Assessment Tool
TM	Thematic map
USDA	United State Department of Agriculture
WCR	Winter Crop Rotation
WEPP	Water Erosion Prediction Project

Introduction

Chapter 1

INTRODUCTION

Rivers play a major role in integrating and organizing the landscape, and moulding the ecological setting of a basin. They are the prime agents controlling the global water cycle and in the hydrologic cycle, they perform the most dynamic modes of transport. Rivers carry elements, in suspended or in dissolved form, from their source and deposit them sequentially based on their physico-chemical nature at different locations. And it is this life-giving liquid treasured in these rivers enables sustenance of life on earth. Rapid increase in demand of water in agriculture, industry and domestic uses, to meet the requirements of exploding population has forced man to develop new management and conservation techniques for river systems.

Out of world's total available water, 1400Mkm^3, about 95% is contained in oceans as saline water and 4% is in the form of snow and ice. Thus, the fresh and unfrozen water is only 1% of the total availability, out of which 99% is ground water and only 1% is present as surface water in lakes, rivers, soil and atmosphere. The cumulative requirement of water by different sectors by 2025 is estimated to be 105Mham and the demand of water for agriculture is estimated to increase from 50Mham to 70Mham and this can be met if proper watershed management principles are applied. Watershed is an ideal unit for carrying out scientific resource management for ensuring continuous benefits on sustainable basis. Watershed models are very effective tool for planning watershed development activities to gain better understanding of hydrologic phenomena operating within the watershed area and how changes in watershed may affect these phenomena.

Kerala state is agro-climatically situated on the south-west corner of India receiving about 300cm of average rainfall and blessed with 40 minor rivers and 4 medium rivers, chain of backwater bodies, tanks, ponds, springs and wells. Hence Kerala is often considered as a land of water. Still the state experience severe shortage of water during the summer months. The rivers hardly contain any water during 6 months in a year. Compared to national average, Kerala receives 2.78 times more rainfall, but due to steep slopping and undulating topography rain water is not much retained on land. At the same time, unit land of Kerala has to support 3.6 times more population when compared to national level scenario. Hence for self sufficiency unit land of Kerala has to meet 3.6 times drinking water, food biomass and associated water requirement compared to national average. Proper management of water resource of Kerala would certainly make situation more comfortable.

1.1 Watershed Management

A watershed is a basin like landform defined by high points and ridge lines that descending to lower elevations, valleys and streams. It is a natural integrator of all hydrological phenomena pertaining to an area bounded by a natural divide and is a logical unit for planning the optimal development of soil, water and biomass resources. It is a spatial unit within which hydrologic principles must hold and therefore all hydrologic analysis must be validated within this unit.

Watershed management implies the rational utilization of land and water resources for optimum production with minimum hazards to natural resources. The aims of these practices are proper land use, protecting land against all forms of deterioration, building and maintaining soil fertility, conserving water for farm use, proper management of local water for drainage, flood protection and sediment reduction and increase in productivity for all land uses. The strength of watershed development program will largely determine the growth in agriculture.

Watershed models are very effective tool for planning watershed development activities. The term watershed Modelling has a broad connotation. It generally refers to the simulation of the processes that take place in the watershed. The aim of watershed modeling is to gain better understanding of hydrologic phenomena operating within the watershed area and how changes in watershed affect these phenomenon.

1.2 Geographic Information System

Use of GIS is gaining more importance these days because it plays an important role in resource management, environment monitoring and land use planning activities. A Geographic Information System (GIS) can be defined as a computerized data base system for the capture, storage, retrieval, analysis and display of tabular and spatial data. GIS can provide a great deal of more problem- solving capabilities than using a simple mapping program or adding data to an online mapping tool.

1.3 Remote Sensing

Remote Sensing technology has been playing an important role in effective and timely mapping of geo resources. It is generally understood to imply the acquisition of information about an object or phenomenon on earth surface by scientific means or devices called sensors without being in any physical contact between the object and sensing device. This is done by sensing and recording reflected or emitted electromagnetic energy and processing, analyzing and applying that information. Air crafts and satellites are the common platforms for remote sensing observation. Remote sensing data having high resolution available from IRS, LANDSAT-TM and SPOT have been improved and computer based image processing system have become comparatively less expensive and more effective.

1.4 Application of GIS in Watershed Modeling

Application of Geographic Information Systems (GIS) is gaining more importance in watershed modeling. The Geographic Information Systems can capture, store, manipulate, analyze and visualize diverse set of geo referenced data. The GIS can help in design, calibration, modification and a comparison of watershed models. The GIS technology is suitable for efficient management of large and complex data base. Spatial statistics and grid design capabilities of GIS can improve the effectiveness of watershed modeling. GIS data base for watershed modeling comprises details on landuse, soils, hydrologic characteristics, drainage network, water use etc. A digital representation of watershed characteristics in GIS format is used in watershed modeling.

1.5 Overview of ILWIS

ILWIS is an acronym for the Integrated Land and Water Information System. It is a Geographic Information System (GIS) with Image Processing capabilities. ILWIS has been developed by the International Institute for Aerospace Survey and Earth Sciences, Enscheda, The Netherlands. As an Integrated GIS and Remote Sensing package, ILWIS allows to generate information on the spatial and temporal patterns and processes on the earth surface and these information can be analyzed on GIS platform.

1.6 Overview of SWAT

SWAT is an acronym for Soil and Water Assessment Tool, a river basin or watershed scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, landuse and management conditions over long periods of time.

It is designed to predict the impact of management on water, sediment and agricultural chemical yields in gauged and ungauged watersheds. The model is physically based, computationally efficient and capable of continuous simulation over long time periods. Major model components include weather, hydrology, sediments and nutrients. In SWAT, a watershed is divided into multiple sub watersheds. These are then further sub divided into hydrologic response units (HRUs) that consist of homogeneous land use, management and soil characteristics. The capability of SWAT model is particularly limited in terms of dealing with ground water flow, due to its lumped nature.

1.7 Bharathapuzha at a Glance

Bharathapuzha, the second largest river of Kerala which is one of the populous states in India, is catering to the needs of several millions of people. The river is currently facing tremendous pressure due to encroachments, sand and clay mining, and illegal diversion of water. Bharathapuzha takes its origin at an elevation of 1964m above M.S.L from Anamalai hills and flows through the districts of Coimbatore, Palakkad, Malappuram and Thrissur and joins Arabian Sea near the Ponnani town, where it is known as Ponnanipuzha. Its four main tributaries are, Gayatripuzha, Chitturpuzha, Kalpathypuzha and Thuthapuzha.

The length of the river is 209km with a catchment area of 6186Km^2. The catchment area is spread over 11 taluks from the Western Ghats to the Arabian Sea. About 2/3rd of the drainage area of the basin i.e. 4400Km^2 lies in Kerala state and the balance in Tamil Nadu. The Bharathapuzha basin is bounded by Tirur and the Kadalundi basins on the north and the Kecheri river basin on the south. At present, 10 major irrigation projects are existing on various tributaries of the river in addition to a number of minor and lift irrigation schemes.

Most of the minor irrigation projects are not functional for want of river flow during summer. Drinking water projects in the river are also affected by the very poor lean flow. The ground water table on either side of the land area of the river channel network has also gone considerably down compared to the past days. Hence, this project work has been undertaken to solve the important hydrological issues of Bharathapuzha river basin with the following specific objectives.

1. To model the topography of river Bharathapuzha using Remote Sensing and Geographic Information System (GIS).

2. To study the existing hydrologic processes of the river basin using watershed simulation models.

3. To suggest suitable interventions to improve the summer flow regime of river Bharathapuzha.

Review of Literature

Chapter 2

REVIEW OF LITERATURE

2.1 GIS and RS in Watershed Characterization

Geographic Information System(GIS) is defined as an information system that is used to input, store, retrieve, manipulate, analyze and output geographically referenced data or geospatial data, in order to support decision making for planning and management of landuse, natural resources, environment, transportation, urban facilities, and other administrative records. The efficiency of GIS is in the integration of data set from various sources to analyze it as a whole and implement it for critical decision making in planning and management options.

Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. Remote sensing provides a means of identifying and presenting planimetric data in convenient media and efficient manner. Imagery is available in varying scales to meet the requirements of many different users.

Kioshi Honda *et al*. (1994) conducted a study on remote sensing and GIS technologies for denudation in a Siwalik watershed of Nepal. The study was made as an attempt to use remote sensing to identify the land degradation in Ratu watershed in the central Siwalik area, and established a method to estimate the rate of denudation in this perspective, Landsat data procured for a period of 20 years from 1973-1993 were analyzed for the change of forest cover in the watershed and topographical parameters were used in a model to estimate the probable annual soil loss. Model was further improved for flood event soil yield estimation using factors that have identified in the field as main causes for intensive erosion during a heavy rainy season.

Garbrecht *et al*. (2001) described GIS and distributed watershed models which addresses selected spatial data issue, data structures and projections, data sources, and information on data solution and uncertainties. Spatial data that are covered include digital elevation data, steam and drainage data, soil data, remotely sensed data and radar precipitation data.

Sharma *et al*. (2001) conducted a study on micro-watershed development plans using Remote Sensing and GIS for a part of Shetrunji river basin, Bhavnagar district, Gujarat. Here an approach using remote Sensing and GIS has been applied to identify the natural resources problems and to generate local specific micro-watershed development plans for a part of Shetrunji river basin. Study of the multi-date satellite data has revealed that the main land use or land cover in the area is rainfed agriculture, waste land with or without scrubs in the plains and undulating land and scrub forest with forest blanks on the hills. The depleting vegetation cover has resulted in excessive soil erosion exposing barren rocky waste.

Ravinder Kaur *et al*. (2002) made a study on GIS based digital delineation of watershed and its advantage over conventional manual method in Hazaribagh and Bankura district of Jharkhand and West Bengal. Besides this, the benefits of digital delineation procedure over conventional (AISLUS) manual method have also been highlighted. The study indicated that the traditional manual delineation of watershed involves subjectivity in locating the ridge lines, which often leads to a slight change in actual watershed shape and thus area. Digital delineation of watershed boundaries avoids this subjectivity and thus gives more accurate shape and size of the delineated watershed.

ChattoPadhyay and Sujith Choudhury (2005) conducted study on application of GIS and Remote Sensing for watershed development projects. GIS is a very powerful tool for development of watershed area with all natural and socio economic facts for better planning, execution and monitoring of the project .GIS based model help to plan the infra structure development needed such as connecting market with local place.

Gupta and Mathur (2005) conducted a study with Geographical Information System on flood management. Use of satellite data and geographic information system technology has been employed to understand the river behavior during monsoon and non- monsoon season and achieved desired results. It was found that the active river channel during 1989-90 has deviated at many places when compared with old river course of 1965-70. The Indian Remote Sensing Satellite data have been found to be useful in mapping the river meandering during non-flood season.

Upadhye *et al*. (2005) used remote sensing and GIS technique for prioritization of watershed for development and management in India. Remote sensing and GIS technique can be effectively used for priority delineation of sub-watersheds. Initially, polarization of watershed was mainly done with the help of aerial photographs and FCC. Then with progressing remote sensing and availability of data, work was carried out with visual interpretation techniques like LISS II and LISS III, PAN data as well as GIS techniques for overlapping maps. The maps were in 1:100000 scale. The satellite remote sensing technique provides data on land slope, land use and land cover which can be integrated with data on rainfall, erosivity using GIS to arrive quantitative estimation of soil loss.

Selvi *et al*. (2006) studied about utilities and limitations of remote sensing and GIS applications in micro-watershed planning with an image map obtained on 1:12,500 scale of Kuruthukuli watershed in Kundah basin of the Nilgiris district, Tamil Nadu. The geocoded image was subjected to visual interpretation. Slope map was generated from SOI toposheets (1:50,000) in GIS environment (ARC/INFO) and other thematic maps on land use, soils and cropping patterns were prepared in GIS after field verification. On the basis of these thematic maps together with information obtained from field visits and Participatory Rural Appraisal (PRA) exercises, watershed management plan was prepared for KG-4-1 watershed. Crucial factors apart from land use categories, which are needed for land use planning, like irrigation status, cropping status and land management conditions could not be obtained from the image map of KG-4-1 watershed processed at 1:12,500 scale. It was concluded that, GIS was an ideal system to support watershed planning which is an integrative process, especially with the help of topological overlays of different thematic layers.

Asis Mazumdar and Sujana Dhar (2007) have conducted an exhaustive study on the Jamtara watershed, west Bengal of Ajay river catchment under changed climate scenario from soil moisture accounting parameters. An attempt has been made to quantify the impact of climate change on the water recourses of that catchment outlet using a distributed hydrological model HEC-HMS after due calibration using historical data. The study used the Hardley Regional Model daily weather data to determine the control and GHG- green house gas (future climate scenario) water availability in space and time. A total of 15 years of simulation spanning the entire catchment has been conducted. Seasonal shift of stream flow pattern, reduction of peak flow and water stressed condition have been observed.

2.2 GIS and RS in Modeling Watershed Processes

Ravat (1994) conducted a study on water resource assessment and management in Himalayan catchments through remote sensing and GIS technology to compare the calculated runoff (SCS method), observed runoff and water balance method using 2-3 years data.

Devesh Sharma *et al*. (2000) studied the application of SCS model with GIS data base for estimation of runoff in arid watershed. Soil conservation service model (SCS) has been applied in the estimation of runoff from a 509ha watershed which is a part of upper Jojri in Nagaur district of Rajasthan. This method involves various types of information related to topography and soil. The thematic map of soil, land use etc is prepared from satellite and topographic map from survey of India. And all this information was converted into raster format at scale 1:50000 and used as an input to derive SCS runoff curve number. The SCS model was then applied to estimate the runoff of daily storm and was validated comparing it with the measured runoff of five events during monsoon period.

Sarangi *et al*. (2000) studied the use of GIS in assessing the erosion statistics of watersheds. In this study, two watersheds, Banha watershed at upper Damodar valley, Jharkhand and IARI watershed at Delhi were considered. These watersheds were digitized along the contour lines using the GIS tool. The hypsometric analysis performed on these watersheds revealed that the Banha watershed is less susceptible to erosion whereas IARI watershed is at stabilized state. Hypsometric analysis aims at developing relationship between horizontal cross sectional area of the watershed and its elevation in a dimensionless form. They concluded that conservation measures are needed in Banha watershed whereas no activity is needed in IARI.

