RESTORATION OF WATER RESOURCES IN CHANGING CLIMATE

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

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in

WATER RESOURCES DEVELOPMENT (CIVIL)

By

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CANDIDATE'S DECLARATION

I hereby certify that the work, which is being presented in this Dissertation entitled **"Restoration of Water Resources in Changing Climate "** in partial fulfillment of the requirements for the award of the degree of MASTER OF TECHNOLOGY in Water Resources Development (Civil) and submitted to the Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, Roorkee, is an authentic record of my own work carried out during the period from July 2010 to June 2011 under the supervision and guidance of **Dr. Deepak Khare**, Professor, Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, India.

I have not submitted the matter embodied in this dissertation for the award of any other degree.

Dated: June 29th, 2011

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This is to certify that the above mentioned statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

Among the existing and projected impacts of climate change, impacts on water resources are expected to exacerbate the current and future threat of global water scarcity. In the present study, water scarcity is examined as an impact of climate change in Barinallah watershed. Villages dependent on this watershed for water needs, confirms that climate change is one of the factors causing depletion of water resources.

In order to show the linkage between climate change and water scarcity, evidence is presented on changes occurring in these villages on local climate parameters such as snowfall, rainfall and temperature. Also evidence is analyzed in changes occurring in the hydrology of the water bodies that make water available to these villages. This establishes that water scarcity in these villages has been induced not only by increasing demand, but also by decreasing supply of water.

In view of the water scarcity facing in the region, an investigation of the measures taken to address this issue is presented, which reveals that the primary adaptive response employed in these villages is supply augmentation. Additionally, climate change considerations have been largely absent in the policy/ planning processes that govern water management in the study area, implying that the responses of this area to water scarcity have been influenced by the pursuit of short-term economic benefits in a local economy that fails to recognize the importance of the integrity of water resources to its sustenance. The perpetuation of unsustainable economic development and failure to account for climate change impacts in local water management points to the presence of several technological, structural, financial, and political barriers to the planning/ implementation of holistic climate-centric strategies for adaptation to water scarcity in Barinallah watershed.

To conclude in brief, the study makes an attempt to establish the climatic response in the availability of water resources in the region. The study confirms the increasing variation in temperature and rainfall pattern in each passing days, resulting in erratic and uneven rainfall. Finally, restoration measures through tapping the falling rainfall in the region is suggested by constructing check dams, gabions etc. in different streams/ nallah in Barinallah watershed.

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Alfa_Bf	=	Base flow alpha factors
AMC	=	Antecedent Moisture Condition
CN	=	Curve Number
CO_2	=	Carbon dioxide
d	=	Index of agreement
DEM	=	Digital Elevation Model
ESCO	=	Soil Evaporation compensation factor
ERDAS	=	Earth Resource and Data Analysis System
GIS	=	Geographical Information System
GWQMN	=	Threshold depth of water in the shallow aquifer required for return flow to occur
H_{day}	=	Total solar radiation reaching the earth's surface on that day
HFL	=	High flood level
HRU	=	Hydrologic Response Units
Km^2	=	Square Kilometer
m/s	=	Meter per second
m^3/s	=	Cubic meter per second
n	=	Manning's roughness coefficient
NSE	=	Nash and Sutcliffe efficiency
PME	=	Persistence Model Efficiency
Q	=	Discharge
q	=	Discharge intensity
Qavg	=	Average value of observed discharge
Qmod	=	Model discharge
Qobs	=	Observed discharge
R^2	=	Coefficient of determination
RE	=	Relative error of the stream flow volume
REVAPMN	=	Threshold depth of water in the shallow aquifer for 'revap' or percolation to the deep aquifer to occur
RS	=	Remote Sensing
SCS	=	Soil Conservation Service
SDN_{day}	=	Standard normal deviate calculated for the day

SNO_{mlt}	=	Amount of snow melt on a given day (mm H_2O)
SOI	=	Survey of India
SOL_AWC	=	Available water capacity of soil layer
STN	=	Meteorological station
SW_0	=	Initial soil water content on day i (mm H_2O)
SWAT	=	Soil and Water Assessment Tool
t	=	time (days)
USGS LULC	=	United State Geological Survey Landuse / Landcover

CHAPTER 1
INTRODUCTION

1.1 General

Water, next to the air, is the most important requirement for human life to exist. Water is the integral fabric in the quilt of life. The Earth's ecosystems, societies and individuals need it. Without it, food security and human health, energy supplies and industrial production would be unobtainable. Plants and wildlife and their ecosystems need water. Water helps in regulating the global climate and as we are continuing to see, water resources themselves are affected by global climate change.

Earth is the only planet known where water exists in its three forms: as water vapour, as flowing water and as ice. The global water cycle between the sea, the atmosphere and the continents is a vital circulatory system for nature and man. This system brings about 110,000 km^3 of water to the continents every year by precipitation. Most of it evaporates back into the atmosphere from the ground and vegetation. The remaining water refills groundwater aquifers, springs, lakes and rivers.

In earlier times, the major town and cities developed on the banks of river systems as these were required to fulfil the basic need of water for drinking, bathing, cooking etc. In hilly areas the springs, streams are the main sources of water. Due to human activities like urbanisation, increase in population, deforestation etc. in the catchment of the discharge springs, streams is reducing day by day. The demand of water is increasing due to increase in population, change in living standard etc. The discharge from these sources is reducing gradually and at the same time the demand is increasing. Due to increase in demand and decrease in the discharge in the water resources like springs and streams their restoration is more important as they are the only sources of water supply.

India being the monsoonic country, the rain falls only for 3 to 4 months in a year with high intensity, which results in more runoff and soil erosion. Total rain occurs in about 100 hours out of 8760 hours in a year. Further, the rainfall is erratic and fails once in every 3 to 4 years. This is very common in many parts of the country.

The perennial rivers, springs, lakes are becoming dry and ground water table is depleting in most of the areas. The solution of the water problem, which is in our hand, is to harvest rainfall. Hence it is necessary to conserve the rainwater where it falls according to the local and geological needs. In this process the ground water is recharged in addition to augmenting the supply at water source. Hence this would stop the decline of the water levels, supplements the existing supplies and surplus water is made available to tide over the shortage in the dry seasons.

In India, our approach to water consumption and management is unsustainable. Few environmentally degrading practices which affect water resources include:

- Over-extraction from rivers, mostly for the benefit of irrigation and industry
- Over-extraction of groundwater of particular concern is the unregulated
- Reduction in infiltration and aquifer recharge and maximizing run-off through increasingly impervious urban surfaces, roads, car parks, houses, etc.
- Increasing water demand based on profligate usage and lifestyle choices

Water scarcity is not only limited to the arid regions but also is occurring in high rainfall areas. Cherapunji gets more than 11,000mm of average annual rainfall but face drinking water problem before monsoon commences whereas in Ralegoan Siddhi, in Maharastra there is no water scarcity problem though the annual average rainfall is about 450mm. Hence to mitigate water problem, there is an urgent need to follow traditional way of water harvesting including latest technologies adopted in soil and water conservation measures on watershed basis.

The main source of all the water supplies is rainfall. As the time pass it become necessary to find out the substitutes for rainfall as source of water supply. 71% of the total earth's surface is covered by sea and the remaining 29% by land. The total quantity of water on the surface of the earth is estimated as 1455×10^6 km^3. The percentage distribution of water resources in the earth is as follows:

Table 1.1 Distribution of water

Water in the ocean	97%
Fresh water	3%
From 3% fresh water	
Ice caps and glaciers	68.7%
Ground water	30.1%
Other	0.9%
Surface water	0.3%
0.3% surface water	
Lakes	87%
Swamps	11%
Others	2%

India has 2.4% of the world's total area has 16% of the world's population, but has only 4% of the total available fresh water. This clearly indicates the need for water resources development, conservation and their optimum use. Fortunately, at a macro level India is not short of water. The problems that seem to loom large over the sector are manageable and the challenges facing it are not insurmountable.

Climate change is one of the major challenges to researchers in recent times. The impact of climate change on water resources around the globe has serious implications like, changing water levels and climatic temperatures which in turn affect the economy and future as a whole. In addition, water resources are depleting day by day due to the exponential demand from sectors like irrigation, domestic consumption and industry. Water availability and quality will be the main pressures on, and issues for, societies and the environment under climate change. Along with quantity, quality is also deteriorating mainly due to the indiscriminate use of water to hazardous levels, pollution of rivers and improper management of waste water.

This necessitates water conservation strategies to be adopted at the national, state and local levels. Climate-related impacts on water resources are already being documented. In all corners of the world, there is growing empirical evidence of increased severe weather events, flooding, and diminished ice cover, all of which can be attributed to climate change. Numerous scientific studies also reports increases in the intensity, duration, and spatial extent of droughts, higher atmospheric temperatures, warmer sea surface temperatures, changes in precipitation patterns, and diminishing glaciers and snowpack.

Several studies have been undertaken worldwide by researchers to assess the water resources in the changing climate scenario. An International Panel on Climate Change (IPCC) has been formulated comprising of scientists, policy makers to ascertain impact of climate change on water resources. As per IPCC, four main factors aggravating water stress worldwide are:

- Population growth: in the last century, world population has tripled. It is expected to rise from the present 6.5 billion to 8.9 billion by 2050. Water use has been growing at more than twice the rate of population increase in the last century, and, although there is no global water scarcity as such, an increasing number of regions are chronically short of water.

- Increased urbanization will focus on the demand for water among a more concentrated population. Asian cities alone are expected to grow by 1 billion people in the next 20 years.
- High level of consumption: as the world becomes more developed, the amount of domestic water used by each person is expected to rise significantly.
- Climate change will shrink the resources of freshwater.

Most of the studies on the climate change have undertaken encompassing large areas concentrating mainly to assess the impact on water resources. Climate change is inevitable. Mankind can not check the problems arising due to climate change. But, certainly we can think of its mitigation and adaptation strategies. The present study is an attempt to assess the water resources availability in the changing climate scenario in a hilly region. Also the study provides an insight how to restore the dying water sources in hilly areas including its structural design with the following specific objectives.

1.2 Objectives of the Study

The specific objectives envisaged in the present study are:

1. To assess the long term hydrological trend in the study area
2. To quantify the water resources availability in the study area and its supply-demand assessment thereby using ArcSWAT model
3. To find out the restoration plan for water resources under changing climate

1.3 Scope of the Work

Along with achieving the objectives discussed above, the study further provides a scope to model the study area using ArcSWAT (2009), ERDAS 9.2 and ArcGIS 9.3 model. The output from the ArcSWAT program has been calibrated and validated with the observed data.

1.4 Organization of Dissertation Work

The present thesis has been divided into six chapters. CHAPTER 1 introduces the problem and defines the objectives of the study. CHAPTER 2 presents a review of the literature. CHAPTER 3 contains study area and data availability. CHAPTER 4 presents the methodology. CHAPTER 5 presents analysis and discussion of results. Finally, CHAPTER 6 concludes the study.

CHAPTER 2
LITERATURE REVIEW

2.1 General

Water resources of a country constitute one of its vital assets. India receives annual precipitation of about 4000 km^3. The rainfall in India shows very high spatial and temporal variability and paradox of the situation is that Cherapunji, which receives the highest rainfall in the world, also suffers from a shortage of water during the non-rainy season, almost every year. The total average annual flow per year for the Indian rivers is estimated as 1953 km^3. The total annual replenishable groundwater resources are assessed as 432 km^3. The annual utilizable surface water and groundwater resources of India are estimated as 690 km^3 and 396 km^3 per year, respectively. With rapid growing population and improving living standards the pressure on our water resources is increasing and per capita availability of water resources is reducing day by day. Due to spatial and temporal variability in precipitation the country faces the problem of flood and drought syndrome. Overexploitation of groundwater is leading to reduction of low flows in the rivers, declining of the groundwater resources, and salt water intrusion in aquifers of the coastal areas. The climate change is expected to affect precipitation and water availability.

2.2 Climate System

Climate of region represents the long-term average of weather (more than thirty years). It is a resultant of extremely complex system consisting of different meteorological variables, which vary with time. Climate in a narrow sense is defined as "average weather", or more rigorously, as the statistical description in terms of mean and variability of relevant quantities of weather parameters over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by WMO. These parameters are most often surface variables such as temperature, precipitation and wind.

The climate change is a very common word in the present day world. The common man, media and scientists all seem to be concerned with this phenomenon. It is generally because the mean global temperature of earth is showing an increasing trend. However, this might not be true in a regional scale, but enough evidences have been gathered showing this increasing trend of temperature. The important evidences include worldwide retreat of glaciers in all latitudes, rising of the mean sea level, breaking of Antarctic ice sheets etc. Such changes may have severe impact on mankind and all other living species. Such scenarios of projection have urged researchers from all over the world and of all fields of science to study the problem in a greater depth.

The climate is defined as the mean physical state of the climatic system, which is constituted by atmosphere, hydrosphere, cryosphere, lithosphere and biosphere, which are intimately interconnected. Therefore, the climate is determined by a set of time-averages of quantities that describe the structure and the behaviour of the various parts of the climatic system, as well as by the correlations among them (Peixoto and Oort, 1992). Climate system is complicated system, which has various components. Climate system consists of the atmosphere, cryosphere, hydrosphere and land interacting through physical, chemical and biological process. The atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere, forced or influenced by various external forcing mechanisms, the most important of which is the Sun. Also the direct effect of human activities on the climate system is considered an external forcing.

The atmosphere is the most unstable and rapidly changing part of the system. Its composition, which has changed with the evolution of the Earth, is of central importance to the problem which occurred in Earth. The hydrosphere is the component comprising all liquid surface and subterranean water, both fresh water, including rivers, lakes and aquifers, and saline water of the oceans and seas. The cryosphere, including the ice sheets of Greenland and Antarctica, continental glaciers and snow fields, sea ice and permafrost, derives its importance to the climate system from its high reflectivity (albedo) for solar radiation, its low thermal conductivity, its large thermal inertia and, especially, its critical role in driving deep ocean water circulation. Because the ice sheets store a large amount of water, variations in their volume are a potential source of sea level variations.