Teeter *et al*. (2000) have focused their studies on the use of remote sensing and GIS in watershed level analyses of non-point source pollution problems. Basin characteristics such as land use/land cover, slope, and soil attributes affect water quality by regulating sediment and chemical concentration. Among these characteristics, land use/land cover can be manipulated to gain improvements in water quality. These land use/land cover types can serve as nutrient detention media or as nutrient transformers as dissolved or suspended nutrients move towards the stream. This study examines a methodology to determine nitrate pollution 'contributing zones' within a given basin based on basin characteristics. In this process, land use/land cover types were classified and basins and 'contributing zones' were delineated using geographic information system (GIS) and remote sensing (RS) analysis tools. A 'land use/land cover-nutrient-linkage-model' was developed which suggests that forests act as a sink, and as the proportion of forest inside a contributing zone increases (or agricultural land decreases), nitrate levels will decrease in downstream. In the model, the residential/urban/built-up areas have been identified as strong contributors of nitrate. Other contributors were orchards; and row crops and other agricultural activities.

Moharana and Kar (2001) had made Watershed simulation in a sandy terrain of the Thar Desert using GIS. The sandy landscape in a desert contains very few stream channels. This poses a problem for delineating watersheds for analysis. Since large-scale topographical sheets of sandy terrain also contain very little information on height, delineation of watersheds from topographical sheets often becomes difficult. In order to find a simple solution to the problem in the Thar desert of Rajasthan, India, the authors used the well-known ARC/INFO software for simulation of height and drainage network using the scarce topographical information for a sandy terrain near Jodhpur. Superimposition of data layers generated from remote sensing and secondary sources validated the simulation results, and suggested suitability of the method for application in similar handicapped areas.

Pandey *et al*. (2004) developed the DEM of Bankduth agricultural watershed using ARC/INFO GIS software from contour map. Flow direction and flow accumulation themes were developed using depression-less DEM. Topographical parameters and stream properties relating to land surfaces of watershed were extracted. The DEM and associated parameters derived from their study may be successfully used for simulation of runoff and sediment yield from Banikdih watershed for planning of management practices.

Deshmukh *et al*. (2007) had made an attempt to integrate Geological Information System (GIS) with the Modified Universal Soil Loss Equation (MUSLE) for identification of sediment source areas and the prediction of storm sediment yield from the Banha catchment of upper Damodar river valley in Jharkhand state. The Integrated Land and Information System (ILWIS) package has been used for carrying out geographic analysis. The catchment was first discretized into hydrologically homogenized grid cells to capture the catchment heterogeneity. Various input parameters were worked out using information on distributed digital data base pertaining to land use, soil and DEM.

Selvi *et al*. (2007) studied on digital micro watershed atlas which is a tool for watershed development planning. The soil and landuse survey of India (SLUSI) prepared digital data base through rapid reconnaissance survey on watershed prioritization using GIS and updated certain data set with remotely sensed data. They developed digital layers of drainage, micro watershed and EIMU (erosion intensity mapping units) and integration of these layers were done with the help of GIS. Finally they made spatial distribution of different priority and categories of micro watershed using sediment yield index model.

Poornima and Ravi Babu (2008) made studies on the application of advanced hydrology tools of Geographical Information System (GIS) for field level design of a drop structure. Recent advances in GIS could be effectively used in identification of suitable sites, delineation of catchments area, estimation of runoff and proper design of different soil and water conservation structures. An attempt was made to delineate the catchment of a proposed drop structure in an agricultural micro-watershed in Kashipur block of Purulia district using hydrology modelling extension tools. Runoff of the desired return period was estimated using an integrated approach of GIS based hydrology modeling extension tools and Soil Conservation Service - Curve Number (SCS-CN) model and there after the structure was designed taking into account the site conditions. The study revealed that GIS based catchment delineation and runoff estimation is highly useful in the design of expensive Soil and Water Conservation engineering structures.

Daniel *et al*. (2008) had estimated stream channel geometry in Idaho using GIS and derived the watershed characteristics and described the estimation of stream channel geometry with multiple regression analysis of GIS-derived watershed characteristics including drainage area, catchment -averaged precipitation, mean watershed slope, elevation, forest cover, percent area with slopes greater than 30 percent, and percent area with north-facing slopes greater than 30 percent. Results from this multivariate predictor method were compared to results from the traditional single-variable (drainage area) relationship for a sample of 98 unregulated and undiverted streams in Idaho. Root-mean-squared error (RMSE) was calculated for both multiple- and single-variable predictions for 100 independent, random sub samples of the dataset at each of four different sub sample levels. The multiple-variable technique produced significantly lower RMSE for prediction of both stream width and depth when compared to the drainage area-only technique. In the best predictive equation, stream width depended positively on drainage area and mean watershed precipitation, and negatively on fraction of watershed consisting of north-facing slopes greater than 30. They concluded that within a given physiographic province, multivariate analysis of readily available GIS-derived watershed variables can significantly improve estimates of stream width and depth for use in flow-routing software models.

2.3 Watershed Models and their Applications

Watershed is an area drained by river or a stream system. A process of planning and implementing a course of action that involves a region's natural and human resources and taking into account social, political, economic, environmental and institutional factors operating within a watershed and the surrounding river basins and other relevant regions to achieve the desired social goal. Delineation of the priority areas can be done by using aerial photographs of scale 1:60000. The major phases of hydrology which are influenced by the watershed characteristics are rainfall, infiltration, transpiration, evaporation, groundwater flow and runoff.

There are a number of watershed hydrologic models available and they are broadly grouped as empirical and physically based models (Singh, 1988; Arnold *et al*. 1998; Merrit *et al*. 2003; Gassman *et al*. 2007). Empirical models are black box models and they try to fit a relationship between input and output variables without looking into the governing physical laws. On the other hand, physically based models try to incorporate the physics based processes governing the input output relationship.

Cooke *et al*. (1997) used AGNPS model to assess the impact of management practices on the water quantity and quality from Owl Run, a 1153ha watershed in the Piedmont Region of Virginia. Prior to this assessment, the model was calibrated using 2 years of hydrologic and water-quality data from the same watershed. It was concluded that the model is applicable to nonpoint source (NPS) impact assessment for watersheds similar to Owl Run. Better agreement was found between simulated and observed runoff volumes than between simulated and observed peak rates, sediment or nutrient yields. The results were found to be close to average observed values for the watershed.

Premraj (1999) has conducted a study of Bharathapuzha basin with special reference to check dam. The study includes general study of river basin monitoring of existing and post structure ground water profile, drill holes to find the depth of clay levels, laboratory investigation, water requirement details, and construction details of sub surface dam. From the study it has been found that this type of check dams is cheap, economical, eco-friendly and fast method of construction.

Refsgaard *et al*. (1999) made hydrological modelling of a small watershed using MIKE SHE for irrigation planning. Simulation is first conducted over 109 days, concentrating the attention on the main cropping season, i.e., Kharif (Jul–Oct), and the average water balance is calculated. It is observed that in spite of the frequent rainfall in the season, there are phases when the water content in the root zone goes below the allowable deficit. Hydrological water balance simulation is further extended to the second cropping season, i.e., Rabi (Nov–Feb), over 100-day period. Here, the water stored in the existing tank at the outlet is used for the supplemental irrigation in the season. It is seen that the actual yields obtained are very close to the potential yields of the selected crops. The results overall illustrate the applicability of a comprehensive hydrological modelling system for the management of water resources for agricultural purposes in a watershed.

Purushottam *et al*. (2004) conducted study to find out the organizational issues in implementation of watershed management program at Bara Padampura near Jaipur, Rajasthan. The project experienced many organizational issues at field level implementation. This included high expectations created at the beginning, conflicts between farmers and project staffs on payments, people's participation were not encouraged and lack of leadership. There were also organizational issues perceived by project personnel like lack of training, poor coordination and ego among line departments and lack of commitments. Majority of scientists show their concern in wrong execution of project without associating people in planning and development process.

Loganadhan *et al*. (2005) carried out a study on the impact of watershed development program on awareness, knowledge and attitude of farmers in P.C.Pyapili watershed of Anantapur district of Andhra Pradesh. Among the total of 70 farmers, 35 from the watershed 35 from outside the watershed were selected. The impact of watershed awareness, knowledge and attitude of the farmers were studied with suitable interview schedule and analyzed with apt statistical methods. The results showed that there were significant differences between farmers inside and outside the watershed with regards to their awareness, knowledge and attitude.

Anil Kumar *et al*. (2006) estimated direct runoff based on geomorphologic characteristics of a hilly watershed. A geomorphologic instantaneous unit hydrograph (GIUH) based on two parameters gamma type conceptual model was developed for estimation of direct runoff from a hilly sub watershed of Ramganga river catchment in Uttaranchal, India. The instantaneous unit hydrograph developed after determining both the parameters n and k, i.e. the shape and scale parameters, from the measured hydrologic data, geomorphic parameters and characteristics of the watershed, is called the GIUH for the given watershed, the performance of the developed GIUH model was evaluated by visual observation of the shape of the predicted and observed direct runoff hydrograph for different storm events.

Ashish Pandey *et al*. (2006) The WEPP (Water Erosion Prediction Project) watershed model was calibrated and validated for a small hilly watershed (Karso) of India. Sensitivity analysis of the model was carried out for the input parameters. The analysis shows that the sediment yield is highly sensitive to inter rill erodibility and effective hydraulic conductivity, whereas, runoff is sensitive to effective hydraulic conductivity only. Initially, the model was calibrated using data from the 1996 monsoon season and subsequently its performance was evaluated by estimating the daily runoff and sediment yield using the monsoon season data of different years. Coefficient of determination (R^2) (0.86–0.91), Nash–Sutcliffe simulation model efficiency (0.85–0.95), and percent deviation values (7.90–15.15) indicate accurate simulation of runoff from the watershed. Performance of the WEPP model for simulation of sediment yield was also evaluated. High value of coefficient of determination (R^2) (0.81 – 0.95), Nash–Sutcliffe simulation model efficiency (0.78 –

0.92) and percent deviation values (4.43 –19.30) for sediment yield indicate that the WEPP model can be successfully used in the upper Damodar Valley, India.

De Carlo *et al*. (2006) used the physically distributed modeling system, MIKE SHE, which is applied to the Manoa–Palolo stream system on the island of Oahu, Hawaii, to study the watershed response to storm events. Because of the unavailability of detailed spatially distributed data, a single-valued hydraulic conductivity for the saturated zone is used as the representative of the entire watershed. It is shown that a well-calibrated MIKE SHE with the single-valued hydraulic conductivity is able to produce consistent results with correlation coefficients greater than 0.7. The rainfall distribution along the watershed is the driving factor for the estimation of streamflow.

Gronsten and Lundekvam (2006) estimated yearly and daily surface runoff and soil loss simulated by the WEPP Hillslope model and were compared with measurements from two different soil erosion plot sites in southeastern Norway. The soil at Bjornebekk (Bj) was a levelled silty clay loam (2% organic matter) and the soil at Syverud (Sy) was a loam (5% organic matter).. Four management systems for grain production were used: autumn ploughing (AP), winter crop rotation (WCR), autumn harrowing (AH) and spring ploughing (SP). Hydraulic conductivity and soil erosion parameters were determined using WEPP-recommended equations based on measured soil parameters. In particular, calculations of soil frost development and infiltration into frozen soil need to be improved. The WEPP-recommended soil erosion parameter equations were unsuitable for these two Norwegian soils, especially for levelled soil.

Dass *et al*. (2007) has conducted a hydrological study and water resource assessment in Kokriguda watershed of Orissa for sustainable water management. They made an assessment of water resource potential, availability and demand in Kokriguda watershed, a representative of Eastern Ghats of Orissa, by considering all the sources of water, land uses for sustainable water management. The results showed the annual fresh water potential of 312.45 ha-m including runoff and surface flow

299.39 ha-m and 13.06 ha-m ground water. The annual water requirement in the watershed was estimated to be 155.46ha-m, which included irrigation water requirement and public water demand. Therefore different interventions like installation of underground pipeline irrigation system, proper use of water, in-situ moisture conservation measures, crop diversification etc were executed and found to be effective for sustainable water management.

Dennis *et al*. (2007) tested the Water Erosion Prediction Project (WEPP) model using data from a detailed study conducted on experimental plots in the Apennines Mountain Range, northern Italy. Runoff, soil water and sediment data, together with weather information, were collected on an hourly basis at the study site. WEPP was first applied to simulate transient surface runoff, soil water and erosion. Two important input parameters, the biomass energy ratio for crop and the effective hydraulic conductivity of surface soil, were calibrated using field-observed runoff, soil water, erosion and plant biomass data. The calibrated model was then used to simulate the hydrologic and erosion impacts of three typical crop rotations, thereby to evaluate their abilities in reducing surface runoff and sediment yield. Results indicated that, with the definition of a restrictive layer at the bottom of the soil profile and the calibration of the two crucial model parameters, WEPP could adequately account for the water balance for the modeled experimental plot.

Hongbing *et al*. (2008) tested and evaluated the agricultural non-point source (AGNPS) model for the Wuchuan catchment, a typical agricultural area in the Jiulong River watershed, Fujian Province, China. The AGNPS model was calibrated and validated for the study area with observed data on ten storms. The data on eight storms in 2002 were used for calibration while data on two storms were used for validation of the model. Considering the lack of water quality data over a long-term series, a novel method of comparing an internal nested catchment with its surrounding catchment was used to supplement the less long-term series data. Dual calibration and validation of the AGNPS model was obtained by this comparison. The results indicated that the correlation coefficients were 0.99 and 0.98 for runoff, 0.94

and 0.95 for the peak runoff rate of the large catchment and the small catchment, respectively, and 0.76 for the sediment of the small catchment only

Gong *et al*. (2009) made a comparison of WEPP and SWAT for modeling soil erosion of the Zhangjiachong watershed in the Three Gorges Reservoir Area. In this study, two widely used models – the Water Erosion Prediction Project (WEPP) and the Soil and Water Assessment Tool (SWAT) – were applied to simulate runoff and sediment yield for the Zhangjiachong watershed in the Three Gorges Reservoir Area. The models were run and the simulated runoff and sediment yield values were compared with the measured runoff and sediment yield values. In the calibration period, the model efficiency (E_{NS}) values for the WEPP and SWAT were 0.864 and 0.711 for runoff, and 0.847 and 0.678 for sediment yield, respectively. In the validation period, the E_{NS} values for WEPP and SWAT were 0.835 and 0.690 for runoff, and 0.828 and 0.818 for sediment yield, respectively. The results of E_{NS} and the other criteria indicate that the results of both models were acceptable.