Vegetation and soils at the land surface control how energy received from the Sun is returned to the atmosphere. Some is returned as long-wave (infrared) radiation, heating the atmosphere as the land surface warms. Some serves to evaporate water, either in the soil or in the leaves of plants, bringing water back into the atmosphere. Because the evaporation of soil moisture requires energy, soil moisture has a strong influence on the surface temperature. The texture of the land surface (its roughness) influences the atmosphere dynamically as winds blow over the land's surface. Roughness is determined by both topography and vegetation. Wind also blows dust from the surface into the atmosphere, which interacts with the atmospheric radiation. The marine and terrestrial biospheres have a major impact on the atmosphere's composition. The biota influences the uptake and release of greenhouse gases. Through the photosynthetic process, both marine and terrestrial plants (especially forests) store significant amounts of carbon from carbon dioxide. Thus, the biosphere plays a central role in the carbon cycle, as well as in the budgets of many other gases, such as methane and nitrous oxide.

Many physical, chemical and biological interaction processes occur among the various components of the climate system on a wide range of space and time scales, making the system extremely complex. All subsystems are open and interrelated. As an example, the atmosphere and the oceans are strongly coupled and exchange, among others, water vapour and heat through evaporation. This is part of the hydrological cycle and leads to condensation, cloud formation, precipitation and runoff, and supplies energy to weather systems. On the other hand, precipitation has an influence on salinity, its distribution and the thermohaline circulation. Atmosphere and oceans also exchange, among other gases, carbon dioxide, maintaining a balance by dissolving it in cold polar water which sinks into the deep ocean and by out-gassing in relatively warm upwelling water near the equator. Some other examples: sea ice hinders the exchanges between atmosphere and oceans; the biosphere influences the carbon dioxide concentration by photosynthesis and respiration, which in turn is influenced by climate change. The biosphere also affects the input of water in the atmosphere through evapotranspiration, and the atmosphere's radiative balance through the amount of sunlight reflected back to the sky (albedo). (IPCC, 2001).

2.2.1 Definition of Climate Change

Classical climatology provides a classification and description of the various climate regimes found on Earth. Climate varies from place to place, depending on latitude, distance to the sea, vegetation, presence or absence of mountains or other geographical factors. Climate varies also in time, from season to season, year to year, decade to decade or on much longer time-scales, such as the Ice Ages. Statistically significant variations of the mean state of the climate or of its variability, typically persisting for decades or longer, are referred to as "climate change".

Climate change in United Nation Framework Convention Climate Change (UNFCCC) is defined as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

Climate change (Intergovernmental Panel on Climate Change) is defined as referred to in the observational record of climate occurs because of internal changes within the climate system or in the interaction between its components, or because of changes in external forcing either for natural reasons or because of human activities. It is generally not possible clearly to make attribution between these causes. Projections of future climate change reported by IPCC generally consider only the influence on climate of anthropogenic increases in greenhouse gases and other human-related factors.

2.2.2 Causes of Climate Change

Many factors determine the Earth's weather and climate, which from natural factors, such as the intensity of solar radiation, concentrations of atmospheric gases and particles, interactions with the oceans and the changing character of the land surface and human influence. The factor which causes of climate change can be determined into two categories:

2.2.2.1 Natural Causes

a. Plate Tectonics

Over the course of mill ions of years, the motion of tectonic plates recon figures global land and ocean areas and generates topography. This can affect both global and local patterns of climate and atmosphere-ocean circulation. (Forest, et.al., 1999). The existence of mountains (as a product of plate tectonics through mountain - building) can cause orographic precipitation. Humidity generally decreases and diurnal temperature swings generally increase with increasing elevation. Mean temperature and the length of the growing season also decrease with increasing elevation. This, along with orographic precipitation, is important for the existence of low-latitude alpine glaciers and the varied flora and fauna along at different elevations in mountain ecosystems. (Villarroya and Padre, 2010)

The position of the continents determines the geometry of the oceans and therefore influences patterns of ocean circulation. Because the circulation of the ocean and the atmosphere are fundamentally linked, the locations of the continents are important in controlling the transfer of heat and moisture across the globe, and therefore, in determining global climate.

The size of continents is also important. Because of the stabilizing effect of the oceans on temperature, yearly temperature variations are generally lower in coastal areas than they are inland. A larger super-continent will therefore have more area in which climate is strongly seasonal than will several smaller continents and/or island arcs.

b. Solar Output

The predominant source of warming is energy received from the Sun in the form of solar radiation. Both long and short term variations in solar intensity are noted to affect global climate. Energy from the Sun enters the top of the atmosphere with an average intensity of about 342 watts per square meter. About 25% of this energy is immediately reflected back to space by clouds, aerosols and other gases in the atmosphere. An additional 5% is reflected back to space by the surface, making the overall reflectivity (or albedo) of the Earth about 30%. Of the other 70% of incoming solar radiation, about 20% is absorbed in the atmosphere and the rest is absorbed at the surface. Thus, 70% of incoming solar energy is the driving force for weather and climate (Kiehl and Trenberth, 1997).

Solar output also varies on shorter time scales, including the 11 year solar cycle (Willson et al., 1991) and longer term modulations .The 11 year sunspot cycle produces only a small change in temperature near Earth's surface (on the order of a tenth of a degree) but has a greater influence in the atmosphere's upper layers. Solar intensity variations are considered to have been influential in triggering the Little Ice Age, and for some of the warming observed from 1900 to 1950. The cyclical nature of the sun's energy output is not yet fully understood, it differs from the very slow change that is happening within the sun as it ages and evolves, with some studies pointing toward solar radiation increases from cyclical sunspot activity affecting global warming (Svensmark et al., 2009)

c. Volcanism

For many years, climatologists have noticed a connection between large explosive volcanic eruptions and short term climatic change. Volcanism is the process of conveying material from the crust and mantle of the Earth to its surface. Volcanic eruptions, geyser, and hot springs, are examples of volcanic processes which release gases and/or particulates into the atmosphere.

Eruption large enough to affect climate occur on average several times per century, and cause cooling for a period of a few years. It was thought that the dust ejected into the atmosphere from large volcanic eruptions was responsible for longer-term cooling by partially blocking the transmission of solar radiation to the Earth's surface. However, measurements indicate that most of the dust hurled into the atmosphere may return to the Earth's surface within as little as six months, given the right conditions.

Emission of Aerosols, which emitted by explosive volcanic eruptions have the potential to inject substantial amounts of sulfate aerosols into the lower stratosphere. In contrast to aerosol emissions in the lower troposphere, aerosols that enter the stratosphere may remain for several years before settling out, because of the relative absence of turbulent motions there. Consequently, aerosols from explosive volcanic eruptions have the potential to affect Earth's climate. Less explosive eruptions, or eruptions that are less vertical in orientation, have a lower potential for substantial climate impact. Another emission from volcanoes is Carbon dioxide (C02), it is a greenhouse gas which has a warming effect (USGS, 2006). For about two-thirds of the last 400 million years, geologic evidence suggests C02 levels and temperatures were considerably higher than present. One theory is that volcanic eruptions from rapid sea floor spreading elevated CO2 concentrations, enhancing the greenhouse effect and raising temperatures. However, the evidence for this theory is not conclusive and there are alternative explanations for historic CO2 levels (NRC, 2005).

d. Ocean Currents

The heating or cooling of the Earth's surface can cause changes In ocean currents. Because ocean currents play a significant role in distributing heat around the Earth, changes in these currents can bring about significant changes in climate from region to region. Short- term fluctuations (years to a few decades) such as the El Nifio-Southern Oscillation, the Pacific oscillation, the North Atlantic oscillation, and the Arctic oscillation, represent climate variability rather than climate change. On longer time scales, alterations to ocean processes such as thermohaline circulation play a key role in redistributing heat by carrying out a very slow and extremely deep movement of water, and the long-term redistribution of heat in the world's oceans.

Another possible consequence of global warming is a decrease in the global ocean circulation system known as the thermohaline circulation or great conveyors belt This system involves the sinking of cold saline waters in the sub-polar regions of the oceans, an action that helps to drive warmer surface waters pole ward from the subtropics. As a result of this process, a warming influence is carried to Iceland and the coastal regions of Europe that moderates the climate in those regions.

2.2.2.2 Anthropogenic Factor

Anthropogenic factors are human activities that change the environment. Various hypotheses for human-induced climate change have been argued for many years. Presently the scientific consensus on climate change is that human activity is very likely the cause for the rapid increase in global average temperatures over the past several decades (IPCC, 2007).

Global warming is the increase in the average temperature of the Earth's near-surface air and oceans since the mid_20th century and its projected continuation. Increasing greenhouse gas concentrations resulting from human activity such as fossil fuel burning and deforestation caused most of the observed temperature increase since the middle of thezo" century. The increase in CO2 levels due to emissions from fossil fuel combustion,followed by aerosols (particulate matter in the atmosphere) and cement manufacture.

Gases that trap heat in the atmosphere are often called greenhouse gases. Some greenhouse gases such as carbon dioxide occur naturally and are emitted to the atmosphere through natural processes and human activities. Other greenhouse gases (e.g., fluorinatedgases) are created and emitted solely through human activities. The principal greenhouse gases that enter the atmosphere because of human activities are:

Carbon dioxide (CO2), it enters the atmosphere through the burning of fossil fuels (oil, natural gas, and coal), solid waste, trees and wood products, and also as a result of other chemical reactions (e.g., manufacture of cement). Carbon dioxide is also removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle.

Methane (CH4), it is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills.

Nitrous Oxide (NO2), it is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.

Fluorinated gases such as hydro-fluorocarbons, per-fluorocarbons, and sulphur hexafluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. Fluorinated gases are sometimes used as substitutes for ozone depleting (i.e., CFCs, HCFCs, and halons). These gases are typically emitted in smaller quantities, but because they are potent greenhouse gases, they are sometimes referred to as High Global Warming Potential gases ("High GWP gases").

2.2.3 Impact of Climate Change in Hydrology and Water Resources

Water is involved in all components of the climate system (atmosphere, hydrosphere, cryosphere, land surface and biosphere). The effect of climate change on stream flow (Manoj, et.al. 2006, Ma. Xing et.al.2009) and groundwater recharge (William and Monica, 2007) varies regionally and between climate scenarios, largely following projected changes in precipitation. Flood magnitude and frequency could increase in many regions as a consequence of increased frequency of heavy precipitation events, which can increase runoff in most areas as well as groundwater recharge in some floodplains (Xu et. a1.2008; Zhang et al. 2006). Land-use change could exacerbate such events, while land cover change may have a moderate impact on annual stream flow, which strongly influences seasonal stream flow and alters the annual hydrograph of the basin. (Changnon.S.A., 1996, Wang. et.al., 2007). Stream flow during seasonal low flow periods would decrease in many areas due to greater evaporation (Zhang et. al., 2001); changes in precipitation may exacerbate or offset the effects of increased evaporation. (Adamowski et.al. 2003)

Consequently, there have been a great many studies into the potential effects of climate change on hydrology (focusing on cycling of water) (Gosain. A.K et.al. 2006, Ma. Xing et.al. 2009) and water resources (focusing on human and environmental use of water) (Eastham. J et. al., 2008, Matondo and Msibi, 200 I; and Chen et al.2007). The majority of these studies have concentrated on possible changes in the water balance; they have looked, for example, at changes in stream flow through the year. Milly et al.(2002) investigated the changes in risk of great floods by using both stream flow measurements and numerical simulations of the anthropogenic climate change. They found that there was evidence of an increasing risk of great floods in a warming climate as the result of an intensification of the global water cycle. Chiew and McMahon (2002) investigated the effects of climate change on runoff in catchments across Australia by comparing the water balance components simulated by a hydrological model using present climate data and future climate change scenarios.

a. Impact on Precipitation

Precipitation is the main driver of variability in the water balance over space and time, and changes in precipitation have very important implications for hydrology and water resources. Hydrological variability over time in a catchment is influenced by variations in precipitation over daily, seasonal, annual, and decadal time scales. (Chen. Huan. et. al., 2007, Xu. Z.X et. al., 2007). Rainfall prediction plays an important role in designing the water harvesting structures, erosion control measures and for developing the management plan for the critical erosion-prone areas of a watershed. Several research workers across the world have developed rainfall prediction models to solve the aforesaid problems (Richardson, 1981).

Precipitation intensity increases almost everywhere, but particularly at mid and high latitudes where mean precipitation also increases. Some studies about trends in precipitation, shows that there are different trends in different parts of the world, with a general increase in Northern Hemisphere mid and high latitudes (particularly in autumn and winter) and a decrease in the tropics and subtropics in both hemispheres.(Chen. Huan et al., 2007,) There is evidence that the frequency of extreme rainfall has increased in the United States (Karl and Knight, 1998) and in the United Kingdom(UK) (Osborn et al., 1999); in both the countries, a greater proportion of precipitation is falling in large events than in earlier decades.

b. Impact on Evaporation

Evaporation from the land surface includes evaporation from open water, soi I, shallow groundwater, and water stored on vegetation, along with transpiration through plants. The rate of evaporation from the land surface is driven essentially by meteorological controls, mediated by the characteristics of vegetation and soils, and constrained by the amount of water available.

The primary meteorological controls on evaporation from a well-watered surface (often known as potential evaporation) are the amount of energy available (characterized by net radiation). Increasing temperature generally results in an increase in potential evaporation, largely because the water-holding capacity of air is increased.

Several studies have assessed the effect of changes in meteorological controls on evaporation (e.g., Chattopadhyary and Hulme, 1997), using models of the evaporation process, and the effect of climate change has been shown to depend on baseline climate (and the relative importance of the different controls) and the amount of change. Chattopadhyary and Hulme (1997) calculated increases in potential evaporation across India from GCM simulations of climate. The actual rate of evaporation is constrained by water availability. Ameli (1996) estimated for a sample of UK catchments that the rate of actual evaporation would increase by a smaller percentage than the atmospheric demand for evaporation, with the greatest difference in the "driest" catchments, where water limitations are greatest.

c. Impact on Soil Moisture

The amount of water stored in the soil is fundamentally important to agriculture and is an influence on the rate of actual evaporation, groundwater recharge, and generation of runoff. Soil moisture contents are directly simulated by global climate models, albeit over a very coarse spatial resolution, and outputs from these models give an indication of possible directions of change.