Nikhil and Azeez (2009) have made studies on spatial and temporal variation in surface water chemistry of a tropical river, the river Bharathapuzha, India. They examined the spatiotemporal variation in water quality and quantity of Bharathapuzha river basin using multivariate statistical analysis tools. The sub-basins varied notably in terms of river discharge, elemental concentration as well as elemental load. It was found that in basins that are more disturbed, monsoonal discharge was much higher than the discharges in other seasons, while the slightly disturbed basin had consistent level of discharge throughout the season. Changes in land use and the impact of dams are major reasons for the spatiotemporal variations in the surface water chemistry of the river.

2.4 Watershed Modelling using SWAT

SWAT is a continuous time model which enables users to study long-term impact which is computationally efficient. The physical process associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modeled by SWAT. Simulation of very large basins or a variety of management strategies can be performed without excessive investment of time or money.

John and Muleta (2005) conducted a study,"Sensitivity and uncertainty analysis coupled with automatic calibration for a distributed watershed model"**.** This paper describes an automatic approach for calibrating daily streamflow and daily sediment concentration values estimated by the US Department of Agriculture's distributed watershed simulation model, Soil and Water Assessment Tool (SWAT). The automatic calibration methodology applies a hierarchy of three techniques, namely screening, parameterization, and parameter sensitivity analysis, at the parameter identification stage of model calibration. The Generalized Likelihood Uncertainty Estimation methodology is subsequently implemented to investigate uncertainty of model estimates, accounting for errors due to model structure, input data and model parameters. To demonstrate their effectiveness, the parameter identification, parameter estimation, model verification, and uncertainty analysis techniques are applied to a watershed located in southern Illinois.

Kamble *et al*. (2006) estimated the surface runoff from micro watershed using Soil and Water Assessment Tool (SWAT) and was tested on daily and monthly basis for estimating the runoff from a micro watershed in Chhattisgarh, India. The model was calibrated and validated for the monsoon season of the years 1994 and 1995 using observed daily rainfall and temperature data for the respective years. The major components of SWAT model include hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, groundwater and lateral flow and agricultural management. The model uses SCS curve number method for estimation of runoff volume and adjusts curve number based on antecedent moisture conditions (AMC). On the basis of results obtained through this study, it can be concluded that SWAT model can simulate daily and monthly surface runoff satisfactorily from a micro watershed.

Arun Jose *et al*. (2007) carried out the assessment of runoff and erosion using GIS. The study has been carried out on Gayathri sub basin of Bharathapuzha river basin, with focus on runoff and erosion generating process of the watershed. The specific objective of the study included characterization of watershed from the stand point of runoff and erosion process and quantification of these physical processes. Surface runoff has been computed by SCS curve number method and the result indicate that 38% of annual runoff flows out as surface runoff.

Easton *et al*. (2007) studied on the re-conceptualizing the Soil and Water Assessment Tool (SWAT) model to predict runoff from Variable Source Areas (VSA). In the study, SWAT model was re-conceptualized to distribute overland flow in ways consistent with VSA hydrology by modifying how the CN and available water content were defined. The new modeling approach was called SWAT-VSA. Both SWAT and SWAT-VSA were applied to the subwatershed in the Cannonsville in upstate New York to model predictions of integrated and distributed responses, including surface runoff, shallow perched water table depth, and stream phosphorous loads against direct measures. Similarly, event runoff was predicted well for SWAT-VSA and SWAT. This had important consequences for using model to evaluate and guide watershed management.

Abbaspour *et al*. (2008) Compared uncertainty analysis techniques for a SWAT application to the Chaohe Basin in China. They implemented all the techniques for the soil and water assessment tool (SWAT) and applied them to the Chaohe Basin in China and compared the results with respect to the posterior parameter distributions, performances of their best estimates, prediction uncertainty, conceptual bases, computational efficiency, and difficulty of implementation. The comparison results for these categories are listed and the advantages and disadvantages are analyzed. From the point of view of the authors, if computationally feasible, Bayesian-based approaches are most recommendable because of their solid conceptual basis, but construction and test of the likelihood function requires critical attention.

Divya *et al*. (2009) studied about the watershed simulation using GIS integrated physically based model. They focused on Kadalundi river basin of Kerala state to study the hydrologic behavior of the basin. Widely recommended SWAT model has been used for the study. It emphasis on watershed processes simulation and calibration. GIS techniques are made use of to incorporate spatial variability more thoroughly and efficiently. This study revealed that the model predict the low flow of the river with very good accuracy. Contribution of different sub watersheds towards the total stream flow has been quantified. Hence, recommendations to alleviate the water scarcity and developmental measures for micro watersheds can be given more specifically and effectively.

Sathian and Syamala (2009) had focused their studies on application of GIS integrated SWAT model for basin level water balance. SWAT developed by USDA has been used to analyze and quantify the water balance of a river basin namely, Kunthipuzha in Kerala. The model has been chosen as SWAT is an integrated physically based distributed watershed model. For the study, first the AV-SWAT model has been built for the basin with the help of GIS and remote sensing softwares. DEM, landuse, soil and digitized stream network were prepared in ILWIS package developed by ITC, Netherlands. Landuse of the area has been prepared from LISS-III imagery of IRS 1C. Climatic data has been collected from two meteorological observatories at Pattambi and Mannarkkad. Then the model has been calibrated using observed river flow data. The study reveals the impact of terrain slope on base flow and lateral flow. The study makes the recommendation that SWAT model can be effectively used for assessing the water balance components of a river basin.

Material & Methods

Chapter 3

MATERIAL AND METHODS

3.1 Study Area

Bharathapuzha locally known as Ponnanipuzha which joins the Arabian Sea at Ponnani has been taken for the study. The length of the river is 209km with a catchment area of 6186Km^2. The catchment area is spread over 11 taluks from the Western Ghats to the Arabian Sea. About 2/3rd of the drainage area of the basin i.e. 4400Km^2 lies in Kerala state and the balance in Tamil Nadu. The river basin is bounded by Tirur and Kadalundi basins on the north and Kecheri River on the south. The basin contains about 1, 25,700ha of wet lands, 46,050ha garden lands and 35,400ha waste land.

3.2 Basic Maps and Software Used

1. Toposheets from survey of India (SOI) bearing numbers 49N/13, 58A/8, 58A/12, 58B/1, 58B/2, 58B/5, 58B/6, 58B/7, 58B/9, 58B/10, 58B/11, 58B/13 and 58B/14 prepared in 1:50000 scale.
2. Soil map from National Bureau of Soil Survey and Land Use Planning (NBSS and LUP) prepared in 1:500000 scale.
3. Satellite imagery of LISS III of IRS P6 having four bands from NRSA, Hyderabad.
4. Daily rainfall and temperature data from various meteorological observatories controlled by WRD, Kerala and Kerala Agricultural University.

- ILWIS 3.3 developed by ITC, Netherlands for the generation of GIS maps and attribute data.
- SWAT developed by USDA ARS.

3.3 Description of SWAT model

SWAT is the acronym for Soil and Water Assessment Tool is a complex integrated river basin scale model which simulates the hydrologic processes of each HRUs on daily or hourly time step (Arnold *et al*., 1990 & 1993, Jayakrishnan *et al*., 2005 and Bouraoui *et al.*, 2005). The model has been developed by United State Department of Agriculture (USDA) and has undergone many capability expansions (Neitsch *et al.*, 2005). The model can predict the impacts of land management practices on water, hydrologic components, sediment load and water quality. It can assist the land and water managers to assess the impact of land management practices in hydrology, erosion and non point source pollution. It is a physically based model in which rather than incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation and land management practices occurring in the watershed SWAT divides the watershed into sub watersheds based on land slope direction and channel network. The sub basin is further classified into smaller modeling units, known as hydrologic response units (HRU) depending upon the variation of land use and soil. The flow chart of SWAT is given in figure 3.1

3.4 Important Hydrologic Equations of SWAT

The important equations to predict the watershed of hydrology is given below. The hydrologic cycle is simulated by the water balance equation:

$$SW_t = SW_O + \sum_{i=1}^{t}\left(R_i - Q_i - ET_i - P_i - QR_i\right) \qquad 3.4.1$$

Where, SW_t and SW_0 are the final and initial soil water content respectively (mm).

R = daily rainfall (mm); Q = daily surface runoff (mm); ET = daily evapotranspiration (mm); P = daily percolation (mm) and QR = daily lateral flow (mm).

Surface runoff is predicted by:

$$Q = \frac{(R - 0.2S)^2}{R + 0.8S} \quad \text{For } R > 0.2S \qquad 3.4.2$$

Q = 0.0 for R<0.2S 3.4.3

$$Q = 254\left(\frac{100}{CN} - 1\right) \quad 3.4.4$$

Where, Q = daily surface runoff (mm); R = daily rainfall (mm); S = retention parameter (mm); CN = curve number.

CN1 and CN3 are found out as function of CN2

$$CN1 = \frac{20(100 - CN_2)}{\left(100 - CN2 + e^{(25.33 - 0.0636(10 - CN2))}\right)} \quad 3.4.5$$

$$CN\ 3 = CN\ 2\ e^{(0.00673\ (100 - CN_2))} \quad 3.4.6$$

Lateral flow is predicted by:

$$q_{lat} = 0.024^{\frac{(2SxScSin\alpha)}{\theta_d L}} \quad 3.4.7$$

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

The base flow is estimated by

$$Q_{gw} = Q_{gwj-1} e^{(-\alpha_{gw}\Delta t)} + W_{rchrg}\ (1 - e^{(-\alpha_{gw}\Delta t)}) \quad 3.4.8$$

Where, Q_{gwj} = groundwater flow into the main channel on day j; α_{gw} = base flow recession constant; Δt = time step.

The evapotranspiration is estimated by Penman- Montieth equation

$$\lambda ET_o = \frac{\Delta(R_n - G) + \rho C_p (e_a - e_d)/r_a}{\Delta + \gamma(1 + r_c / r_a)} \quad 3.4.9$$

Where, R_n = net radiation flux at surface [kJ m^{-2} s^{-2}]; $(e_a - e_d)$ = vapour pressure deficit [kPa]; r_a = aerodynamic resistance [sm^{-1}]; r_c = crop canopy resistance [sm^{-1}];

γ = psychrometric constant [kPa $^oC^{-1}$]; Δ = slope of vapour pressure curve [kPa $^oC^{-1}$]; ρ = atmospheric density [Kg m^{-3}]; C_p = specific heat of moist air [kJ kg^{-1} $^oC^{-1}$]; λET_o = latent heat flux of evaporation [kJ m^{-2} $^oC^{-1}$]; G =soil heat flux [kJ m^{-2} s^{-2}]; λ = latent heat of vaporization [MJ kg^{-1}]

3.5 Digital Thematic Maps required by SWAT and their preparation

3.5.1 Drainage map:

Drainage network of the study area are digitized from the toposheets mentioned in section 3.2 using on-screen digitization capability of ILWIS software. Thus segment map of drainage network was prepared. Universal Transverse Mercator (UTM) projections corresponding to zone 43 was used as the co-ordinate system for all the thematic maps. Drainage map of the Bharathapuzha watershed is shown in the figure 4.2

3.5.2 Digital Elevation Model (DEM)

Digital Elevation Model can store continuously varying variables such as elevation, groundwater depth or soil thickness. The accuracy of a DEM depends very much on the detail of the contour lines and the scale of the original topographic map from which the contour lines were digitized. The larger the scale of map, smaller the contour interval, the more accurate the DEM will be. Contour lines given in the toposheets were digitized to get the contour map for the study area. While digitizing the contours, the contour lines lying at the outer premises of the river basin boundary were also included to make the interpolation of the contour values possible at the time of DEM generation. Corrections were applied to remove the errors caused due to surface overlaps, dead end and intersections. After the error corrections, the segment contour map was rasterised using the segment to raster feature of ILWIS. Then a point elevation map was prepared for the entire study area using the point elevation data given in the toposheet. Point map was then rasterised to get a raster point map. Using the raster contour segment map and raster point map DEM was prepared.

3.5.3 Soil map

An analog soil map has been collected from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) containing the details of different soil classes and their aerial coverage. The map is scanned and imported to ILWIS environment using the "File-import" option of the software. Then boundaries of the different soil groups were digitized and segment soil map was generated. A point map was then prepared giving labels to individual soil types. Using this segment soil map and the label points the polygon map of the soil was prepared.

3.5.4 Landuse map

Landuse details like agriculture, non-agriculture, forest, plantation, grass land with demarcation of its boundaries are represented in the landuse map. If the thematic map on land use is available, the particulars are to be verified in the field and appropriate correction is carried out. If the thematic map is not available, land use particulars is collected survey number wise and verified. The land use map was prepared from satellite imagery of IRS P6, LISS-III using the spectral bands of I (0.52-0.59μm), II (0.62-0.68μm) and III (0.77-0.876μm). A False Colour Composite (FCC) of the imagery was prepared using ILWIS and it was geo-referenced. A sample set for the supervised classification of the imagery was prepared and was classified to get the landuse map. Extensive ground truthing were carried out to verify the result of supervised classification with the help of hand held GPS.

All the above said thematic layers in digital format and the corresponding attribute data were given as input to the SWAT and the modelling of the physical characteristics and simulations of the hydrological processes of the watershed were carried out.

The basic map inputs required for the AVSWAT include digital elevation, soil maps, land use/cover, hydrography (stream lines). In addition, the interface requires the designation of land use, soil, weather, as well as the simulation period, to ensure a successful simulation. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling etc are directly modeled by SWAT using this input data.