The local effects of climate change on soil moisture, however, will vary not only ith the degree of climate change but also with soil characteristics. The water-holding capacity of soil will affect possible changes in soil moisture deficits, the lower the capacity, the greater the sensitivity to climate change. Climate change also may affect soil characteristics, perhaps through changes in water logging or cracking, which in turn may affect soil moisture storage properties. Infiltration capacity and water-holding capacity of many soils are influenced by the frequency and intensity of freezing. (Arnell, 1992; Chiew et al., 1995)

d. Impact on Groundwater and Resources

Climate change affects the rate of groundwater recharge and depths of ground water tables. (Mikko I et.al., 2007) However, knowledge of current recharge and levels in both developed and developing countries is poor, and there has been very little research on the future impact of climate change on groundwater, or ground water-surface water interactions. (Eckhardt and Ulbrich, 2003) Groundwater systems generally respond more slowly to climate change than surface water systems.

Groundwater levels correlate more strongly with precipitation than with temperature, but temperature becomes more important for shallow aquifers and in warm periods.

At high latitudes, (thawing of permafrost) causes changes in both the level and quality of groundwater. As groundwater level change and recharged from surface water, impacts of surface water flow regimes are expected to affect groundwater. Increased precipitation variability may decrease groundwater recharge in humid areas because more frequent heavy precipitation events may result in the increased infiltration and capacity of the soil being exceeded more often (Mileham et al., 2008) In semi-arid and arid areas, however, increased precipitation variability may increase groundwater recharge, because only high-intensity rainfalls are able to infiltrate fast enough before evaporating, and alluvial aquifers are recharged mainly by inundations due to floods.

e. Impact on Runoff and River Flow

Changes in river flows, as well as lake and wetland levels, due to climate change depend primarily on changes in the volume and timing of precipitation and, crucially, whether precipitation falls as snow or rain (Boyer et al.: 2010) Changes in evaporation also affect river flows. Several hundred studies of the potential effects of climate change on river flows have been published in scientific journals, and many more studies have been presented in internal reports (Sankarasubramanian and Vogel, 2003, Thodsen.H.,2007, Liu and Cui 2009). A very robust finding is that warming would lead to changes in the seasonality of river flows where much winter precipitation currently falls as snow, with spring flows decreasing because of the reduced or earlier snowmelt, and winter flows increasing. The timing, volume, and extent of mountain snow pack, and the associated snowmelt runoff, are intrinsically linked to seasonal climate variability and change. Warmer cold season temperatures reduce snow accumulation, as a greater fraction of the precipitation comes as rain (lower snow to total precipitation (SIP) ratio), while warmer spring temperatures hasten snowmelt, thereby shifting the timing of runoff to earlier in the season and reducing the amount of summer and fall flows (e.g. Stewart et al., 2005).

Annual runoff is also increased or decreased by alterations in precipitation and evapotranspiration (ET) rates (e.g. Singh and Kumar, 1997, Lee and Chung, 2007). The few global-scale studies that have been conducted using both runoff simulated directly by climate models and hydrological models run off-line show that runoff increases in high latitudes and the wet tropics and decreases in mid-latitudes and some parts of the dry tropics.(Qiang. L et al. 2009). Runoff is notably reduced in southern Europe and increased in south-east Asia and in high latitudes, where there is consistency among models in the sign of change (although less in the magnitude of change). The larger changes reach 20% or more of the simulated \980-1999 values, which range from 1 to 5 mm/day in wetter regions to below 0.2 mm/day in deserts. (JPCC Report, WG J, 2007)

f. Impact on Water Quality

A climate-related warming of lakes and rivers has been observed over recent decades. As a result, freshwater ecosystems have shown changes in species composition, organism abundance, productivity and phenomenon shifts (including earlier fish migration) (Bilby.R et. al, 2007) Also due to warming, many lakes have exhibited prolonged stratification with decreases in surface layer nutrient concentration, and prolonged depletion of oxygen in deeper layers. Due to strong anthropogenic impacts not related to climate change, there is no evidence for consistent climate-related trends in other water quality parameters (e.g., salinity, pathogens or nutrients) in lakes, rivers and groundwater (H. Somura et al., 2009).

The projected climate change would degrade water quality through higher water temperatures and increased pollutant load from runoff and overflows of waste facilities. (Jun Tu., 2009). Quality would be degraded further where flows decrease, but increases in flows may mitigate to a certain extent some degradation in water quality increasing dilution. Many studies around the world have also shown that land use has a strong impact on water quality (Sliva and Williams, 200 I). However, very few studies have analyzed the combined effects of climate and land use changes on stream flow and water quality (Chang, 2004; Qi et al., 2009).

2.3 Water Resources and its Restoration

Water is the most important and precious natural asset. It also provides life support system for all living beings like: human, animals and vegetations etc. It is also a vital part of socio-economic system.

2.3.1 Rainwater Harvesting

The capture and utilization of rainwater is an ancient tradition which dates back to similar techniques used in today's India around 5000 years ago. Modern methods usually represent improvements with respect to technical variations (Mbilinyi 2005).

The term 'rainfall harvesting' is broadly defined as the collection of any form of precipitation from a catchment (Babu and Simon 2006). Rainwater harvesting (RWH) is the process of collecting and storing rainwater from rooftops, land surfaces (steep slopes, road surfaces and rock catchments) using simple components (pots, tanks, cisterns) or more complex methods (underground dams) (Zhu *et al.* 2004).

Kahinda *et al.* (2008) defined RWH as the collection, storage and use of rainwater for small-scale productive purposes. Critchley (1991) defined it as the collection of runoff for productive use. Oweis (2004) defined it as the concentration of rainwater through runoff into smaller target areas for beneficial use. Mati *et al.* (2006) defined RWH as the deliberate collection of rainwater from a surface known as catchment and its storage in physical structures or within the soil profile.

RWH can be categorized according the catchment method used as: in-field RWH (IRWH), ex-field (XRWH) and domestic RWH (DRWH). In IRWH, part or all of the target area is used as the catchment area. In XRWH the catchment area is separate from the target area and harvested water is transported through channels to the target area (Kahinda *et al.* 2007). In DRWH, rainwater is collected on rooftops or other compact surfaces and stored in underground (UGTs) or aboveground tanks (AGTs) for domestic uses and other small-scale activities (Kahinda *et al.* 2007).

RWH can also be divided into two major systems: runoff rainwater harvesting and rooftop rainwater harvesting. In the former system, water collected is of a low quality as it follows a similar route as surface water in that area (Kahinda *et al.* 2007) and thus requires an added effort on treatment of harvested water before domestic use. Studies show that of the two systems, rooftop rainwater harvesting (RRWH), yields harvested waters with contaminants in levels acceptable by international drinking water standards (Kahinda *et al.* 2007; Zhu *et al.* 2004) and is thus thought to be a superior option when considering domestic water supply, in particular potable water. Components of a typical RRWH system are the catchment (roof area), down pipe and gutters and storage tank.

RWH has become a popular option for obtaining a relatively clean, accessible water supply in many areas with limited water supply. Other than as a direct source of water for human consumption, RWH often serves as an artificial recharge (AR) to groundwater that has been over exploited (Sundaravadivel 2007). Lowering of the water table due to depletion of groundwater can cause environmental problems like land collapse, loss of vegetation, desertification and soil erosion. In the case of groundwater pollution, such as episodes of arsenic contamination in India (Pandey *et al.* 2003), rainwater can be used to dilute contaminants within the aquifer (Sundaravadivel 2007). Using RWH to replenish groundwater is considered the most cost efficient way of storing rainwater (Sundaravadivel 2007).

Albeit RWH is an old tradition, scientific interest in the design and improvement of these systems recently expanded after open predictions of global water crisis arose. For this reason, most literature on the topic lightly focuses on past uses and more on the need to implement RWH within government policy. Some studies discuss the use of RWH to supplement water supply for agricultural use during dry seasons in parts of Southeast Asia and Sub-Saharan Africa. Domestic use systems are put in operation in many countries in Africa, Asia (Sundaravadivel 2007) and even a few areas in Eastern Europe and western United States.

Research shows that there is still a considerable amount of untapped rainwater potential in Asia that can be used to supply adequate water to an immense portion of the population (UNEP 2008). However, before adopting RRWH systems, it is important to verify the RWH potential of the area of interest and conclude whether the conditional parameters produce a satisfactory reliability for water supply.

The RRWH potential of any region depends on the amount of rainfall, the surface (rooftop) area used to capture the rainwater and surface runoff coefficient (that is, the proportion of total rainfall that can be captured). The runoff coefficient used depends on the type of material of the roof surface (Table 1). The potential rainwater supply of the system is usually deduced by the following equation (Tripathy and Pandey 2005):

$$S = R \times A \times Cr \qquad (2.1)$$

where, S is the potential rainwater supply in m^3, R is the mean annual rainfall in m, A is the catchment area in m and Cr is the runoff coefficient.

(Liaw and Tsai 2004) determined that RRWH reliability of a system defines its quality of performance through two equations:

RRWH reliability of a system defines its quality of performance and can be determined through two equations (Liaw and Tsai 2004): (1) the volumetric reliability, that is, the total actual amount of rainwater supply over demand or (2) the fraction of time that demand can be met:

$$R_e = 1 - n/N \tag{2.2}$$

where, n is the number of time units (days) when demand exceeds storage while N is the total number of time units in the time sequence.

In their study, Tripathi and Pandey (2005) used the equation 1 to calculate the rooftop rainwater potential for Zura village in Kutch district in Gujarat, India. The number of households with different roof areas was used to determine the total rooftop area which was then multiplied by the annual rainfall and runoff coefficient to obtain the amount of water stored collectively from the *pucca* houses in the village. The researchers then divided the stored water supply by the demand (total population x daily per capita water demand) to determined the amount of time the collected water could be used (without replenishing) by the village. Tripathi and Pandey concluded that the RRWH can be used as a source of domestic water supply for similar water stressed (500 mm of annual rainfall) villages in arid parts of India.

In another study done by M. Dinesh Kumar (2004) in the city of Ahmadabad in a semi-arid part of India, the RWH equation was used to determine the per capita water harvested for 3 different household stocks; independent bungalow, 3-story apartment and 10-story apartment. Rooftop areas were dependent on the household stock and the highest, average and lowest precipitation values with once in 6 years probability of occurrence were used to access the feasibility of RWH in low-rainfall areas (Kumar 2004). The study concluded that the physical feasibility of RWH in urban areas with low rainfall is less than desirable. In addition government subsidies for RWH systems were not recommended for areas characterized with annual rainfall of less than 400 mm.

These two studies considered both the regional variation of RWH and its dependence on the social demography of the study area. Several other studies (Kumar 2007; Pudyastuti 2006; Thomas 1998) show that RWH is suitable in areas that receive above 1200 mm of rainfall to solely sustain domestic demand. However, the study on Zura village in India shows that even under low rainfall conditions, the number of households used in harvesting and the population allowed for a satisfactory water supply through rooftop harvesting, perhaps due to large roof areas and storage volume

(Kumar 2007). In addition to storage and demand characteristics, poor roofing structures, high household density and sparsely distributed houses, typical in many Asian and African countries, are factors that can greatly reduce the practicality of RWH in low rainfall areas.

2.3.1.1Adoption of RWH

As a traditional practice, RWH has gained popularity in the formal settings within the last decade. The practice, that is still used in many tropical islands and semiarid rural areas (Tripathi and Pandey 2005), has been introduced more efficiently into urban areas and in temperate regions as a way to satisfy higher demand or as a water conservation method. Although literature on this technique is not extensive, current literature does highlight the main geographical regions that play key roles in the development and research of RWH.

2.3.1.2 Critical factors for RWH site selection

Although the government and non-governmental organizations have been advocating the use of RWH, its performance and adoption rate is not as much as it was anticipated as different evaluation studies. It must be underscored, however, that the technology by itself is often not the problem for the low performance and adoption, but rather the poor implementation. Proper implementation including area selection and design could improve the performance of RWH and improve the livelihoods of many poor.

The identification of potential areas suitable for RWH is therefore the key for a successful RWH intervention. One of the main reasons for failure of RWH structures is the lack of scientifically verified information which could be used to identify areas where RWH can be applied and for which type of RWH techniques. The potential of areas for RWH depends on a multitude of parameters, either physical factors like rainfall, land use, soil and topography and/or the combination of the physical factors and socio-economic factors.

FAO (2003) by Kahinda *et al.* (2008) lists six key factors to be considered when identifying RWH sites: climate (rainfall), hydrology (rainfall-runoff relationship and intermittent watercourses), topography (slope), agronomy (crop characteristics), soils (texture, structure and depth) and socio-economic (population density, work force, people's priority, experience with RWH, land tenure, water laws, accessibility and related costs). Rao *et al.* (2003) used land use, soil, slope, runoff potential and proximity to the utility points (like irrigation and drinking water supply schemes), geology, and drainage as criteria to identify suitable sites for RWH. To develop a GIS-based RWH model (RSM) that combines a Multi-Criteria Evaluation (MCE) process, Kahinda *et al.* (2008) used physical (land use, rainfall, soil texture and soil depth), ecological (ecological importance and sensitivity category) and socio-economic factors. Ramakrishnan *et al.* (2008) used slope, porosity and permeability, runoff potential, stream order and catchment area as criteria to select suitable sites for various RWH /recharging structures in the Kali watershed, Dahod district of Gujarat, using remote sensing and GIS techniques.

United Nations Environment Programme (Mati *et al.* 2006) conducted a study to determine if RWH technologies can be mapped at continental and country scales. The project utilized a number of GIS data sets including rainfall, land use, land slope, and population density to identify four major commonly adaptable RWH technologies: roof top RWH, surface runoff collection from open surfaces into pans/ponds, flood flow storages and sand/sub-surface dams and *in-situ* RWH.

For relatively small areas, the critical factors can be assessed by field surveys However, for larger areas the application of GIS can be helpful for a first suitability screening with less time, cost and labour.