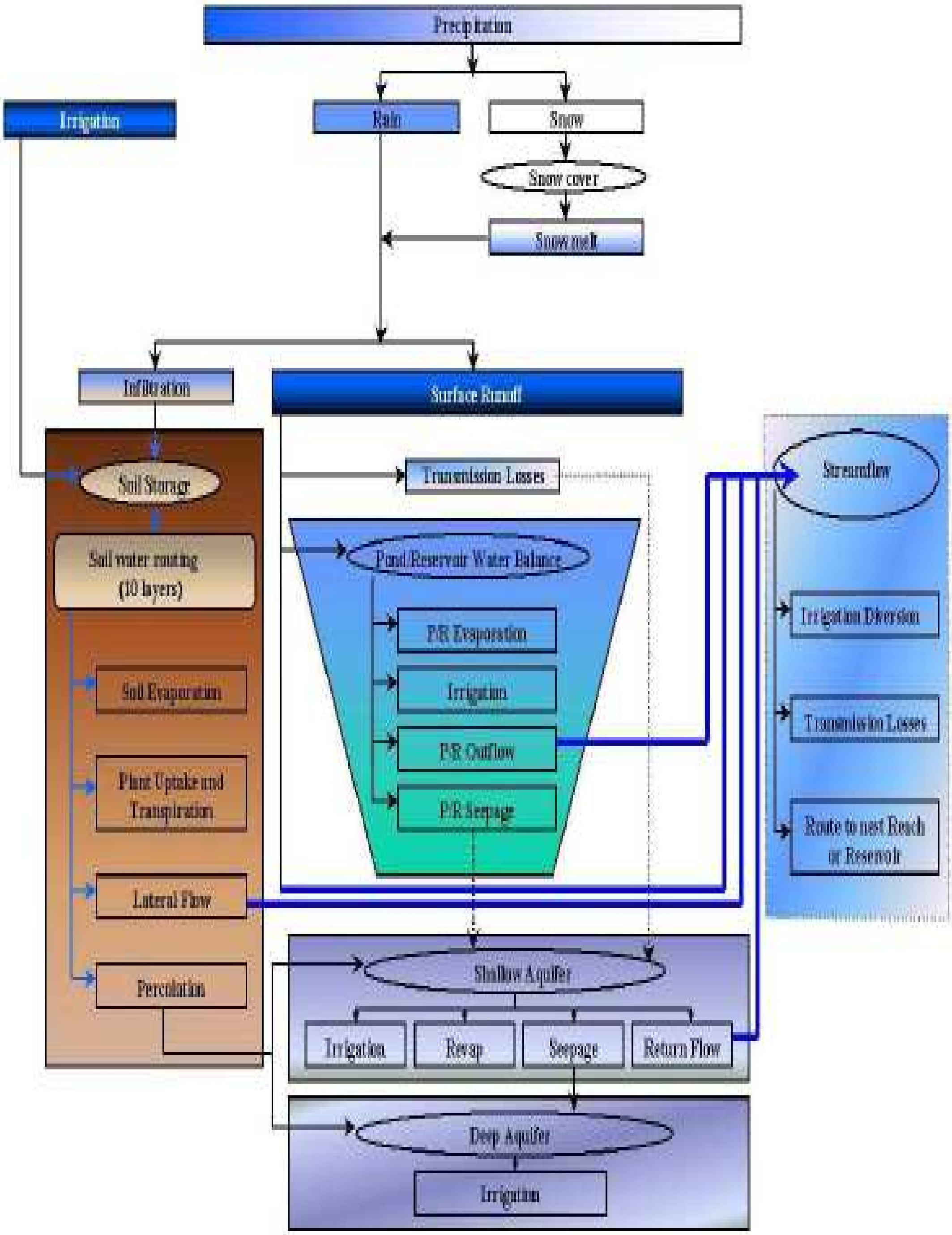

Fig.3.1 The flow chart showing the pathway available for water movement in SWAT

3.6 Attribute Information required by SWAT and Their Preparation

SWAT can be used to simulate a single watershed or a system of multiple hydrologically connected watersheds. Each watershed is first divided into subbasins and then into hydrologic response units (HRUs) based on the land use and soil distributions.

3.6.1 Precipitation Gauge Location Table (dBASE)

The precipitation gauge location table is used to specify the location of rain gauges. The format of the data is given in the table 3.1.

Table 3. 1 Precipitation Gauge Location Table

Field name	Field format	Definition
ID	Integer	Gauge identification number
NAME	String max 8 char	Corresponding table name string
XPR	Floating point	X coordinate in the defined projection
YPR	Floating point	Y coordinate in the defined projection
ELEVATION	Integer	Elevation of rain gauge (m)

3.6.2 Precipitation Data Table (dBASE)

The precipitation data table is used to store the daily precipitation for an individual rain gauge. This table is required if the rain gauge option is chosen for rainfall in the weather data dialog box. There will be one precipitation data table for every location listed in the rain gauge location table. The name of the precipitation data table is "name.dbf" or “name.txt” where name is the character string entered for NAME in the rain gauge location table. This table is formatted as a dBase table.

Table 3. 2 Precipitation Data Table

Field name	Field format	Definition
DATE	Date(yyyymmdd)	Day of precipitation
PCP	Floating point(f5.1)	Amount of precipitation(mm)

3.6.3 Temperature Data Table (dBASE)

The temperature data table is used to store the daily maximum and minimum temperatures for a weather station. This table is required if the climate station option is chosen for temperature in the weather data dialog box. The name of the temperature data table is "name.dbf" or “name.txt” where name is the character string entered for NAME in the temperature gauge location table. This table is formatted as a dBase table.

Table 3. 3 Temperature Data Table

Field name	Field format	Definition
DATE	Date(yyyymmdd)	Day of measure
MAX	Floating point(f5.1)	Daily maximum temperature (°C)
MIN	Floating point(f5.1)	Daily minimum temperature (°C)

3.7 Settting Up of Swat Model

Key Procedures involved in the setting up of the model is given below:

- Load or select the AVSWAT2005 extension
- Delineate the watershed and define the HRUs
- (Optional) Edit SWAT databases
- Define the weather data
- Apply the default input files writer
- (Optional) Edit the default input files
- Set up (requires specification of simulation period, PET calculation method, etc.) and run SWAT
- (Optional) Apply a calibration tool (Optional) Analyze, plot and graph SWAT output.

3.7.1 Watershed Delineation

The Watershed Delineation carries out advanced GIS functions to aid in segmenting watersheds into several hydrologically connected sub-watersheds for use in watershed modeling. The delineation process requires a Digital Elevation Model (DEM) in ArcInfo grid format.

Key Procedures involved are:

1. The DEM is first loaded to the Arc-VIEW - SWAT interface.
2. The digitized stream network is then loaded for the delineation to be accurate.
3. Preprocessing of the DEM is then done.
4. The minimum sub-watershed area (critical source area) is then specified.
5. The stream network points are then reviewed and edited.
6. The calculation of the subbasin parameters are then done in SWAT.

3.7.2 Land Use/Soil Characterization

Land Use and Soil Characterization for a watershed are performed using two commands in the AVSWAT menu of the Watershed View. This tool allows loading land use and soil themes into the current project and determines the land use/soil class combinations and distributions for the delineated watershed and each respective sub-watershed. The themes can be either grid or shape format.

Once the land use and soil themes have been imported and linked to the SWAT databases, the criteria are specified which are used in determining the HRU distribution.

Key Procedures involved for land use/ soil overlay are:

1. The land use theme is defined.
2. The land use theme is then reclassified.
3. Similarly, the soil theme is also defined and reclassified.
4. The land use and soil themes are then overlaid.

3.7.3 HRU Distribution

Once the land use and soil data layers have been imported, the distribution of hydrologic response units (HRUs) within the watershed is determined. One or more unique land use/soil combinations (hydrologic response units or HRUs) can be created for each subbasin. Subdividing the watershed into areas having unique land use and soil combinations enables the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers/crops and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy of load predictions and provides a much better physical description of the water balance. HRU distributions involve selecting multiple HRUs or dominant HRU for each subwatershed. Then for these multiple HRUs, the land use and soil threshold levels are defined. In case multiple HRUs are to be delineated, the threshold levels of landuse and soil are defined.

3.7.4 Weather Data Import

Weather data to be used in the watershed simulation is imported once the HRU distribution has been defined. Weather station locations are loaded into the current project and weather data namely, rainfall and temperature data's of the sub-watersheds are assigned. A -99.0 value is given to fill in skipped daily data and to fill in measured climate records so that all records have the same starting and ending date. The starting date used for measured climate data is the earliest starting date listed in the record while the ending date is the latest ending date listed in the record. The –99.0 value is used to call the weather generator to generate a value to replace the missing data during run time. Other data's like wind speed, solar radiation and relative humidity data's are successfully simulated accordingly.

3.7.5 Creation of Input

The items contained in the Input menu allow one to build database files containing the information needed to generate default input for SWAT. Several commands are listed on the Input menu. These commands are enabled in sequence (the next command is enabled only after the steps associated with the previous command are completed) and need to be processed only once for a project. When all of the default inputs have been generated, the SWAT can be simulated and is made to run.

3.7.6 SWAT Output

The Simulation menu allows finalizing the set up of input for the SWAT model and run the SWAT model; it reads the results of the simulation and builds dBASE tables and applies a calibration tool and performs load calculations. Only the ASCII output files in spreadsheet format are loaded into dBASE tables. Some of the SWAT output files viewed in the study includes Subbasin Output File (.sub) and Main Channel Output File (.rch).

3.8 Model Calibration and Validation

Calibration is a process of model testing with known input and output used to adjust and estimate factors and validation is a process of comparison of model results with an independent data set without further adjustments. Some of the calibration issues include individual landuse parameter determination, location of gauging station data, available information on stream systems etc. Physically based distributed watershed models should be calibrated before they are made use of in the simulation of hydrologic processes. This is to reduce the uncertainty associated with the model prediction. Hence, before going for the determination of the hydrologic components, a thorough attempt has been made to tune the parameters of the model so that the predicted values are in very close agreement with available measured data.

The key considerations of the hydrologic calibration includes water balance and storm sequence. The calibration statistics include the mean and standard deviation of the simulated and measured data, Nash-Sutcliffe Efficiency (NSE) and coefficient of determination (R^2). The model was calibrated by changing the parameters sequentially for obtaining optimum value of Nash-Sutcliffe Efficiency. Since daily rainfall data for the basin was available for seven years only, from 1996 to

2002, the calibration and validation exercise had to be confined to this period. Out of this, five years data (from 1996 to 2000) has been used for calibration and the rest for validation. First, the calibration has been done for annual output values and then it was extended to monthly basis. The mathematical form of Nash-Sutcliffe Efficiency is given as:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(y_o - y_s)^2}{\sum_{i=1}^{n}(y_o - \overline{y})^2}$$

Where, y_o = observed value; y_s = simulated value; $\overline{y}$ = mean of observed values, n = number of pairs of simulated and observed values.

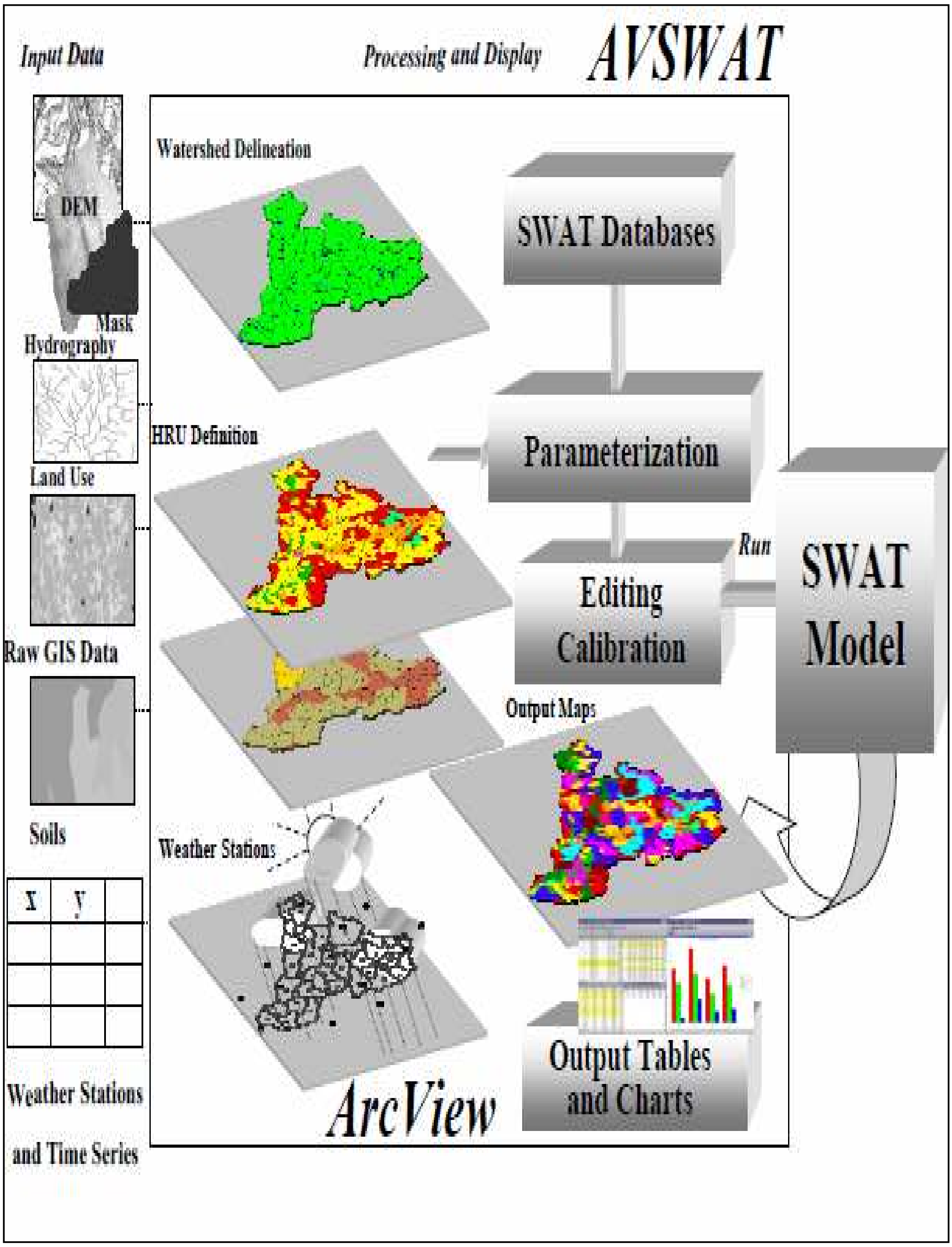

Fig. 3. 2 Schematic diagram of setting up of SWAT model.

Results & Discussion

Chapter 4

RESULT AND DISCUSSION

4.1 Catchment Characteristics

The Bharathapuzha watershed has been divided into 127 subbasins and a total of 366 Hydrologic Response Units (HRU) have been identified by keeping Kumbidi as the outlet of the watershed. Fig 4.1 shows the watershed with watershed boundaries. Threshold area assigned for the sub watershed delineation was 2000ha. Digital drainage map was used for the accurate delineation of the subwatersheds. A threshold area of 20% each was assigned to both landuse and soil for the delineation of HRUs.

4.2 Digital Elevation Model (DEM)

The Digital Elevation Model of Bharathapuzha subbasin is prepared with a resolution of 50m. The DEM has been classified for different elevation ranges and the classified map showing different elevation ranges are shown in Fig.4.1. Elevation ranges from 20m to 2361m with mean elevation at 214.3m.