CHAPTER 3
STUDY AREA AND DATA ACQUISITION

3.1 Location

In the present study a watershed in the Ravi river basin in Himachal Pradesh has been considered. Himachal Pradesh, situated north of India, is also known as the 'Land of Snow' rests in the foothills of Himalayas. The total area of the state is 55,673 km^2. It is surrounded by landforms from all sides, Uttaranchal on the southeast, Punjab on the west, China on the east, Haryana on the southwest and Jammu and Kashmir on the north. It lies between the latitudes 30°22’40” North to 33°12’40” North and longitudes 75°45' 55" East to 79°04' 20" East. The entire region of Himachal Pradesh is hilly with the altitude ranging from 350 meters to 7000 meters above from sea level. The altitude increases from west to east and from south to north.

Barinallah watershed is a part of Ravi river basin. It is situated in the Chamba district of Himachal Pradesh. Chamba district is situated North West of Himachal Pradesh.

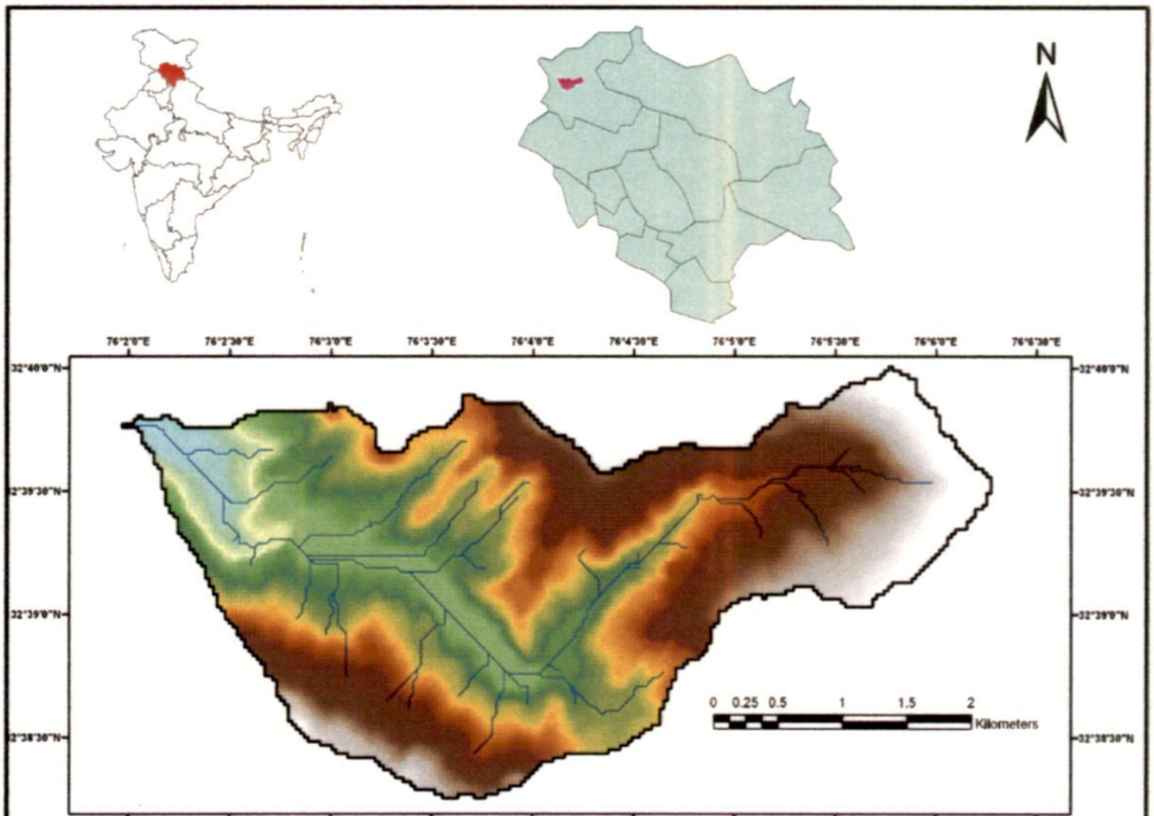

Fig. 3.1 Location of Study area.

The Barinallah watershed is located between 76°01'45'' E to 76°05'00'' E longitude and 32°38'00'' N to 32°40'00'' N latitudes on the western hills in Chamba district. This watershed has some springs and small nallahs. Water supply schemes for drinking water have been constructed to the nearby villages from these springs and nallahs. This area is characterized by elevation 760 m to 1880 m ranging mountains and valleys with drainage features. The location map of the study area is shown in Fig. 3.1.

3.1.1 Climate

The study area part of District Chamba enjoys a pleasant climate. Summers are generally warm and winters are cold. During winter the temperature varies from 1°C to 12°C and in summer it varies between 25°C to 39°C respectively. Mean daily maximum temperature is highest in the month of June being 39°C and mean daily minimum temperature is lowest in the month of January being 1°C.

This area receives about 1265 mm of annual rainfall, during southwest monsoon (July to September) which contributes about 60-70% of the annual rainfall and due to western disturbances (December to March) which contributes about 30-40% of the annual rainfall. The relative humidity in monsoon months varies from 70% to 95%. The annual average evaporation rate of the area is 5.6 mm/day. Evaporation in the dry season of April to June is relatively higher than in the winter season of November to March.

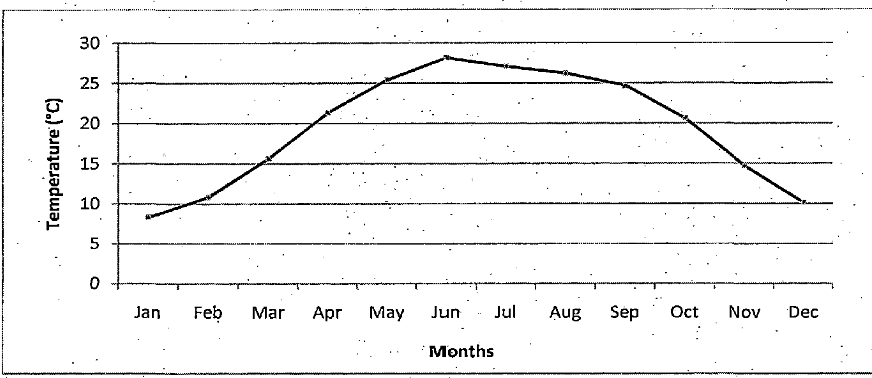

Fig. 3.2 Mean monthly temperature

Figure 3.2 shows the mean monthly temperatures while Fig. 3.3 shows monthly rainfall. The highest temperature occurs during the period April to October and maximum rainfall occurs during the period July to September. Figure 3.4 shows the annual rainfall in the year 1976, 1978, 1990 and 1996 is more than 1200 mm during the year 1963, 1970, 1982, 1987 and 1991 is less than 600 mm and the average annual average temperature is varying between 18.5 °C to 20.6 °C .

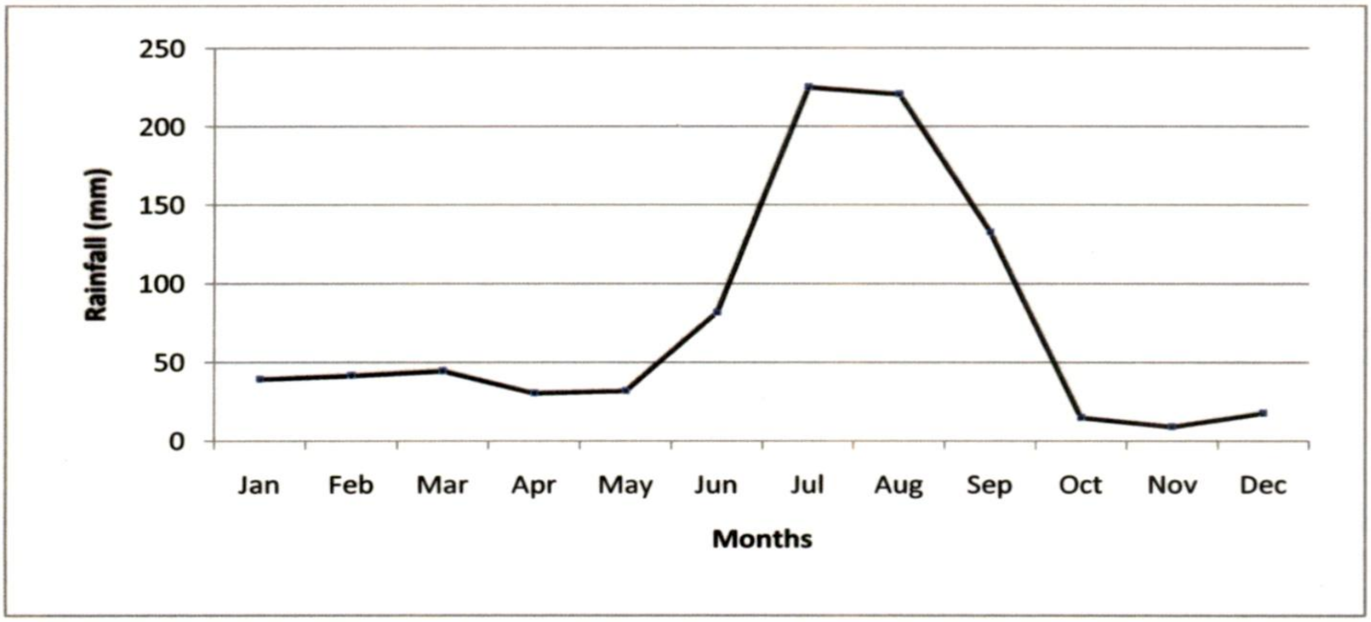

Fig. 3.3 Mean monthly rainfall

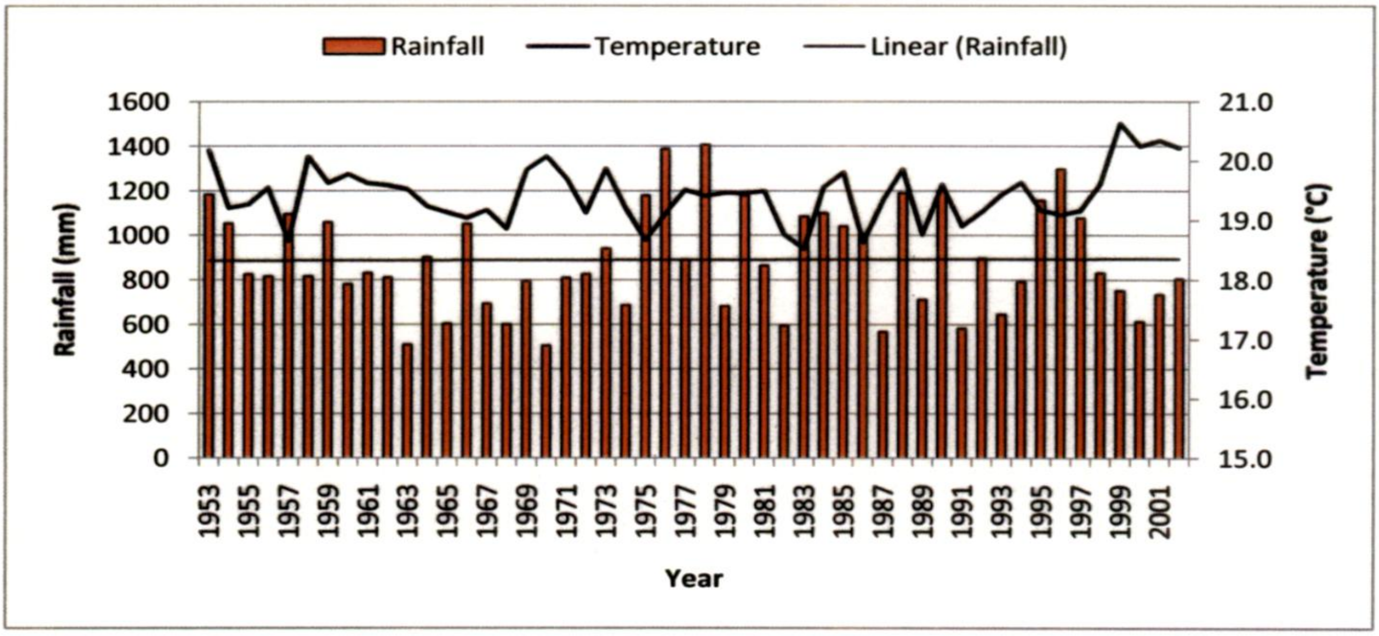

Fig. 3.4 Annual rainfall and annual average temperature

3.1.2 Topography

The elevation of Barinallah watershed varies from 760 to 1880 m above MSL. The topography of the study area is hilly and is less suitable for agriculture and other social activities.

3.1.3 Soils

The soil map was collected from The Department of Agriculture, Himachal Pradesh. Soils vary in texture, color and depth depending upon the topography and land use. The main soils in the study area are sandy loam, loam and sandy clay loam.

3.1.4 Land use/ Land cover

The dominant land use in the region is forest land and fallow land. The main food crops include maize, wheat vegetables, beans, potatoes. Dairy farming is also practiced together with traditional livestock keeping. The watershed provides water for domestic water supply, agriculture through springs, nallahs etc.

3.2 Data Source

Data used in this research was collected from various institutions and agencies while some were downloaded from the World Wide Web. These included hydro-meteorological data, soil, land cover, digital elevation model (DEM) and satellite imagery. Quality control was done by use of graphical, statistical and ground-truthing methods.

3.2.1 Database

Toposheet 52D2 in the scale of 1:50,000 has been used to prepare the reference map for the study area with supplementary information from satellite images. The Barinallah originates at an altitude of 1880 m above M.S.L and the altitude of the outlet is 760 m above M.S.L. The stream is joined by numerous small springs and streams (locally known as Nallahs), from the hills on both banks. The Barinallah is a perennial stream and is flashy and effluent. Water of this nallah is an important natural resource for the economic development of the people of this region. The Barinallah has a length of 9.28 km in south-west direction flowing and finally joins river Siul, a tributary of river Ravi.

3.2.2 Data Acquisition

3.2.2.1 Meteorological Data

The meteorological data were collected from the Office of the Chamera Power Station-I. These are daily rainfall, maximum and minimum temperature data for 11 years (2000–2010). The monthly data for average temperature and rainfall were obtained from India Water Portal website for 50 years (1953 to 2002) are given in Table 3.1 and 3.2.