4.3 Hypsometric curve

The hypsometric curve of the watershed which shows the area elevation relationship is presented in figure. 4.3. The curve shows that about 48.96% of the total watershed area is below 100m elevation; 47.5% is between 100m to 1000m and only 3.54% is between 1000m to 2361m.

4.4 Soil map

The soil map of the river Bharathapuzha with 21 soil classes which is further reclassified into 9 soil series has been developed. The digital soil map showing different soil series are shown in the figure 4.4. About 55.4% of the total area of the watershed is having Anayadi soil series. The other soil series of the watershed include Chelikkuzhi, Cheruvalli, Kanchirappuzha, Kongad, Manimala, Manjallor, Pallippadi and Vijayapuram

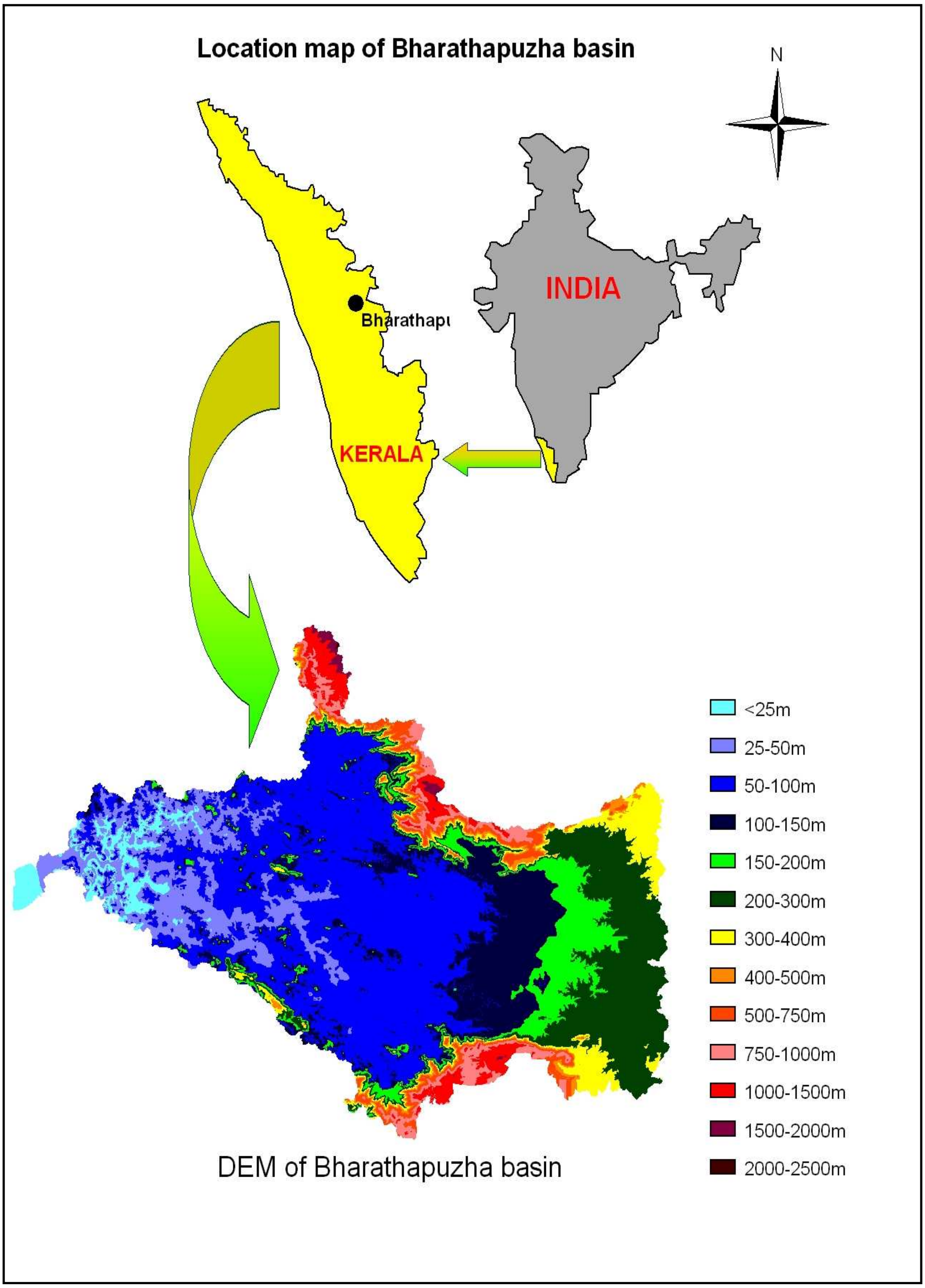

Fig. 4.1 Location of the watershed with Digital Elevation Model.

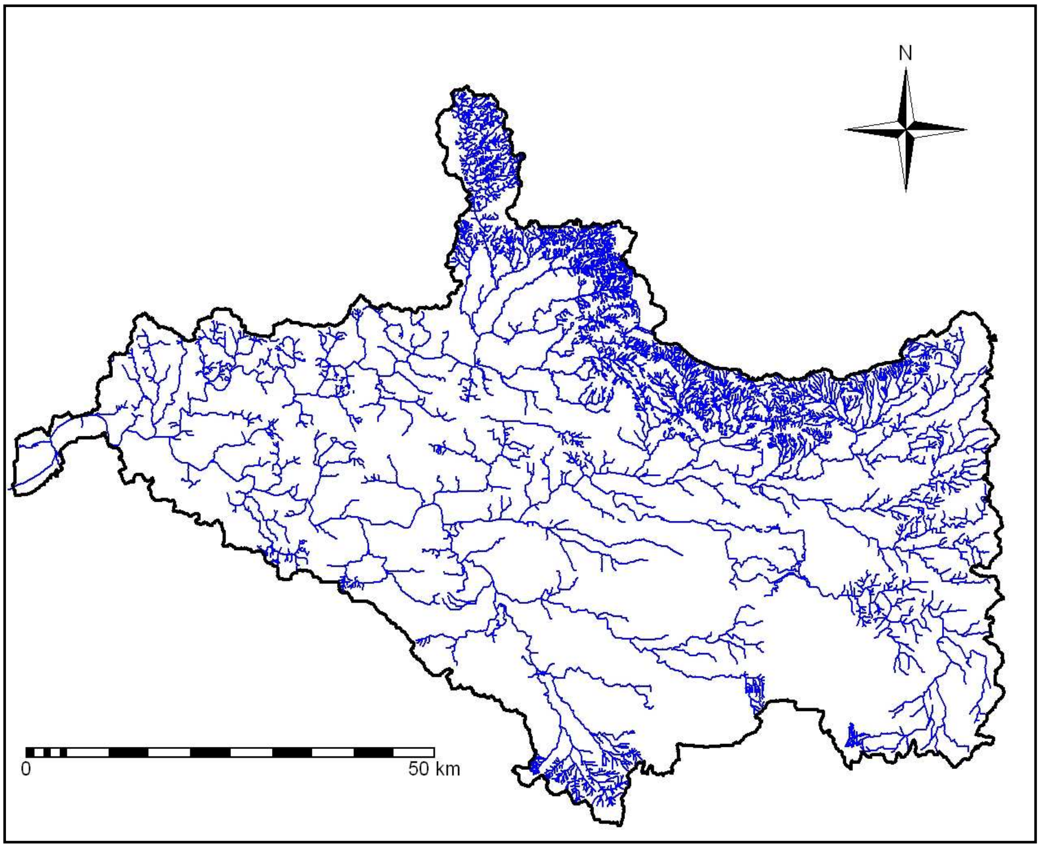

Fig. 4.2 Bharathapuzha catchment with drainage network.

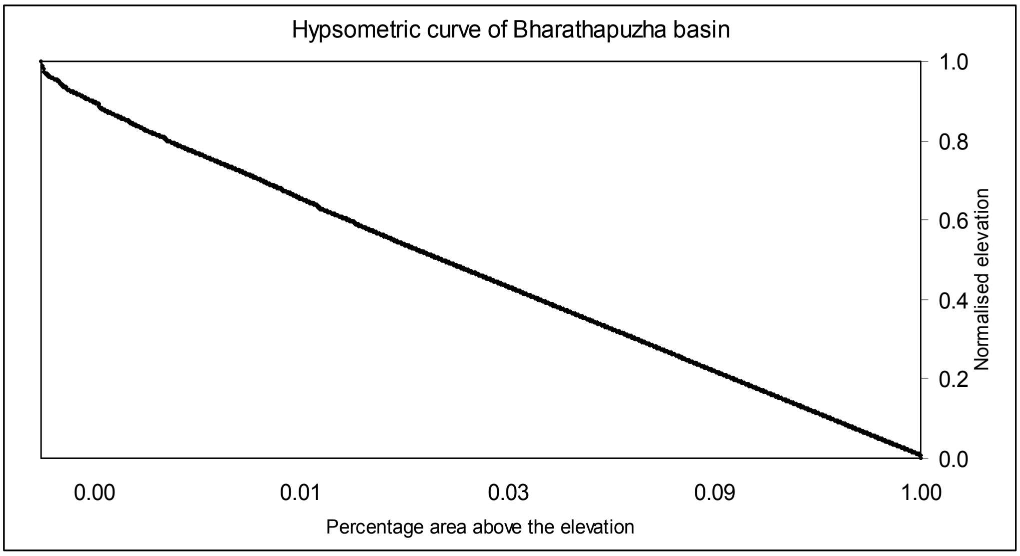

Fig. 4.3 Hypsometric curve of Bharathapuzha basin.

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4.5 Land use map

The land use map (figure 4.5) developed through supervised classification of the satellite imagery shows that there are 10 different land use classes. Major land use types developed in the watershed are paddy (47.33%) and garden land (31.54%). The rest of the landuse classes delineated in the watershed include Dense forest, Medium forest, Moderate dense forest, Plantation, River dry, Rubber and water.

4.6. Physical properties of soil

Majority of the soils have very high clay and sand content with very low fraction of silt. Surface texture of the soils comes under clayey or clayey loam Physical properties are shown in table 4.1.

4.7 Landuse and soil distribution

The area coverage of different land use and soil types is shown in table 4.2.

Table 4. 1 Physical properties of different soil series.

Sl. No.	Soil Series	Clay (%)	Silt (%)	Sand (%)	Sol_CBN (%)	Sol_AWC (Mm)	Area (Km^2)
1	Anayadi	27.8	8.5	63.7	.89	103.7	2600.19
2	Chelikkuzhi	33.7	8	58.3	2.18	105.2	328.99
3	Cheruvalli	34.50	6.1	59.4	2.54	0.06	156.74
4	Kanchirappuzha	33.0	8.6	5.4	2.24	0.08	606.62
5	Kongad	27.7	15.7	56.4	1.24	0.09	66.56
6	Manimala	27.0	9.0	64.0	0.99	0.09	48.64
7	Manjallor	45.0	7.9	47.1	1.83	0.07	54.12
8	Pallippadi	27.0	9.0	64.0	0.99	93.9	545.41
9	Vijayapuram	24.7	9.5	65.8	1.01	58.8	261.07

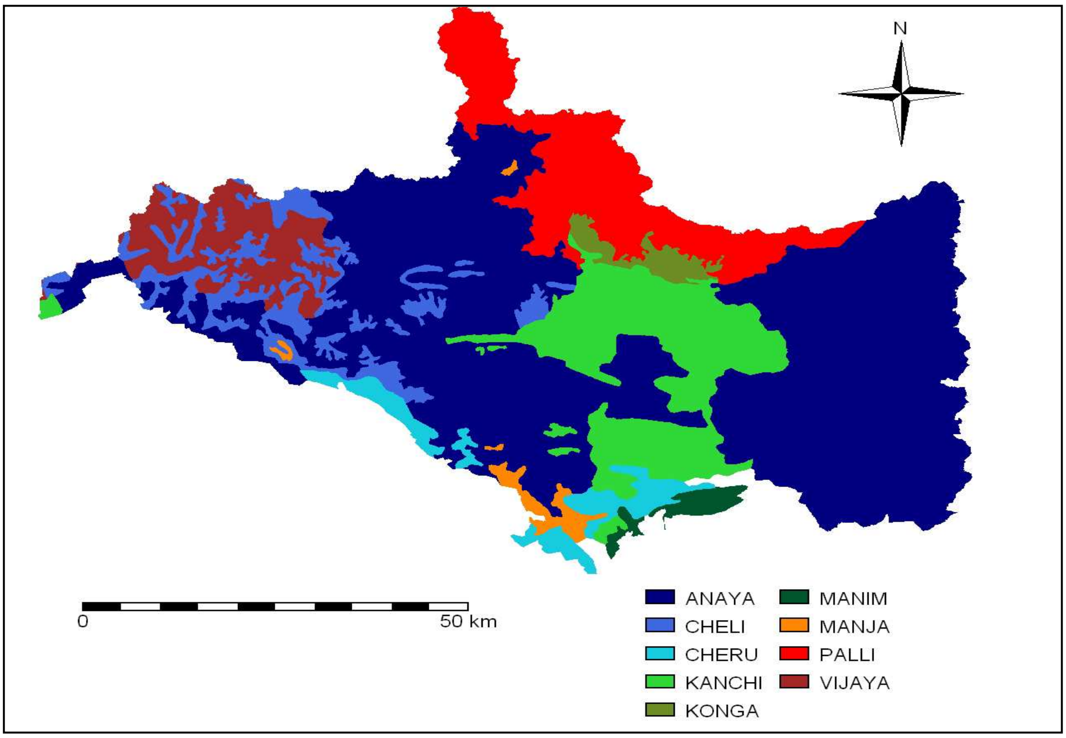

Fig. 4.4 Bharathapuzha watershed – Soil map

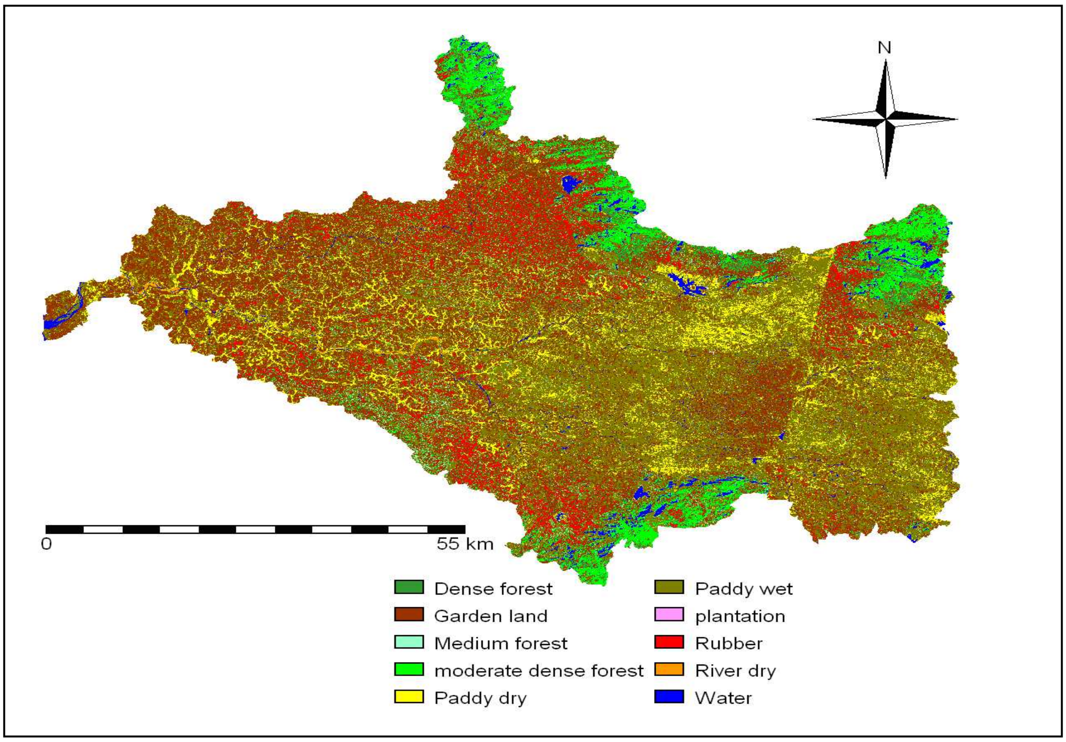

Fig. 4.5 Bharathapuzha watershed – Landuse map

Table 4. 2 Landuse and soil of Bharathapuzha watershed and their area coverage.

Landuse			Soil		
Class	Area (km^2)	% area of ws	Series	Area (km^2)	% area of ws
Dense forest	143.19	3.00	Anayadi	2600.19	55.7
Garden land	1504.02	31.54	Chelikkuzhi	328.99	7.05
Medium forest	129.45	2.71	Cheruvalli	156.74	3.36
Moderate dense forest	330.15	6.92	Kanchirappuzha	606.62	13
Paddy dry	400.13	8.39	Kongad	66.56	1.43
Paddy wet	1856.85	38.94	Manimala	48.64	1.04
Plantation	0.20	0.004	Manjallor	54.12	1.16
River dry	12.31	0.26	Pallippadi	545.41	11.68
Rubber	289.88	6.08	Vijayapuram	261.07	5.59
water	102.12	2.14			
Total	4768.30	100	Total	4668.30	100.00

4.8 Mean monthly rainfall and temperature

Mean monthly rainfall distribution for the study period is shown in figure 4.6 and it indicates that temporal variation of rainfall is very significant. The month of July receives the maximum rainfall of about 570.45mm out of the annual total of 2183.25mm and it is followed by June, October and August (452.62, 338.92, 314.76, mm respectively). Practically there is no rainfall from the month of December to March. The monthly temperature variation shows that maximum temperature is received in the month of March (30^0C), May (29.97^0C) and April (29.36^0C). Lowest temperature is experienced during February and October to December.

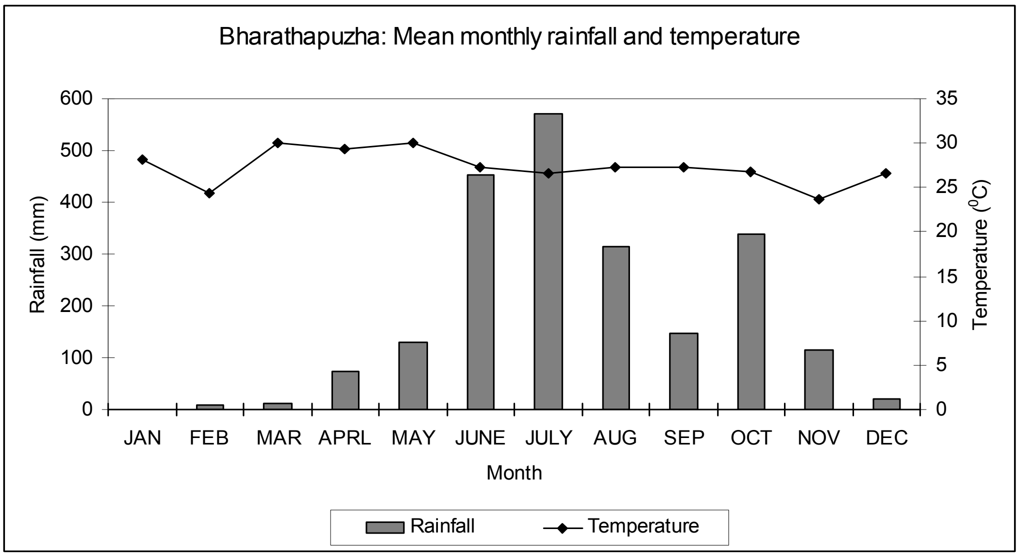

Fig. 4.6 Mean monthly rainfall and temperature of Bharathapuzha

4.9 Mean monthly river flow

The Monthly river flow pattern closely follows the monthly rainfall pattern which indicates that water storage in the basin is poor. It can be observed that 26.5% of river discharge is taking place during July followed by August (21.3%), October (14.7%) and June (12%). River flow in Bharathapuzha is almost nil during February to April (figure 4.7).

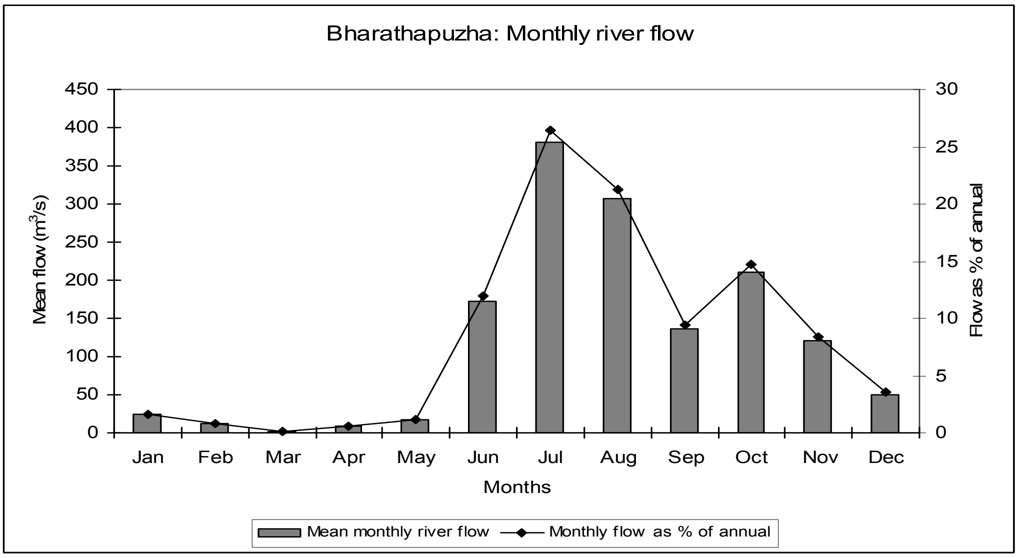

Fig. 4.7 Mean monthly river flow of Bharathapuzha.

The observed Vs simulated values of annual average River flow for precalibrated and postcalibradated model is shown in figure 4.8 and 4.9. It is found that the simulated flow matches well with the observed values. The simulation estimates that the peak values of flow have been experienced in the year of 1998.

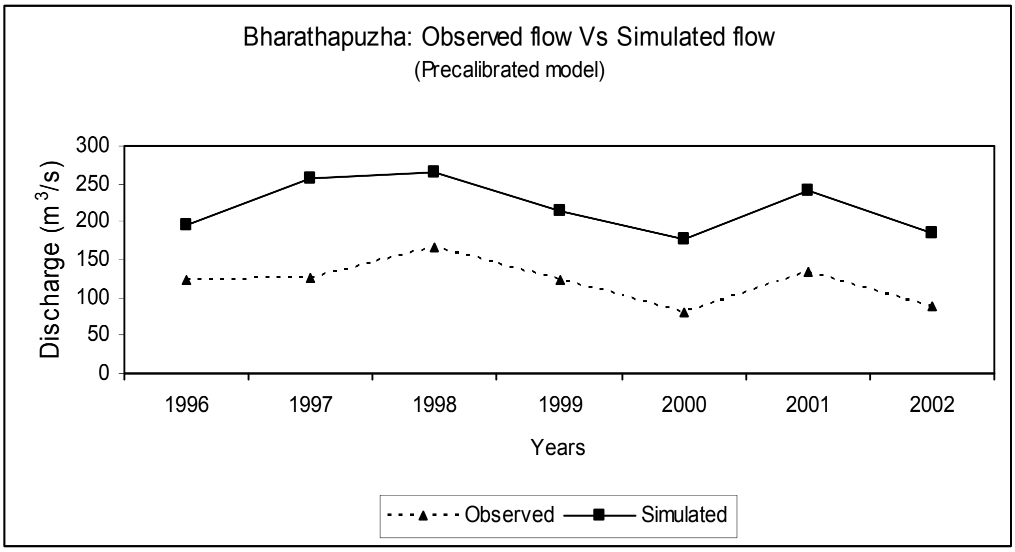

Fig. 4.8 Annual average river flow: Observed Vs Simulated by the Pre-calibrated model

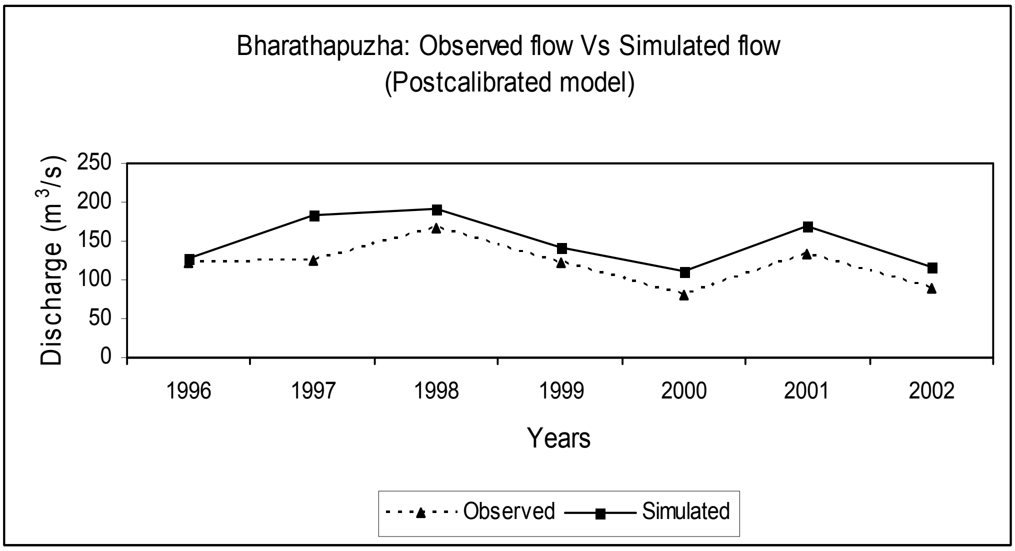

Fig. 4.9 Annual average river flow: Observed Vs Simulated by the Postcalibrated model

4.10 Subwatershed map

The Bharathapuzha basin has been divided in to 127 subwatersheds. Fig 4.10 shows the watershed with subwatershed boundaries.

4.11 Description of Subwatersheds

Table 4. 3 . Physical characteristics of the sub watersheds in Bharathapuzha River basin

Subwater-shed No	Area (km^2)	Mean elevation (m)	Mean slope (m/m)	Channel length (km)	Channel slope (m/m)
1	35.31	567.97	0.272	4.739	0.0440
2	27.99	555.94	0.326	3.196	0.0140
3	128.8	1126.72	0.345	24.961	0.0410
4	33.08	236.068	0.236	3.895	0.0050
5	24.52	327.47	0.321	1.101	0.0170
6	65.61	788.06	0.391	14.861	0.0910
7	33.52	176.79	0.163	7.293	0.0030
8	14.11	73.48	0.033	6.953	0.0020
9	23.04	88.73	0.052	12.204	0.0010
10	50.23	100.27	0.080	15.404	0.0010
11	2.53	69.83	0.047	1.511	0.0010
12	2.07	79.63	0.053	1.566	0.0190
13	20.21	87.57	0.089	0.196	0.0010
14	0.14	44.15	0.048	0.341	0.0010
15	20.97	76.49	0.067	0.758	0.0160
16	50.42	75.91	0.057	9.113	0.0030
17	10.69	72.99	0.083	3.585	0.0030
18	20.99	90.55	0.120	0.560	0.0140
19	3.77	58.0	0.081	3.606	0.0020
20	10.27	72.77	0.059	3.909	0.0020
21	27.77	64.25	0.095	2.287	0.0040
22	88.84	59.72	0.088	14.520	0.0020
23	29.86	72.2	0.110	1.674	0.0020
24	31.11	43.07	0.059	9.788	0.0010
25	40.99	418.76	0.342	8.226	0.0040
26	45.81	194.85	0.173	8.432	0.0020
27	29.94	70.31	0.075	5.842	0.0001
28	28.97	83.84	0.047	3.101	0.0010
29	35.16	105.42	0.087	7.955	0.0040
30	61.52	77.50	0.082	6.821	0.0030
31	23.49	1101.27	0.497	2.413	0.0160
32	24.36	309.0	0.211	1.896	0.0020