Table 3.1 Average monthly temperature

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1953	6.87	13.03	18.42	21.84	26.36	28.96	27.91	26.29	24.84	21.02	14.73	11.90
1954	6.73	10.30	16.34	22.24	25.80	28.12	27.16	26.71	25.31	18.94	13.89	8.96
1955	8.11	11.76	17.19	19.06	23.10	29.09	27.14	26.47	24.77	19.88	14.93	9.77
1956	7.71	11.89	15.17	22.15	28.26	28.31	26.84	25.64	25.46	20.00	14.08	9.13
1957	7.28	9.67	14.30	19.07	23.39	27.32	27.83	26.02	24.16	20.07	14.52	10.15
1958	10.16	11.63	16.00	23.15	24.73	28.68	27.70	26.31	24.99	21.00	15.34	11.18
1959	8.00	8.92	16.61	21.90	24.70	29.37	26.69	27.15	25.15	21.93	14.18	10.98
1960	7.78	14.24	14.21	19.86	25.96	28.94	27.66	27.02	25.22	20.85	14.03	11.57
1961	8.84	9.21	16.32	21.00	25.70	29.21	27.62	26.96	26.64	21.70	14.04	8.28
1962	8.42	11.81	15.64	22.18	24.98	28.59	27.92	26.78	24.60	20.42	14.94	8.88
1963	8.46	11.42	14.76	20.70	24.69	29.04	27.60	26.31	24.46	21.63	15.52	9.73
1964	7.37	9.69	16.04	21.55	24.05	27.46	26.19	26.94	25.28	21.40	14.37	10.50
1965	8.87	10.52	14.99	19.61	24.23	27.95	26.83	25.18	24.60	21.32	15.91	9.59
1966	7.67	11.63	15.20	20.67	25.02	28.27	27.05	26.46	23.97	19.57	13.63	9.42
1967	7.64	12.01	14.76	20.68	24.08	28.42	28.03	26.33	25.20	19.24	14.03	9.71
1968	6.17	7.84	15.57	21.24	24.39	28.99	27.18	26.07	25.67	19.25	13.99	9.95
1969	8.09	11.03	17.77	20.88	24.73	28.31	27.30	27.31	24.87	21.47	16.15	10.37
1970	9.27	10.92	15.71	22.63	27.11	28.21	27.85	26.82	26.01	21.48	14.53	10.43
1971	8.54	11.09	16.63	22.03	25.55	28.83	27.07	26.15	24.11	21.18	14.71	10.69
1972	9.75	8.51	16.64	20.30	25.52	28.78	26.69	25.53	23.83	18.70	15.04	10.32
1973	8.61	12.04	15.05	22.84	26.11	29.27	27.62	26.41	25.58	20.32	15.05	9.59
1974	8.56	8.87	16.95	22.97	25.70	27.07	26.53	26.34	24.35	20.87	13.78	8.43
1975	8.08	9.13	13.87	21.06	25.27	27.14	25.32	25.46	24.43	21.19	13.05	10.00
1976	9.15	9.83	14.71	20.42	25.37	27.29	27.61	25.39	24.16	20.56	15.00	10.01
1977	8.76	10.35	17.00	21.45	24.15	26.88	27.54	26.19	24.41	21.28	16.12	10.12
1978	8.26	10.25	13.45	20.94	27.20	29.56	27.04	26.41	24.41	20.98	13.71	10.82
1979	7.84	10.53	14.37	23.05	24.12	28.41	27.11	26.63	23.20	21.72	15.78	10.85
1980	8.99	10.82	15.17	23.08	26.55	28.27	26.87	26.20	23.87	20.27	14.45	9.00
1981	9.04	11.64	17.44	21.77	26.94	27.73	26.71	25.66	24.16	19.93	13.80	9.13
1982	9.43	9.50	13.68	20.32	23.61	27.41	26.84	26.04	23.60	20.02	14.50	10.26
1983	8.18	9.50	13.12	19.25	24.33	26.34	26.03	26.26	25.35	19.89	14.01	10.00

1984	8.16	9.27	17.40	21.41	27.25	29.75	26.49	26.92	23.39	20.14	14.14	10.41
1985	8.39	11.66	17.77	22.32	26.00	28.21	26.73	26.45	25.02	20.29	14.01	10.89
1986	6.05	10.75	14.90	20.70	23.78	27.44	26.20	25.87	24.21	20.24	15.19	8.31
1987	6.79	11.71	16.35	21.58	22.61	27.13	27.50	26.79	25.59	20.77	15.10	10.12
1988	10.50	12.23	15.12	22.87	26.75	27.79	27.09	25.74	24.63	20.04	15.13	10.45
1989	7.58	10.63	15.06	19.89	24.97	26.87	26.26	24.54	24.27	20.43	14.39	10.25
1990	11.21	11.76	14.05	20.57	26.81	29.39	26.75	26.04	24.84	20.09	13.90	9.85
1991	5.88	10.54	15.65	19.73	24.95	27.55	27.52	25.97	24.61	19.71	14.06	10.68
1992	9.52	10.01	15.00	20.78	24.27	27.41	26.10	25.85	23.96	20.56	14.86	11.41
1993	8.17	12.37	13.58	21.43	26.12	28.01	26.10	26.45	24.51	20.41	15.66	10.42
1994	9.65	10.48	17.28	19.55	25.93	28.97	27.72	26.47	24.14	20.02	15.08	10.41
1995	6.50	10.01	14.95	20.17	26.87	29.41	26.55	25.57	24.02	20.81	14.92	10.27
1996	8.65	12.33	16.44	21.82	24.39	27.15	26.25	24.36	24.74	19.98	14.08	8.99
1997	9.15	11.07	15.67	21.14	24.15	26.71	27.80	25.58	25.34	19.37	14.32	9.70
1998	6.75	11.71	14.16	21.70	26.41	28.66	27.56	26.69	25.50	21.65	14.29	10.26
1999	8.42	13.55	17.03	24.97	26.50	27.30	28.13	26.69	26.03	21.63	16.20	11.16
2000	9.69	9.70	15.32	23.24	27.66	27.39	27.22	26.38	25.42	22.42	16.77	11.78
2001	9.88	12.05	16.89	21.71	27.37	27.00	27.86	26.98	24.86	22.22	15.89	11.48
2002	9.83	11.22	16.92	22.30	27.22	28.41	27.87	26.88	23.17	21.71	16.53	10.64

Table 3.2 Average monthly rainfall

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1953	53.92	35.84	49.46	21.62	4.38	90.44	453.86	192.08	230.87	19.18	3.12	28.59
1954	44.61	95.79	10.79	5.64	39.43	72.22	184.63	98.60	481.32	14.31	0.00	6.48
1955	41.98	3.26	77.12	22.61	37.24	46.26	132.02	229.08	197.36	33.56	0.00	5.04
1956	35.82	34.74	49.22	59.86	22.76	151.75	160.41	223.48	21.88	43.82	0.00	12.99
1957	100.48	19.88	42.73	75.12	21.62	75.91	96.95	479.90	72.92	38.39	26.71	45.57
1958	26.43	12.35	24.52	23.06	20.03	46.30	131.18	237.81	222.56	23.21	2.25	47.14
1959	44.82	25.04	32.46	14.31	93.19	24.36	564.83	152.51	53.02	18.53	32.64	3.51
1960	25.78	10.46	34.06	22.96	33.90	95.32	266.61	198.20	65.41	16.36	0.00	11.88
1961	114.97	36.26	20.43	24.63	12.01	54.45	257.88	129.68	132.05	16.90	4.05	27.22
1962	48.52	31.19	27.45	16.46	11.61	6.54	195.54	118.77	308.52	0.06	11.65	34.87
1963	0.62	46.68	109.77	9.45	26.89	13.01	91.68	90.40	82.05	0.67	3.00	35.20
1964	40.67	24.03	19.20	33.51	22.00	122.33	290.69	233.67	96.86	0.05	3.21	16.04
1965	15.40	45.29	31.61	64.21	20.55	5.93	225.59	149.60	8.16	26.09	11.24	0.20
1966	3.71	77.41	68.86	37.09	38.28	125.07	144.05	158.41	341.66	30.48	25.17	1.16
1967	2.11	53.43	65.83	12.54	40.30	6.93	96.86	295.11	43.81	6.87	3.20	67.39
1968	34.12	42.82	15.51	15.27	8.28	14.23	187.30	247.53	1.22	15.43	0.67	18.45
1969	16.67	35.66	43.10	102.30	39.10	18.37	190.44	171.07	162.04	16.17	0.00	0.20
1970	36.29	34.95	19.20	6.44	15.88	61.18	60.39	194.53	67.42	8.28	0.00	0.42
1971	3.91	20.02	5.46	39.96	80.37	105.59	201.89	284.64	50.01	18.73	0.00	0.21

1972	20.69	28.84	54.10	10.11	47.54	21.49	151.84	154.88	255.94	46.34	18.89	16.38
1973	45.26	29.84	33.75	21.98	23.90	82.08	195.48	387.66	87.91	11.34	0.00	22.31
1974	58.63	57.48	27.88	2.85	35.10	98.81	215.20	88.54	79.29	1.45	0.49	22.38
1975	46.65	49.66	81.86	9.12	11.99	125.07	305.07	332.02	207.62	7.96	0.00	2.74
1976	24.58	55.24	22.64	13.64	18.11	223.56	167.75	688.11	151.83	21.22	0.00	1.68
1977	65.36	5.46	3.52	87.80	49.09	197.18	205.70	142.25	71.85	40.38	2.65	20.38
1978	16.08	12.31	92.38	23.39	9.87	144.34	433.21	409.39	235.49	0.05	28.27	3.46
1979	18.11	68.61	55.76	10.00	33.53	43.77	181.69	85.93	152.52	11.09	15.12	7.47
1980	18.94	46.64	30.71	10.48	22.32	116.54	484.45	268.87	143.14	10.00	10.65	16.04
1981	99.61	30.62	54.28	40.39	23.93	33.27	372.32	143.27	4.91	9.68	51.88	0.95
1982	28.13	31.67	109.31	30.63	46.43	14.23	45.13	185.20	5.44	19.94	41.50	37.27
1983	58.32	36.01	112.50	71.90	78.34	139.38	250.84	233.50	76.63	27.66	0.00	1.65
1984	1.38	70.63	16.26	31.50	21.10	21.97	459.70	249.54	195.34	0.05	1.03	31.82
1985	34.12	3.31	20.33	50.81	27.35	98.64	394.43	240.57	100.56	27.98	2.06	41.57
1986	3.76	51.96	47.48	21.40	35.53	116.56	273.11	224.71	154.42	11.33	17.94	49.55
1987	55.56	35.24	31.36	35.19	31.19	129.27	82.79	111.07	2.06	29.23	0.00	25.10
1988	30.62	25.25	110.41	17.10	1.95	122.21	360.12	180.72	261.44	31.58	0.00	47.86
1989	68.74	14.89	25.98	9.36	20.87	31.76	301.19	165.02	49.79	6.05	13.22	6.04
1990	29.19	108.26	104.40	26.70	63.62	19.72	294.84	237.59	241.25	4.79	13.21	59.67
1991	17.57	32.73	25.89	66.49	35.21	121.25	24.19	157.20	84.93	4.16	0.67	13.67
1992	94.24	67.11	49.67	17.33	41.18	34.46	151.32	195.05	203.50	6.19	31.58	5.63
1993	27.41	27.72	45.72	33.51	22.74	75.32	236.39	18.99	158.27	0.05	0.00	0.20
1994	56.15	35.13	27.97	16.80	65.98	38.30	189.57	172.81	158.93	2.78	0.00	27.73
1995	54.55	138.31	16.66	10.35	4.41	108.16	334.60	342.85	108.47	3.51	29.67	5.92
1996	77.45	79.71	63.43	38.94	55.85	260.37	151.09	483.40	60.52	16.04	0.30	11.58
1997	23.99	17.25	32.83	61.53	26.02	165.45	224.90	373.06	107.07	12.60	22.85	10.92
1998	71.16	62.78	60.25	54.25	46.05	30.36	160.31	136.96	169.59	23.12	3.96	11.77
1999	47.90	36.18	19.14	42.32	32.10	67.98	153.61	260.07	74.21	5.26	9.14	4.96
2000	33.99	52.28	24.99	9.73	28.50	90.19	145.49	141.65	79.87	0.05	3.21	3.80
2001	13.23	22.02	19.06	25.84	36.52	81.89	275.87	146.49	92.17	4.73	8.44	8.35
2002	35.20	63.98	64.47	20.18	14.71	100.60	97.89	187.76	216.77	2.27	0.00	2.86

3.2.2.2 Hydrological Data

Discharge data of Hamled station was collected from the office of HP Irrigation cum Public Health Department. The monthly average discharge data were available for the year 2002 to 2004. The discharge data from the year of 2002-2003 were used for calibration and the discharge data for the year 2004 was used for validation of the ArcSWAT hydrological model.

Table 3.3 Monthly discharge data of stream at Hamled station (2002-2004)

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002	0.793	4.939	12.66	10.26	1.914	3.11	5.89	20.27	28.45	13.65	7.147	3.007
2003	2.344	4.719	19.71	14.9	0.68	2.71	5.029	26.32	18.66	14.77	7.553	4.91
2004	3.212	9.13	10.47	3.287	0.762	5.315	16.78	34.53	22.07	13.72	9.876	5.31

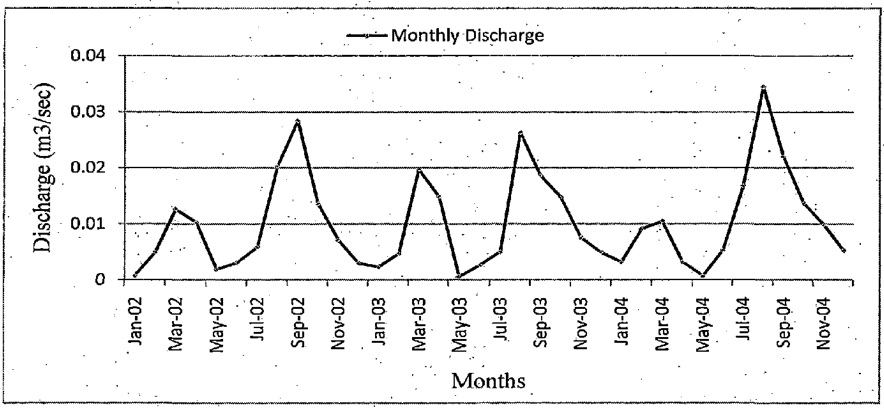

Fig. 3.5 Monthly discharge (2002-2004) in the Hamled station

CHAPTER 4
METHODOLOGY

4.1 General

The methodology for this study is divided into three parts. The first part is to review the climate change using statistical method to evaluate the trend that the climate has exhibited in the past in order to determine recent climate behaviours. The second part is to assess the water resources availability in the study area and gap thereby. The third part is to assess the effect of climate change on design of structures for restoration of water resources.