Subwater-shed No	Area (km^2)	Mean elevation (m)	Mean slope (m/m)	Channel length (km)	Channel slope (m/m)
33	35.61	39.81	0.076	11.803	0.0010
34	26.29	44.38	0.061	3.284	0.0010
35	57.2	63.24	0.075	9.407	0.0030
36	24.84	48.58	0.083	2.510	0.0040
37	59.77	498.15	0.189	6.361	0.0070
38	47.45	343.34	0.124	6.018	0.0110
39	.75	36.08	0.097	1.549	0.0050
40	1.12	37.47	0.068	1.933	0.0040
41	18.86	33.5	0.053	5.616	0.0020
42	26.64	29.55	0.034	8.263	0.0010
43	30.27	493.01	0.348	9.364	0.0060
44	70.05	565.15	0.262	10.145	0.0190
45	5.71	196.25	0.088	3.609	0.0050
46	5.8	191.639	0.018	1.728	0.0020
47	101.42	342.14	0.045	20.897	0.0090
48	34.75	246.79	0.044	6.430	0.0060
49	22.71	60.23	0.056	1.848	0.0010
50	23.49	38.85	0.048	8.241	0.0020
51	36.82	104.29	0.096	3.546	0.0050
52	59.69	91.6	0.045	10.395	0.0050
53	14.19	128.65	0.092	3.913	0.0020
54	32.04	122.36	0.040	10.653	0.0020
55	40.01	178.85	0.136	4.514	0.0001
56	20.69	203.07	0.117	1.113	0.0040
57	28.05	160.21	0.057	10.866	0.0050
58	9.92	82.34	0.011	4.796	0.0001
59	28.99	91.65	0.033	5.888	0.0010
60	52.65	83.64	0.006	19.525	0.0010
61	8.77	87.78	0.007	3.780	0.0030
62	34.81	96.78	0.007	5.627	0.0030
63	43.74	304.04	0.021	6.995	0.0090
64	20.49	284.86	0.028	0.737	0.0080
65	24.19	220.95	0.086	6.773	0.0030
66	29.84	126.71	0.010	10.800	0.0030
67	65.17	54.95	0.058	10.020	0.0020
68	1.59	35.44	0.010	1.616	0.0020
69	22.46	54.36	0.059	1.615	0.0040

Subwater-shed No	Area (km^2)	Mean elevation (m)	Mean slope (m/m)	Channel length (km)	Channel slope (m/m)
70	18.04	48.35	0.045	6.403	0.0020
71	76.84	67.77	0.063	9.094	0.0020
72	33.89	54.49	0.055	9.293	0.0040
73	58.71	196.39	0.022	16.605	0.0050
74	59.13	168.25	0.015	11.690	0.0040
75	49.66	64.34	0.051	11.734	0.0010
76	10.08	57.53	0.056	3.052	0.0020
77	50.63	70.42	0.067	6.743	0.0020
78	0.65	44.67	0.006	1.454	0.0010
79	26.75	65.9	0.061	10.420	0.0010
80	10.67	53.89	0.064	4.251	0.0010
81	74.10	78.74	0.015	11.875	0.0020
82	16.98	80.31	0.043	4.026	0.0060
83	91.88	70.7	0.066	13.362	0.0010
84	31.97	67.57	0.026	9.737	0.0070
85	68.25	123.39	0.011	23.329	0.0020
86	60.43	110.63	0.007	10.104	0.0020
87	51.39	79.14	0.012	12.994	0.0010
88	41.93	78.83	0.023	8.311	0.0010
89	25.92	81.34	0.067	3.431	0.0001
90	87.22	92.2	0.083	7.164	0.0001
91	45.05	241.1	0.019	10.504	0.0050
92	7.82	197.01	0.018	2.644	0.0001
93	38.67	240.9	0.018	7.838	0.0050
94	39.33	243.97	0.017	8.731	0.0060
95	30.49	139.96	0.027	6.340	0.0050
96	74.69	197.57	0.015	17.418	0.0030
97	3.33	52.18	0.039	2.449	0.0010
98	70.74	71.38	0.034	14.954	0.0010
99	37.79	66.71	0.021	11.081	0.0010
100	23.97	78.21	0.039	4.869	0.0030
101	0.70	46.37	0.014	0.957	0.0080
102	49.70	113.25	0.106	8.392	0.0030
103	68.62	87.19	0.018	11.383	0.0020
104	41.38	80.82	0.018	9.705	0.0020
105	48.76	240.03	0.015	13.997	0.0030
106	31.74	244.13	0.021	3.898	0.0050

Subwater-shed No	Area (km^2)	Mean elevation (m)	Mean slope (m/m)	Channel length (km)	Channel slope (m/m)
107	22.08	123.24	0.013	0.418	0.0050
108	21.61	106.22	0.011	1.175	0.0010
109	51.35	145.88	0.024	14.002	0.0040
110	0.16	100.13	0.003	0.341	0.0010
111	18.73	254.47	0.012	7.246	0.0030
112	37.95	217.34	0.012	9.704	0.0030
113	46.99	263.51	0.052	11.340	0.0080
114	34.74	270.75	0.097	6.274	0.0070
115	43.65	102.67	0.012	11.205	0.0030
116	107.89	365.63	0.231	21.892	0.0040
117	13.1	69.43	0.045	4.696	0.0010
118	2.19	74.24	0.020	2.747	0.0040
119	77.17	98.46	0.072	12.584	0.0020
120	65.62	275.86	0.224	10.898	0.0020
121	77.22	385.47	0.105	17.081	0.0070
122	50.37	279.08	0.014	6.384	0.0010
123	22.11	216.1	0.135	1.241	0.0010
124	33.29	206.99	0.141	7.327	0.0040
125	23.18	390.3	0.300	1.341	0.0020
126	31.24	560.51	0.289	5.831	0.0190
127	12.59	39.39	0.073	4.733	0.0010

4.12 Model calibration and validation

Seven years (1996-2002) of daily rainfall data is used for the model simulation and the prediction has been validated using observed river flow. The period of 1998 –1999 is taken as calibration period and the period of 2001-2002 is taken as the validation period for monthly average river flow, in which precalibrated and calibrated models are compared as shown in fig 4.11 and 4.12. Nash Sutcliffe Efficiency and Coefficient of Determination for calibrated and precalibrated models during these periods are shown in table 4.4 and 4.5. Time series curve shows close resemblance for the observed and simulated river flow. The results suggest that the model can be used to predict the average monthly discharge values.

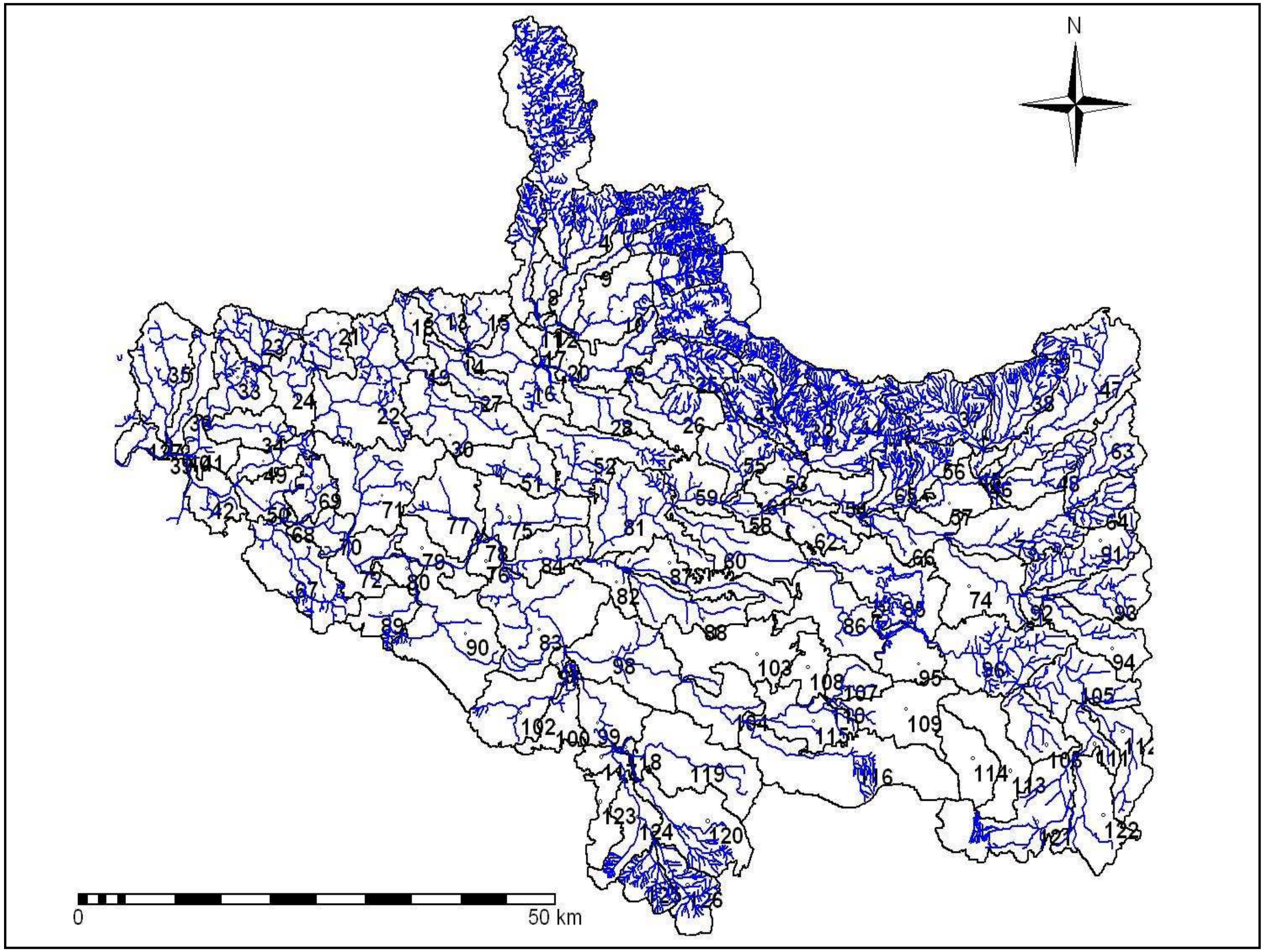

Fig 4.10 Bharathapuzha watershed with sub basins.

Table 4. 4 Descriptive statistics of mean monthly river flow: Calibration Period

Statistics	Precalibrated model		Calibrated model	
	Observed flow (m^3/s)	Simulated flow (m^3/s)	Observed flow (m^3/s)	Simulated flow (m^3/s)
Mean	144.46	238.89	144.04	166.84
SD	151.35	198.16	150.78	180.76
NSE		0.46		0.88
COD		0.57		0.96

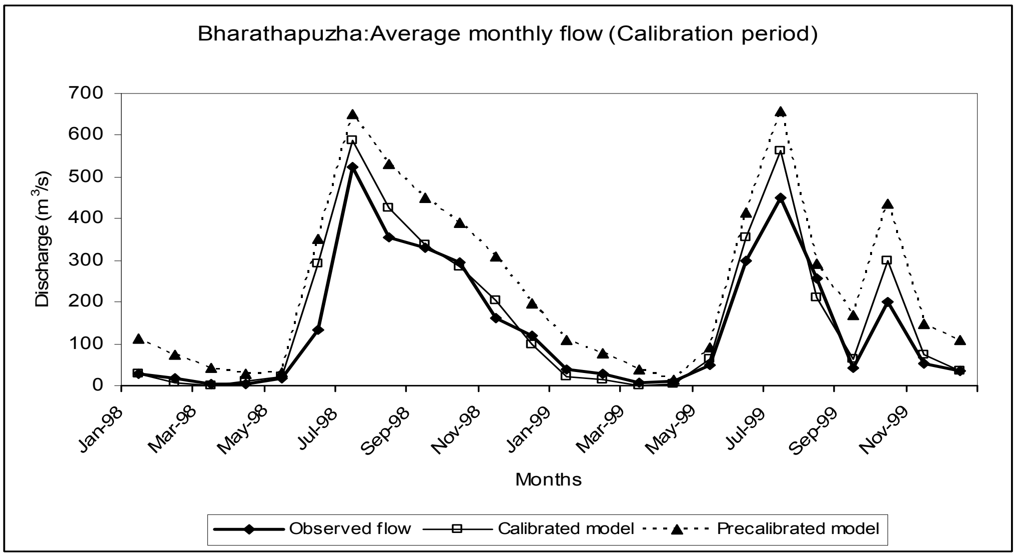

Fig. 4.11 Monthly average river flow: Calibration Period

Table 4. 5 Descriptive statistics of mean monthly river flow: Validation period

Statistics	Precalibrated model		Calibrated model	
	Observed flow (m^3/s)	Simulated flow (m^3/s)	Observed flow (m^3/s)	Simulated flow (m^3/s)
Mean	110.99	213.28	110.99	142.12
SD	123.19	189.96	123.19	164.38
NSE		-0.21		0.62
COD		0.20		0.90

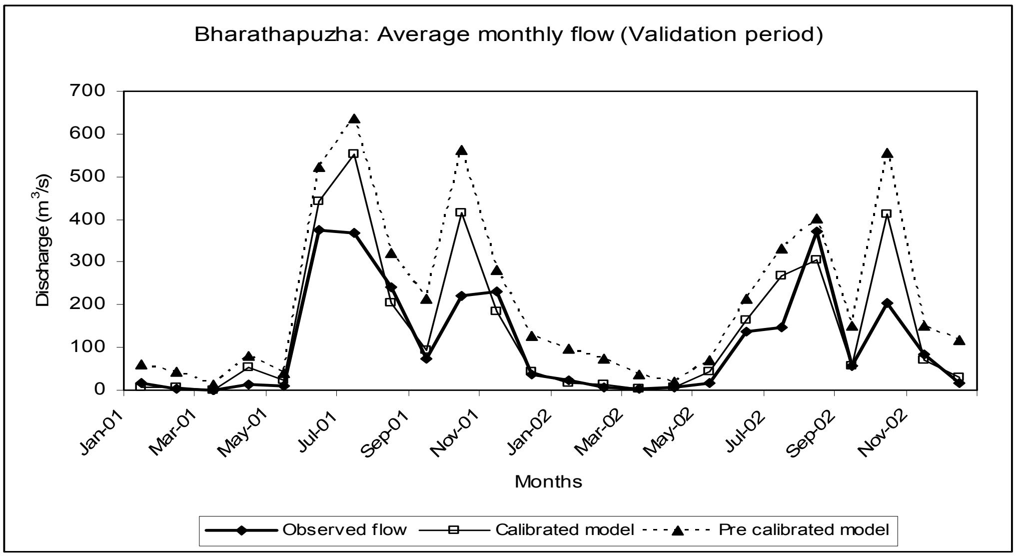

Fig. 4.12 Monthly average river flow: Validation Period

4.13 Water Balancing of the Basin

From the water conservation point of view one must consider the individual hydrologic components rather than the total river flow. Water balance components such as surface runoff, lateral flow, base flow, deep percolation and evapotranspiration have also been simulated and the simulated values have shown very close agreement with their measured or alternately computed counterparts. Thus the study revealed that a properly calibrated watershed model could be of great help in predicting the basin level water balance. The predicted values of the water balance components as a percentage of mean annual rainfall for the years 1996-2002 is shown in figure 4.13. It can be revealed that major portion of the precipitation received by the basin is lost as surface runoff (24-43%). The percentage of annual evapotranspiration and deep recharge is found to be 26-32% and 21-24% respectively. Since the lateral flow is not too high (11%), the shallow subsurface flow is not very significant.