4.2 Statistical methods

Observational and historical hydro-climatic data are generally used for planning and designing water resources projects. Therefore, the need to study the climate change trends in the Bari nallah watershed, such as rainfall and temperature is important. Using the statistical method, this study examines the temporal trends and their spatial distribution of historical annual precipitation and temperature series in the study area. Three different methods has been used to assess the rainfall and temperature trend in the study area based on long term data viz. moving average, Mann-Kendall test and Sen's Slope Estimator.

4.2.1 Moving Average method

In statistics, a moving average, also called running average, is used to analyze a set of data by creating a series of averages of different subsets of the full data set. Given a series of numbers and a fixed subset size, the moving average can be obtained by first taking the average of the first subset. The fixed subset size is then shifted forward, creating a new subset of numbers, which is averaged. This process is repeated over the entire data series. The plot line connecting all the (fixed) averages is the moving average. Thus, a moving average is not a single number, but it is a set of numbers, each of which is the average of the corresponding subset of a larger set of data points.

4.2.2 Mann Kendall (MK) Test

There are many parametric and non- parametric methods which have been applied for detection of trends. Non-parametric trends tests only require the data to be independent and can tolerate outliers in the data. The Mann-Kendall test is a non-parametric test for identifying trends in time series data. The test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987). One benefit of this test is that the data need not conform to any particular distribution. Moreover, data reported as non-detects can be included by assigning them a common value that is smaller than the smallest measured value in the data set. The procedure that will be described in the subsequent paragraphs assumes that there exists only one data value per time period. When multiple data points exist for a single time period, the median value is used. The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, S, is assumed to be 0 (*e.g.*, no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S.

The Mann Kendall test searches for a trend in a time series without specifying whether the trend is linear or nonlinear. The trend test is applied to a time series x_i ranked from i=1, 2.........n-1, and x_j ranked from j=i+1, 2,.........n. Each data point x_i is used as a reference point and is compared with all other data points x_j such that

$$Sgn(x_j - x_i) = \begin{cases} +1 > (x_j - x_i) \\ 0 = (x_j - x_i) \\ -1 < (x_j - x_i) \end{cases} \qquad (4.1)$$

The Kendall statistics S is estimated as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \qquad (4.2)$$

The variance of the statistic S is defined by

$$Var(S) = \frac{n(n-1)(2n+5) - \Sigma t_i(i)(i-1)(2i+5)}{18} \qquad (4.3)$$

In which t_i denotes the number of ties up to sample i.

The test *statistics* z_c is estimated as

$$Z_c = \begin{cases} \frac{(S-1)}{\sqrt{Var(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{(S+1)}{\sqrt{Var(S)}}, & S < 0 \end{cases} \quad \text{.... (4.4)}$$

In which Z_c follows a standard normal distribution. A positive (negative) value of Z indicates an upward (downward) trend. A significance level α is also used to test for either an upward or downward monotone trend (a two-tailed test). If Z_c is greater than $Z_{\alpha/2}$ where α denotes the significance level, then the trend is significant.

4.2.3 Sen's Slope Estimator

In cases where a linear trend is present in a time series, then the true slope can be estimated by using a simple non-parametric procedure developed by Sen (1968). The slope estimate of N pairs of data are first computed by

$$Qi = \frac{x_j - x_k}{j-k} \quad \text{for} \quad i = 1,2,3 \dots\dots\dots\dots N \quad \text{....(4.5)}$$

Where x_j and x_k are data values at times j and k (j>k) respectively. The meridian of these N values of Q_i is Sen's estimator of slope. If N is odd, then Sen's estimator is computed by $Q_{med} = Q_{(N+1)/2}$ and if N is even, then Sen's estimator is computed by $Q_{med}=[Q_{N/2}+Q_{(N+2)/2}]/2$. Finally Q_{med} is tested by a two sided test at 100(1-α) % confidence interval and true slope may be obtained by the non-parametric test.

4.3 GIS Database Preparations

4.3.1 Hardware and Software

The hardware includes the input device, the output device and the system on which it is operated. The computer forms the backbone of the hardware, where data are input through the Scanner or a digitizer board. Scanner converts a picture into a digital image for further processing. The output of scanner can be stored in many formats e.g. TIFF, BMP, JPG etc.

Personal computer equipped with ERDAS IMAGINE 9.2, ArcGIS 9.3 and ArcSWAT 2009 softwares were used for this study.

4.3.2 Scanning and Geometric registration of topographic maps

The scanned topographic maps were geometrically corrected with ERDAS IMAGINE 9.2 using 4 control points as the graticule intersections. The scanned maps were displayed and rectangular coordinates were entered in place of spherical coordinates. Then these were geometrically transformed and transferred to the appropriate location on the blank raster database to finally provide a geometrically rectified map in the digital mode. The geometric precision was tested, by comparing the Root Mean Square Error (RMSE) of the corresponding graticule intersections with their theoretical coordinates kept within one pixel.

4.3.3 Digital Elevation Model (DEM)

Digital Elevation Models are data files that contain the elevation of the terrain over a specified area, usually at a fixed grid interval over the surface of the earth. The intervals between each of the grid points will always be referenced to some geographical coordinate system. This is usually either latitude-longitude or Universal Transverse Mercator (UTM) coordinate systems. The closer together the grid points are located, the more detailed the information will be in the file. The details of the peaks and valleys in the terrain will be better modelled with small grid spacing than when the grid intervals are very large. Elevations other than at the specific grid point locations are not contained in the file. As a result, peak points and valley points not coincident with the grid will not be recorded in the file.

The files can be in either American Standard Code for Information Interchange (ASCII) or binary. In order to read the files directly one must know the exact format of the entire file layout. Usually the name of the file gives the reference location to some map corner point in the file. The files usually contain only the z value (elevation value) and do not contain the actual geographical location that is associated with that point. The actual location associated with that elevation data is calculated by software reading the actual DEM file, knowing the precise location of the data value inside the DEM file. In addition, there will be some needed reference information in the header (first part) of the file. When an elevation is calculated at locations other than the actual grid points, some method of interpolation from the known grid points is used. Again, this is done in software that is external to the actual DEM file.

The DEM file also does not contain civil information such as roads or buildings. It is not a scanned image of the paper map (graphic). It is not a bitmap. The DEM does not contain elevation contours, only the specific elevation values at specific grid point locations.

4.3.4 Generation of Various Thematic Maps

The different maps including base maps, thematic/ derived maps and action plan map were prepared using the collateral data and satellite data.

4.3.4.1 Base Map

For the present study, as a preparatory work the Survey of India toposheet number 52D2 with the scale of 1:50,000 was used for preparing base map. Various base maps such as watershed boundary, drainage network and contour maps were prepared using the satellite data and topographic map. Later these maps were converted into digital maps through the process of digitization using GIS software.

4.3.4.2 Watershed Map

The watershed map was prepared by the technique of codification, such as sub, mini, and nano micro watersheds regions. This can be inferred by areal extension, namely 5000 hectares is sub, 500 is mini and 250 are micro watershed regions.

4.3.4.3 Drainage Map

This map was prepared with the help of Survey of India (SOI) toposheet. The drainage pattern present in SOI topographic sheet was digitized. Digitized drainage pattern was compared with satellite observed drainage pattern. Some of the streams are seasonal in nature and remain dry in non-rainy seasons.

4.3.4.4 Contour Map

The contour map of the study area was drawn with the help of the toposheet with contour interval 40 meter.

4.3.4.5 TIN and DEM

In order to establish flow accumulation points and possible stream network an elevation raster was created. For this contour data thus generated in the vector format was used to generate TIN (Triangulated Irregular Network) using ArcMap 3D analyst functions and the elevation of the watershed was divided into parts which values ranges from 760 m to 1880 m. Later this TIN has been converted to DEM (Digital Elevation Model) raster form by spatial analyst functions and the value of elevation ranges from 760 m to 1880 m.

4.3.4.6 Soil Map

Soil map was collected from The Department of Agriculture, Himachal Pradesh. Georeferencing is done using ERDAS IMAGINE 9.2 and digitalization is done with ArcGIS 9.3 software.

4.3.4.7 Land Use/ Land Cover Map

The land use/ land cover map was generated using satellite image downloaded from the website for the year 2006. The classification of the image was done using supervised algorithm into four different land use categories viz. forest, agricultural land, water bodies and barren/ fallow land.

4.4 ArcSWAT Model

The major goal of the ArcSWAT model development is to predict the impact of management measures on water, sediment and agricultural chemical yields in large ungauged basins. The ArcSWAT model simulates the surface runoff using the SCS curve number method (USDA-SCS, 1972). Sediment yield is computed for each sub-basin with the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977). The model predicts sub-basin nutrient yield and nutrient cycling using EPIC model (Williams *et al.*, 1984). The ArcSWAT model uses a command structure for routing runoff and chemicals through a watershed similar to the structure of HYMO model (Williams and Hann, 1973). The crop model is a simplification of the EPIC crop model (Williams *et al.*, 1984). Crop yield is estimated in the model using the harvest index concept. The ArcSWAT tillage component was designed to incorporate surface residue into the soil. Fertilizer applications can also be scheduled by the user or automatically applied by the model.

4.4.1 Theoretical consideration

A brief description of sub-basin components and the mathematical relationships used to simulate the processes and their interactions in the model as described by Arnold et al. (1996) are considered in this study. The mathematical relationships used in the model for simulating runoff volume and sediment yield are described below.

4.4.2 Runoff Volume

ArcSWAT predicts surface runoff for daily rainfall by using the Soil Conservation Service (SCS) Curve Number (CN) method (USDA-SCS, 1972). The model adjusts curve numbers based on Antecedent Moisture Condition (AMC). The basic equations used in SCS curve number method are as follows;

$$Q = \frac{(R-0.2s)^2}{R+0.8s}, \quad R > 0.2s \qquad \text{....(4.6)}$$

$$Q = 0.0, \qquad R \le 0.2s \qquad \text{....(4.7)}$$

where, Q is the daily runoff, R is the daily rainfall, and s is the retention parameter. The retention parameter varies in space because of varying soil, land use, management, and slope; and in time because of changes in soil water content. The parameter s is related to CN as follows;

$$s = 254\left(\frac{100}{CN} - 1\right) \qquad \text{....(4.8)}$$

The constant, 254, in Eq. (4.8) gives s in mm. Thus, R and Q are also expressed in mm. Curve numbers for moisture conditions I (CN_1) and III (CN_3) can be estimated using CN_2 as follows;

$$CN_1 = CN_2 - \frac{20(100 - CN_2)}{100 - CN_2 + \exp\left[2.533 - 0.0636(100 - CN_2)\right]} \qquad \text{....(4.9)}$$

$$CN_3 = CN_2 \exp\left[0.00673(100 - CN_2)\right] \qquad \text{....(4.10)}$$

Eq. (4.11) describes change in retention parameter based on fluctuations in soil water content:

$$s = s_1\left(1 - \frac{FFC}{FFC + \exp\left[w_1 - w_2(FFC)\right]}\right) \qquad \text{....(4.11)}$$

where, s_1 is the value of s associated with CN_1, w_1 and w_2 are the shape parameters and FFC is the fraction of field capacity and can be computed using Eq. (4.12):

$$FFC = \frac{SW - WP}{FC - WP} \qquad \text{....(4.12)}$$

where, SW is the soil water content in the root zone, WP is the wilting point water content and FC is the field capacity water content.

Values for w_1 and w_2 can be obtained from a simultaneous solution of Eq. 4.11 according to the assumptions that $s = s_2$ when FFC = 0.6 and $s = s_3$, when (SW-FC)/ (PO-FC) = 0.5;

$$w_1 = \ln\left(\frac{60}{1 - s_2/s_1} - 60\right) + 60 w_2 \quad \text{.... (4.13)}$$

$$w_2 = \frac{\ln\left(\frac{60}{1 - s_2/s_1}\right) - \ln\left(\frac{POFC}{1 - s_3/s_1} - POFC\right)}{POFC - 60} \quad \text{.... (4.14)}$$

where, s_3 is the CN_3 retention parameter and POFC is the porosity-field capacity ratio and can be computed with the following equation;

$$POFC = 100 + 50\left(\frac{\sum_{l-1}^{M}(PO_l - FC_l)}{\sum_{l-1}^{M}(FC_l - WP_l)}\right) \quad \text{.... (4.15)}$$

where, PO is the porosity of soil layer l. Eqs. (4.13) and (4.14) assure that CN_1 corresponds with the wilting point and that the curve number can not exceed 100.

The FFC value obtained in Eq. (4.12) represents soil water uniformly distributed through the top 1.0 m of soil. Runoff estimates can be improved if the depth distribution of soil water is known. The model estimates daily water content of each soil layer and thus the depth distribution is available. The effect of depth distribution on runoff is expressed in the depth weighting function;

$$FCC^* = \frac{\sum_{l-1}^{M} FCC_l \frac{Z_l - Z_{l-1}}{Z_l}}{\sum_{l-1}^{M} \frac{Z_l - Z_{l-1}}{Z_l}}, \qquad Z_l \leq 1.0\, m \quad \text{.... (4.16)}$$

where, FFC^* is the depth weighted FFC value for use in Eq. (4.11), Z is the depth in m to the bottom of soil layer l, and M is the number of soil layers.

4.4.3 Generation of discharge using the SWAT model

The ArcSWAT ArcGIS extension is a graphical user interface for the SWAT model (Arnold et al., 1998). Basically, ArcSWAT is a long term, physically based, continuous simulation watershed model developed to quantify the impact of land management practices in large, complex catchments. A large number of inputs are required for running the model to obtain modeled discharge. DEM, Landuse/Landcover map and Soil map of the study watershed are three spatial inputs required for the model. Other inputs required for the model are long term weather data, soil properties and discharge data.