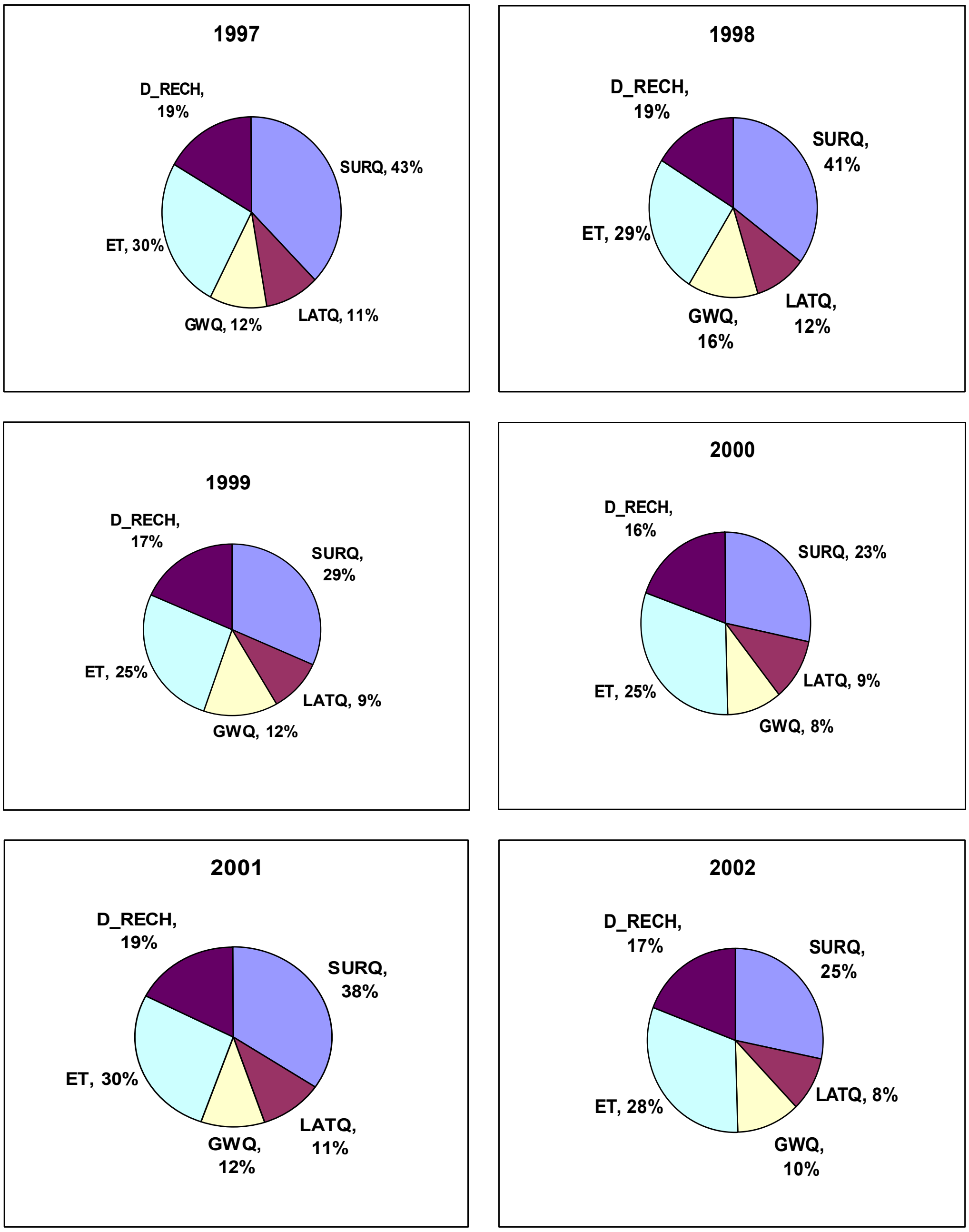

Fig. 4.13 Percentage values of water balance components.

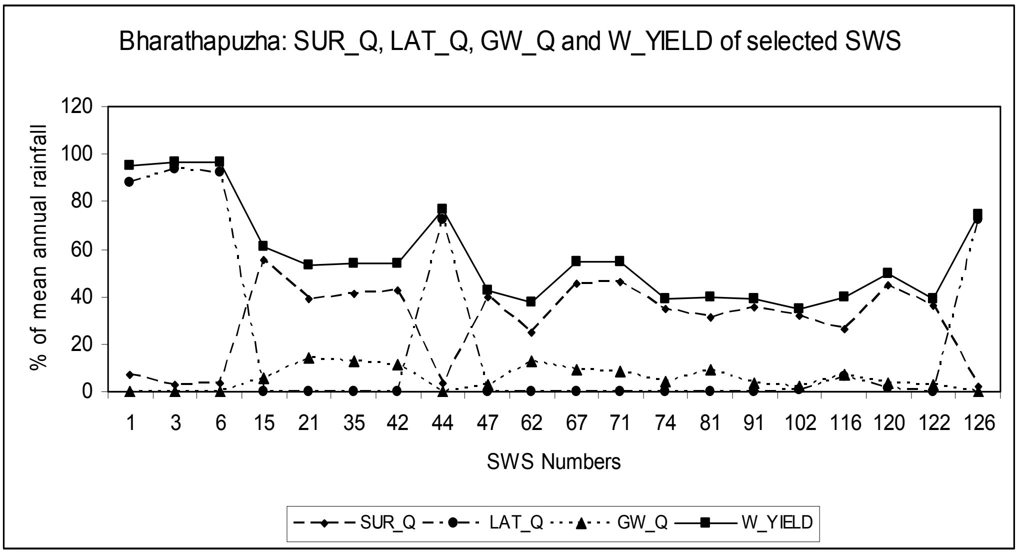

Fig 4.14 Mean of annual ET and groundwater recharge of various subwatersheds

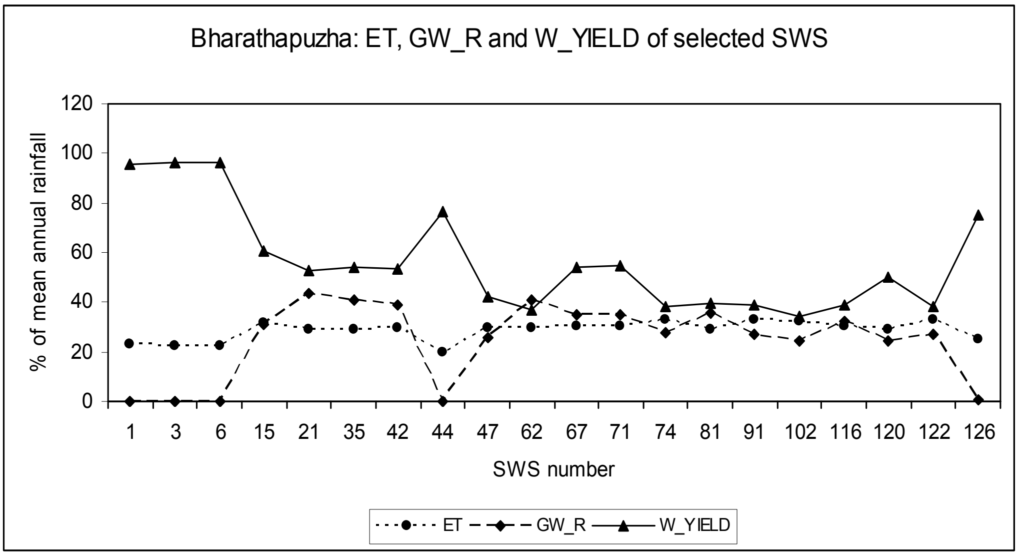

Fig. 4.15Mean of annual runoff components of various subwatersheds

4.14 Recommendation for the River Flow Augmentation

The basin level water balance has shown that major water yield fraction from the basin is surface runoff and the ground water flow is very less. Also, the time-series curve of the river flow shows that the summer river flow is marginal which indicates the fast response of the basin to rainfall. The subbasin water balance shows that from the low sloping subwatersheds, the major water yield fraction is surface runoff. Base flow and lateral flow from these watersheds are very low. At the same time, lateral flow is very considerable from the high sloping subwatersheds.

From the analysis of the flow pattern of the river Bharathapuzha the following recommendations for improving the summer river flow can be proposed. The interventions are given as land treatment and drainage line treatment measures.

4.14.1 Land treatment measures

In the less sloping land areas (<10%) pits and trenches of 0.5 to 1m deep can be constructed to improve the shallow ground water recharge and thereby the ground water flow to the stream. In more sloping land parcels, percolation pits of depth ranging from 1.5 to 2.5m can be constructed. In sloping lands, if water is not recharged to greater depths, the recharged water will be discharged through the process of lateral flow. Roof water from the households should not be allowed to flow along the land surface. Instead, it should be collected and recharged by directing the roof water to percolation pits. This measure can improve the shallow ground water potential of the watershed to a great extent.

Many subwatersheds and HRUs of the Bharathapuzha river basin have very high land slopes. Lateral flow and base flow from these land areas are very fast. To slow down the discharge of infiltrated water, subsurface dike can be proposed in valleys of drainage channels. This measure can improve the availability of water in open wells and ponds, on which people of the area mainly depend to meet their domestic water requirements. Location of the sites can be identified considering the positions of drainage channels and the nature of the valley.

4.14.2 Drainage line treatment measures

Gully plugging cum deep percolation pits may be planned for small drainage channels on the upper region of the subwatersheds. This measure can improve the recharge status of the subbasins considerably and in turn the shallow aquifer potential. A series of low height check dams (2-3m height) can be constructed in the main stream and important tributary channels of the river network. Monthly flow analysis of the different subbasins can give a clear idea about the feasibility of check dams of different locations. Construction of check dams can reduce the hydraulic gradient of the water table towards the stream channel. Possibility of alternative construction methods of check dams also may be explored.

Summary & Conclusions

Chapter 5

SUMMARY AND CONCLUSIONS

Watershed simulation studies have conducted in Bharathapuzha river basin of Kerala state in India using GIS integrated physically based distributed model. The geological location of the watershed is from $10^0 25'$ to $11^0 13'$ North latitude and $75^0 55'$ to 77^0 East longitudes and the total area is 6186km^2. The main objectives of the study include modeling the topography of the river basin using GIS, to study existing flow pattern using watershed simulation model and to suggest suitable interventions to improve the summer flow regime of river Bharathapuzha.

The elevation of the watershed varies from 20m to 2361m as revealed by the Digital Elevation Model (DEM). The soil map of the area has 9 soil series, of which 55.4% of the total watershed area is having Anayadi soil series. The other soil series are Chelikuzhi, Cheruvalli, Kachirapuzha, Kongad, Manimala, Manjallor, Pallippadi and Vijayapuram. A land use map for the study area has been prepared from LISS Ш imagery of IRS P6 by supervised classification. The classified imagery shows about 10 different landuse classes of which paddy and garden land are the major landuse categories.

SWAT model was set up for Bharathapuzha river basin by inputting all thematic and attribute data. The entire watershed was divided in to 127 sub basin and 366 Hydrologic Response Units (HRUs) by selecting the basin outlet at Kumbidi (Geographical location – $10^0 51'$North and $76^0 02'$ East). Model simulations were carried with the default parameter setting and simulated outputs were compared with the observed values. Then the model was calibrated by manually changing the parameters one at a time and evaluating their output performances. Simulations were done on annual and monthly basis for both calibration and validation period. Nash Sutcliffe Efficiency (NSE) and coefficient of determination were used as the statistics to evaluate the model's predictive capability. The calibrated model has Nash Sutcliffe Efficiency (NSE) of 88% and Coefficient of Determination of 96% for the monthly simulation. The study reveals that SWAT model has a good capability to simulate the topography of the watershed and the calibrated SWAT model can predict the average river discharge, annually and monthly with a fair degree of accuracy. Hence, the model can predict the discharge along different section of the stream network, thereby giving useful information for land and water management plans and decisions. The annual water balance of the calibrated SWAT gave 32.3% of the annual rainfall as surface runoff, 10% as lateral flow and 11.67% as ground water flow. Shallow ground water recharge was 17.83% of the annual rainfall.

Micro water balance study at subbasin level was also carried out using the model. Different subwatersheds showed marked variations in the individual hydrologic flow components such as surface runoff, lateral flow, base flow and ground water recharge. Subbasin water balance information can very effectively be used in planning insitu water conservation measures to improve the dry weather flow of the river system. Recommendations to augment the flow condition of the river based on the micro level hydrologic analysis of the river basin is also given in this report.

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RECOMMENDATIONS TO REJUVENATE RIVER BHARATHAPUZHA USING GIS AND WATERSHED SIMULATION MODEL

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PROJECT REPORT

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ABSTRACT

Bharathapuzha, the second largest river of Kerala is the lifeline of several millions of people in the state, but now facing tremendous pressure due to encroachments, sand and clay mining and illegal diversions of water. One of the major issues of the river is that the river is live only during monsoon season and in summer, the flow is practically nil. Considering these circumstances, our study focused on measures for sustaining this water source round the year with the specific objectives of modeling the topography of the river using Geographical Information System (GIS), studying the existing flow pattern of the river using simulation model and on the light of the study, suggesting sustainable interventions to improve summer flow regimes of the river. The project area covers the entire catchment area of the river Bharathapuzha with 6186km^2. Sub watershed delineation was the most important preliminary task involved in the whole exercise. For the quick and efficient delineation of micro watersheds, GIS and Soil and Water Assessment Tool (SWAT) were made use of. Micro watershed delineations and their topographic analysis have been carried out with the help of ILWIS and SWAT. Digital Elevation Model (DEM), drainage network, soil map and land use map for the catchment were prepared by utilizing the integrated GIS and image processing capability of ILWIS. SWAT was set up and calibrated for the basin with good simulation efficiency and the calibrated.s model was used to analyze the water balance of the whole basin and that of the individual subbasins. Based on the detailed hydrologic analysis at micro level, appropriate interventions to improve the summer flow regimes of the river is recommended.