Finally, the ArcSWAT model required discharge data at representative outlets of the streams for calibration and validation of the model. Discharge data recorded at the outlet of the study watershed during 2002-2004 have been taken for these purposes.

4.4.4 Preparation of Arc SWAT input data set

To create an ArcSWAT dataset, the interface will need to access ArcGIS compatible raster (GRIDs) and vector datasets (shapefiles and feature classes) and database files which provide certain types of information about the watershed. The necessary spatial datasets and database files need to be prepared prior to running the interface.

4.4.4.1 Digital Elevation Model (DEM): ESRI GRID Format

The ArcSWAT interface allows the DEM to use integer or real numbers for elevation values. The units used to define the GRID resolution and the elevation is not required to be identical. The GRID resolution can be defined in one of the following units: meters, kilometres, feet, yards, miles, decimal degrees. The elevation can be defined in one of the following units: meters, centimeters, yards, and feet.

The ArcGIS compatible raster (GRIDS) was extracted from the DEM image file. The GRID resolution and the elevation for this study were both defined in meters.

4.4.4.2 Landuse/Landcover Map: ESRI GRID Format

The categories specified in the landcover/land use map needed to be reclassified into ArcSWAT land cover/plant types. There are three options for reclassifying the categories.

The first option is to use a landcover/ landuse lookup table that is built into the ArcSWAT interface. The interface contains the USGS LULC and NLCD 1992 lookup tables in the ArcSWAT2009.mdb database that identifies the different ArcSWAT land cover/plant types used to model the various USGS LULC or NLCD 1992 land uses.

The second option is to type in the 4-letter SWAT landcover/plant type code for each category when the land cover/land use map theme is loaded in the interface. The third option is to create a user look up table that identifies the 4-letter SWAT code for the different categories of land cover/land use on the map.

The third option is used for this study; the user look up table that identifies the 4-letter SWAT code for each category was created. The ArcGIS compatible raster (GRIDS) image was extracted from the vector files.

4.4.4.3 Soil Map: ESRI GRID Format

The categories specified in the soil map needed to be linked to the soil database (U.S. soils data only) included with the interface or to the User Soils database, a custom soil database designed to hold data for soils not included with the United State soil database. There are four options for linking the map to the soil database.

(i) The STATSGO polygon (MUID) number method.
(ii) The STMUID method.
(iii) Linking the soils map to the database.
(iv) Linking the soils data from the User Soils database are to be utilized.

The fourth option was used to reclassify the map categories, by linking the soil data from the user soils database. A look up table was loaded which has this information listed. The ArcSWAT spatial datasets were created in the same projection as the DEM and Landuse/Landcover projection.

4.4.4.4 Weather Station set up

The user Weather Station set up was done by entering the climatic variables required by the SWAT model to the model database. The climatic variables input to set up the weather station database are as follows:

(i) Longitude and Latitude of the user weather station.
(ii) Elevation of the weather station.
(iii) Average or mean maximum air temperature for month (°C) Average or mean minimum air temperature for month (°C).
(iv) Standard deviation for daily maximum air temperature in month (°C).
(v) Standard deviation for daily minimum air temperature in month (°C).
(vi) Average or mean total monthly precipitation (mm).

(vii) Standard deviation for daily precipitation in month (mm/day).

(viii) Skew coefficient for daily precipitation in month.

(ix) Probability of a wet day following a dry day in the month.

(x) Probability of a wet day following a wet day in the month.

(xi) Average number of days of precipitation in a month.

(xii) Maximum 0.50 hour rainfall in the entire record period for month (mm).

(xiii) Average daily solar radiation for month (MJ/m^2/day).

(xiv) Average daily Dew point temperature in month (^{o}C).

(xv) Average daily wind speed in month (m/s).

4.4.5 Delineation of Stream network

Stream networks are delineated from a DEM using the output from the ArcINFO grid flow direction and flow accumulation functions. Flow direction uses a DEM to determine the direction of flow from every cell in the raster. Flow accumulation, in its simplest form, is the number of upslope cells that flow into each cell. By applying a threshold value to the results of flow accumulation, stream networks are delineated.

4.4.6 Establishment of Stream Network

After the threshold value has been selected for the flow accumulation, the stream network having the threshold value or greater was generated by the ArcSWAT model. This method is arbitrary, because it is based on the threshold selected by the user. The model generates the stream network in shape file format.

The drainage network is also extracted and digitized from the topographic map for comparison with the stream network generated by the model. It is found that the stream network generated by the model closely follows the stream network extracted from the topographic map.

4.4.7 Delineation of watershed and Subwatershed Boundary

It is the process of delineating an area that contributes to drainage or flow to the considered outlet. The watershed boundary was delineated from the topographic map in the ArcGIS environment with the ERDAS IMAGINE 9.2 software. This boundary was used as a mask in the ArcSWAT environment to finalize the watershed boundary.

In the ArcSWAT model each single stream are assigned to one catchment and have a separate outlet. This was achieved by manually minimizing the numbers of the sub-watershed outlet from the automatic watershed delineator in ArcSWAT.

4.4.8 Map overlay and Hydrological Response Unit (HRU) analysis

The ArcSWAT model subdivides the sub basins into smaller homogenous units known as hydrologic Response Units (HRU). The HRUs are lumped land areas within the sub basin comprising of unique features of land cover, soil and its management (Arnold *et.al.* 1993 and Neitsch *et.al.* 2001). The land use and soil datasets were imported and linked to the ArcSWAT databases and reclassified.

HRU analysis in ArcSWAT includes division of HRUs by slope classes in addition to land use and soils. This is particularly important if subbasins are known to have a wide range of slopes occurring within them. The slope classification was made for multiple slopes with 3 classes as 3% slope, 5% slope and above 5% slope. Finally, the slope map was also overlaid to create a unique landuse/soil/slope combination (hydrologic response units or HRUs) for each subbasin.

4.4.9 HRUs generation

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. Multiple HRUs are created for this study keeping the sensitivities for the land use, soil, and slope data are fixed at 5 %, 20% and 12 % respectively.

4.4.10 Import weather data

Weather data to be used in a watershed simulation is imported once the HRU distribution has been defined. The weather data were formulated in dbf file conforming to the ArcSWAT format. Weather data is loaded using the first command in the Write Input Tables menu item on the ArcSWAT toolbar. This tool allows users to load weather station locations into the current project and assign weather data to the sub-watersheds. For each type of weather data loaded, each sub-watershed is linked to one stream gauge.

4.4.11 Creation of Inputs

The database files containing the information needed to generate default input for ArcSWAT was build using the Write Input command. This command is enabled after weather data is successfully loaded. 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. Before ArcSWAT can be run, the initial watershed input values must be defined. These values are set automatically based on the watershed delineation and landuse/ soil/ slope characterization.

4.4.12 Model Output

A number of outputs are created in every ArcSWAT simulation. These files are: summary input files (input.std), the summary output file (output.std), the HRU output file (output.hru), the subbasin output file (output.sub), and the main channel or reach output file (output.rch).

The details of the data printed out in each file are controlled by the print code in the master watershed file. Average daily values are always printed in the HRU, subbasin and reach files, but the time period they are summarized over will vary. Depending upon the print code selected, the output file can include all daily values, daily amounts averaged over the month, and daily amounts averaged over the year.

4.4.13 Model calibration

Model calibration is the modification or adjustment of model parameters, within recommended ranges, to optimize the model output so that it matches with the observed set of data. The calibration tool of ArcSWAT provided several different parameters for adjustment through user intervention. These parameters can be adjusted manually or automatically until the model output best matches with the observed data. The discharge data recorded during the years 2002 and 2003 were used for the calibration of the model. The model calibration was done manually by changing the various ArcSWAT parameters one by one until the simulated model output matches the observed discharge data.

4.4.14 Model validation

Validation is the process of determining the degree to which a model or simulation is an accurate representation of the observed set of data from the perspective of the intended uses of the model. The values of simulated discharge at specified location will be compared with the observed discharge for validation of the model (Gassman et. al., 2007). The model performance can be evaluated using established indices like (i) coefficient of determination (R^2), (ii) Index of agreement (d), (iii) Nash and Sutcliffe efficiency, and (iv) Relative Error (RE) etc.

(i) Coefficient of determination is given by:

$$R^2 = \left\{ \frac{n(\sum Q_{mod} \cdot Q_{obs}) - (\sum Q_{mod}) \cdot (Q_{obs})}{\sqrt{[n(Q_{mod}^2) - (\sum Q_{mod})^2] \cdot [n(Q_{obs}^2) - (\sum Q_{obs})^2]}} \right\}^2 \qquad \text{....(4.17)}$$

R^2 is most often used in linear regression. Given a set of data points, linear regression gives a formula for the line most closely matching those points. It also gives an R-Squared value to say how well the resulting line matches the original data points. The value of R^2 ranges from 0 to 1, a value between 0.6 to 1.0 indicates a good correlation.

(ii) Index of agreement is given by:

$$d = 1.0 - \left[\frac{\sum_{i=1}^{n} (Q_{mod} - Q_{obs})^2}{\sum_{i=1}^{n} [|Q_{mod} - Q_{avg}| + |Q_{obs} - Q_{avg}|]^2} \right] \qquad \text{....(4.18)}$$

The value of d ranges from 0 to 1.0, nearer the value is to 1.0 better is the flow prediction.

(iii) Nash and Sutcliffe model performance coefficient is given by:

$$NR = 1.0 - \frac{\sum_{i=1}^{n} (Q_{obs} - Q_{mod})^2}{\sum_{i=1}^{n} (Q_{obs} - Q_{avg})^2} \qquad \text{....(4.19)}$$

The value of Nash and Sutcliffe model coefficient ranges from 0 to 1.0 and higher is the value better is the model prediction output.

(iv) Relative Error:

$$RE = \frac{\sum_{i=1}^{n} Q_{mod} - \sum_{i=1}^{n} Q_{obs}}{\sum_{i=1}^{n} Q_{obs}} \qquad \text{....(4.20)}$$

The range of RE is -1 to α, and zero is the perfect match. When the RE value near 0 the prediction of the model is more acceptable.

where, Q_{mod} is Model discharge,

Q_{obs} is observed discharge,

Q_{avg} is average value of observed discharge,

n is numbers of data being considered.

Validation of the calibrated model is essential to test its simulation performance. Calibrated model was validated using the discharge data recorded during the year 2002 and 2003 by the office of HP Irrigation cum Public Health Department. The simulated values were obtained on monthly basis. The value of simulated discharge at the outlet was compared with the observed discharge for validation of the model. The model performance was evaluated using above four established indices (Krause *et al.* (2005); Gassman *et al.* (2007)) *viz.*, Coefficient of determination (R2), Nash and Sutcliffe efficiency (NSE) and index of agreement (d), and relative error of the stream flow volume (RE). Anticipating differences in hydrologic behaviour of the watershed in rainy and non-rainy seasons, the validation were separately tested for entire period, and for dry and rainy periods.

4.4.15 Sensitivity analysis

Sensitivity analysis is the determination of the most influential independent parameter of the model in predicting the flow. The ArcSWAT model has various inbuilt parameters affecting the flow with a prescribed range of value. The process involves varying the various values of parameter of model to see the effect on the output value.

The analysis was done based on the hydrological simulation at the catchment outlet by varying the various parameters one by one and comparing the percentage deviation in the flow simulated. This helps the ArcSWAT user in calibrating the model and choosing the right and minimum parameter for calibration. The sensitivity of parameters varies from basin to basin due to physical properties, landuse, and different climatic conditions. The sensitivity analysis was performed for the year 2004.

4.5 Model application

The ArcSWAT model has the capability not only to create the boundary of the watershed and subwatershed but also calculate geomorphic characteristics of the sub-basins and reaches giving the area of each subbasin, maximum and minimum elevation and slope etc. The model also calculates the detailed characteristics of the stream network which was generated using the input DEM. The ArcSWAT model gives the length of each streams and their outlet along with the stream maximum and minimum elevation.

The model also, by default, gives all the outlets of the Subwatershed at every confluence point of the rivers. Subwatershed outlets are the points in the drainage network of a subwatershed where stream flow exits the sub-watershed area. The ArcSWAT model has a provision for editing the outlet of a sub-watershed either removing or adding a new outlet through user intervention.

The ability of the ArcSWAT model to generate detailed information of the stream is utilized for identification of the RWH sites along the stream network and estimation of flow in each selected potential sites.

4.6 Identification of sites for RWH

The ArcSWAT model is run without editing subbasin outlet to have knowledge on the characteristics of the stream as the model by default gives subbasin outlet for each single stream. Once the characters of the stream are known, the search for potential site is started. The DEM input is first analyzed to find position of the required elevation in the upstream of the main outlet by clicking on each pixel to know the elevation. The search for the required elevation is carried out along the stream network generated by the ArcSWAT model. After locating the pixel having the required elevation, the stream length is measured from the outlet to check for the distance criteria. The subbasin outlet is then added manually in the stream network and the subwatershed is delineated again. The detailed information generated by the model is checked for the height and distance criteria. When both the criteria are met the site is selected as potential site for rain water harvesting structures. The next site is assessed in the same manner starting from the last selected site till the stream ends.

4.7 Estimation of flow

The discharge is generated using a validated ArcSWAT model for each of the selected RWH structures sites. Since the subbasin outlets are added to each potential site at the time of head assessment, the discharge at each sites are obtained. This gives a more realistic discharge for RWH structures as the discharge at each site is simulated separately. The model estimates the discharge on monthly basis which can be used for the design of reservoir of check dam as per the requirement.

4.8 Surface Water Harvesting

During the last 100 years there has been considerable technological development in the design and construction of water harvesting structures for various purposes. The structures, which are commonly built for surface storage and / or ground water recharge, are:

4.8.1 Check Dams:

These are concrete or masonry structures built across small streams for surface storage and incidental benefit of ground water recharge as shown in Fig 4.1. The design of these structures are done taking into consideration the volume of water that can be stored in the stream channel upstream, the surplus flood discharge that must be evacuated safely, stability of the structure against various forces and the likely ground water recharge.

These are the modified and improved versions of the traditional temporary or semi-permanent structures that people in the villages usually build across natural streams or drainage channels.

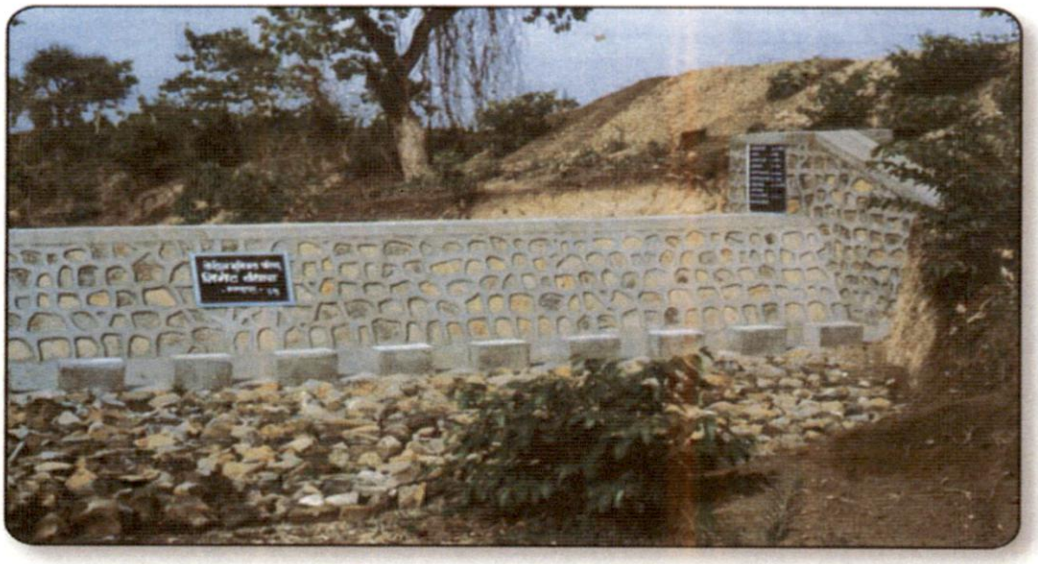

Fig.4.1 Schematics of a Typical Check Dam

4.8.2 Gabion Structure:

This is a kind of check dam commonly constructed across small streams to conserve stream flows with practically no submergence beyond stream course as shown in Fig4.2. A small bund across the stream is made by putting locally available boulders in a mesh of steel wires and anchored to the stream banks. The height of such structures is around 1.0 m and is normally used in the streams with width of less than

10 m. The excess water over flows this structure storing some water to serve as source of recharge. The silt content of stream water in due course is deposited in the interstices of the boulders and with growth of vegetation, the bund becomes quite impermeable and helps in retaining surface water runoff for sufficient time after rains to recharge the aquifer.

Fig.4.2 Schematics of a Gabion Structure

4.8.3 Contour Bunding/ Trenching

In hilly/ rural areas, rain water harvesting is taken up considering watershed as a unit. Surface spreading techniques are common since space for such systems is available in plenty and quantity of recharged water is also large. Following techniques may be adopted to save water going waste through slopes. These aim at augmenting soil moisture retention and preventing soil erosion and land degradation.

4.8.3.1 Contour Bunding:

These are small earthen bunds built horizontally in parallel rows across the hill slope. These help in augmenting soil moisture and prevent erosion of topsoil. Contour Bunds are effective methods to conserve soil moisture in watershed for long duration. These are suitable in low rainfall areas where monsoon run off can be impounded by constructing bunds on the sloping ground all along the contour of equal elevation. Flowing water is intercepted before it attains the erosive velocity by keeping suitable spacing between bunds. Spacing between two contour bunds depends on the slope the area and the permeability of the soil. Lesser the permeability of soil, the closer should be spacing between bunds. Contour bunding is suitable on lands with moderate slopes without involving terracing as shown in Fig.4.3.

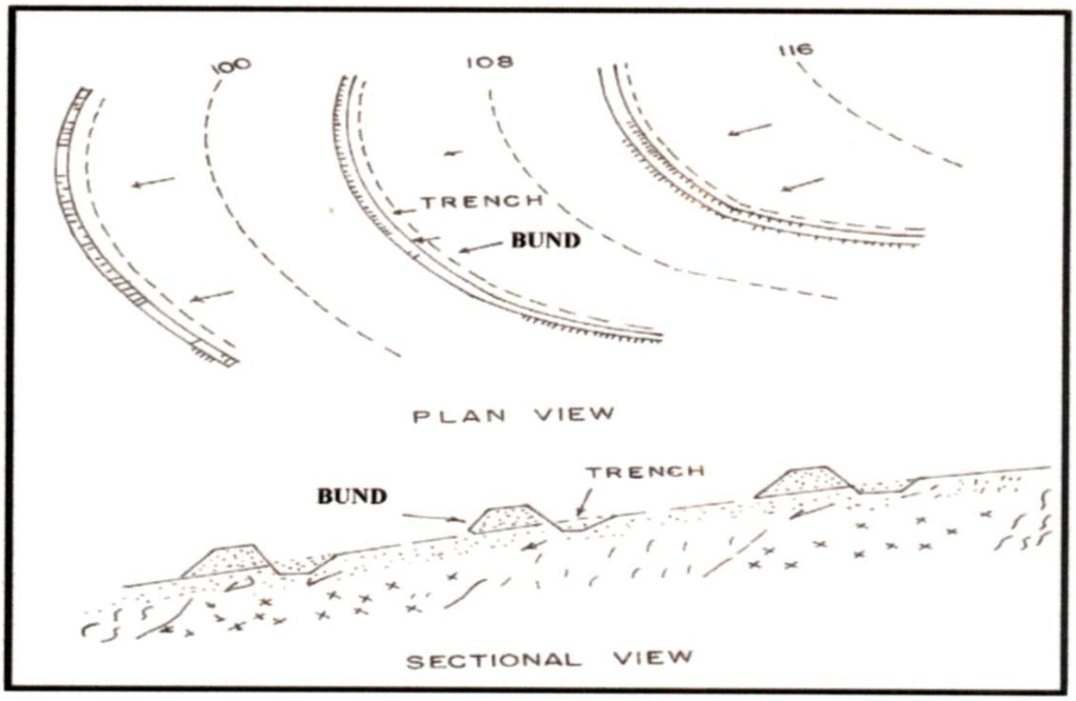

Fig.4.3 Schematics of a Contour Bund

a. Spacing of Bunds:

Spacing of contour bund is commonly expressed in terms of vertical interval (V.I.), which is defined as the difference in elevation between two similar points on two consecutive bunds. The main criterion for spacing of bunds is to intercept the water before it attains the erosive velocity. Spacing depends on slope, soil, rainfall, cropping pattern and conservation practices.

Spacing of contour bunds is normally calculated using the formula

Vertical Interval (V.I.) = 0.305 (XS+Y), ...(4.21)

where, X is the rainfall factor, S is the land slope (%), Y is the factor based on soil infiltration and crop cover during the erosive period of rains

The rainfall factor 'X' is taken as 0.80 for scanty rainfall regions with annual rainfall below 625 mm, as 0.60 for moderate rainfall regions with annual rainfall in the range of 625 to 875 mm and as 0.40 for areas receiving annual rainfall in excess of 875 mm. The factor 'Y' is taken as 1.0 for soils having poor infiltration with low crop cover during erosive rains and as 2.0 for soils of medium to good infiltration and good crop cover during erosive rains. When only one of these factors is favourable, the value of Y is taken as 1.50. Vertical spacing can be increased by 10 percent or 15 cm to provide better location, alignment to avoid obstacles.

The horizontal interval between two bunds is calculated using the formula Horizontal Interval (H.I) = V.I x 100/Slope ....(4.22)

b. Cross Section of Contour Bunds:

A trapezoidal cross section is usually adopted for the bund. The design of the cross section involves determination of height, top width, side slopes and bottom width of the bund.

The height of the bund depends on the slope of the land, spacing between bunds and the rainfall excess expected in 24-hour period for 10-year frequency in the area. Once the height is determined, other dimensions can be worked out depending on the nature of the soil.

Height of the bund can be determined by the following methods:

a) Arbitrary Design: The depth of impounding is designed as 30 cm. 30 cm is provided as depth of flow over the crust of the outlet weir and 20 cm is provided as free board. The overall height of the bund in this case will be 80 cm. With top width of 0.50 m and base width of 2 m, the side slope will be 1:1 and the cross section, 1 m^2.

b) The height of bund to impound runoff from 24 hour rain storm for a given frequency can be calculated by the formula

$$H = \frac{\sqrt{Re \times VI}}{50} \qquad \text{...(4.23)}$$

where, H is the depth of impounding behind the bund (m), Re is the 24 hour rainfall excess (cm) and VI is the vertical interval (m)

To the height so computed, 20 percent extra heights or a minimum of 15cm is added for free board and another 15 to 20 percent extra height is added to compensate for the settlement due to consolidation.

Top width of the bund is normally kept as 0.3 to 0.6 m to facilitate planting of grasses. Side slopes of the bund are dependent on the angle of repose of the soil in the area and commonly range from 1:1 for clayey soils to 2:1 for sandy soils. Base width of the bund depends on the hydraulic gradient of the water in the bund material due to the impounding water. A general value of hydraulic gradient adopted is 4:1. The base should be sufficiently wide so that the seepage line should not appear above the toe on the downstream side of the bund.

Size of the bund is expressed in terms of its cross-sectional area. The cross sectional area of bunds depends on the soil type, rainfall and vary from 0.50 to 1.0 m^2 in different regions.

The length of bunds per hectare of land is denoted by the Bunding Intensity, which can be computed as

Bunding Intensity = 100 x S/V.I.

where, S is the land slope (%) and V.I is the vertical interval (m)

The earthwork for contour bunding includes the main contour bund and side and lateral bunds. The area of cross-section of side and lateral bunds is taken equal to the main contour bund. The product of cross sectional area of the bund and the bunding intensity gives the quantity of earthwork required for bunding per hectare of land.

4.8.3.2 Contour Trenches

Contour trenches are rainwater harvesting structures, which can be constructed on hill slopes as well as on degraded and barren waste lands in both high and low rainfall areas. Cross section of a typical contour trench is shown in Fig.4.4.

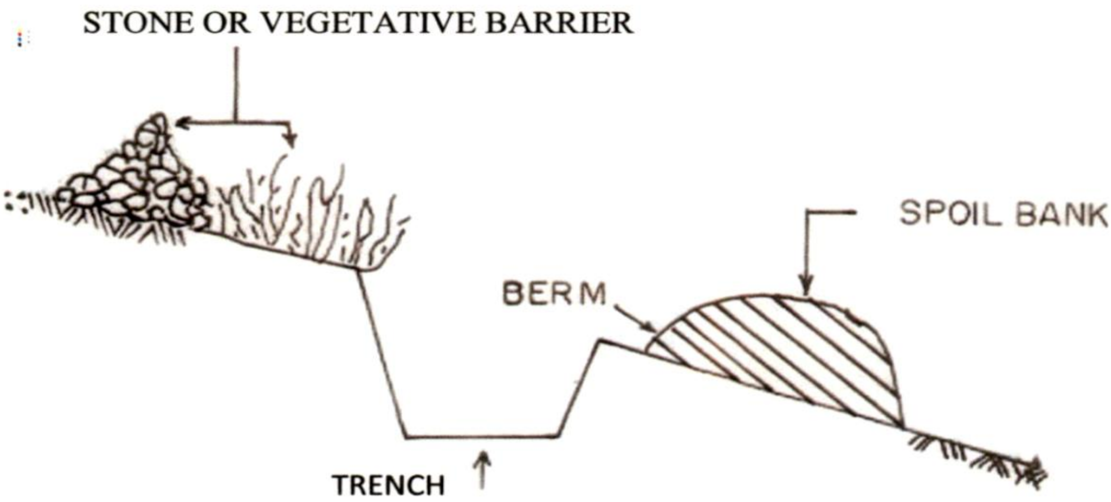

Fig.4.4 Schematics of a Contour Trench

The trenches break the slope at intervals and reduce the velocity of surface runoff. The water retained in the trench will help in conserving the soil moisture and ground water recharge.

The size of the contour trench depends on the soil depth and normally 1000 to 2500 cm^2 cross sections are adopted. The size and number of trenches are worked out on the basis of the rainfall proposed to be retained in the trenches. The trenches may be continuous or interrupted and should be constructed along the contours. Continuous trenches are used for moisture conservation in low rainfall area whereas intermittent trenches are preferred in high rainfall area.

The horizontal and vertical intervals between the trenches depend on rainfall, slope and soil depth. In steeply sloping areas, the horizontal distance between the two trenches will be less compared to gently sloping areas. In areas where soil cover is thin, depth of trenching is restricted and more trenches at closer intervals need to be constructed. In general, the horizontal interval may vary from 10 m in steep slopes to about 25 m in gentle slopes.

CHAPTER 5
ANALYSIS AND RESULTS

5.1 General

In this study the analysis procedure is divided into following steps:

1) Assessment of climate change with statistical analysis, to find out trend analysis with historic data.
2) Hydrology modeling using "Arc Soil Water Assessment Tools" (Arc SWAT 2009), to find out impacts of climate change in the watershed.
3) Input for watershed planning to get best condition to adapt climate change.

5.2 Trend Detection for Temperature and Rainfall

Monthly temperature and rainfall records from the recording stations were summed to provide annual totals for each year. Monthly and annual time series were analyzed statistically by using Mann-Kendall (MK) test.

The statistics for annual temperature and rainfall are given in Table 5.1 which shows that the annual temperature ranges from 8.3 to 28.1°C, with an average 19.4°C. The annual rainfall range from 1008 to1738 mm, with an average of 1265 mm during the study period from 1953-2002.

Table 5.1 Statistics of annual temperature and rainfall in the watershed

Statistics	Temperature (°C)	Rainfall (mm)
Average	19.4	1265
Standard Deviation	0.48	231.67
Coefficient of Skewness	0.23	0.354
Maximum value	28.1	1738
Minimum value	8.3	1008

A five year moving average analysis was carried out for annual average air temperature and annual rainfall. The annual temperature data was tested to show trend of temperature change in the Barinallah watershed in (Fig. 5.1) and the annual rainfall data was tested to show trend of change in rainfall pattern in the Barinallah watershed in (Fig. 5.2).

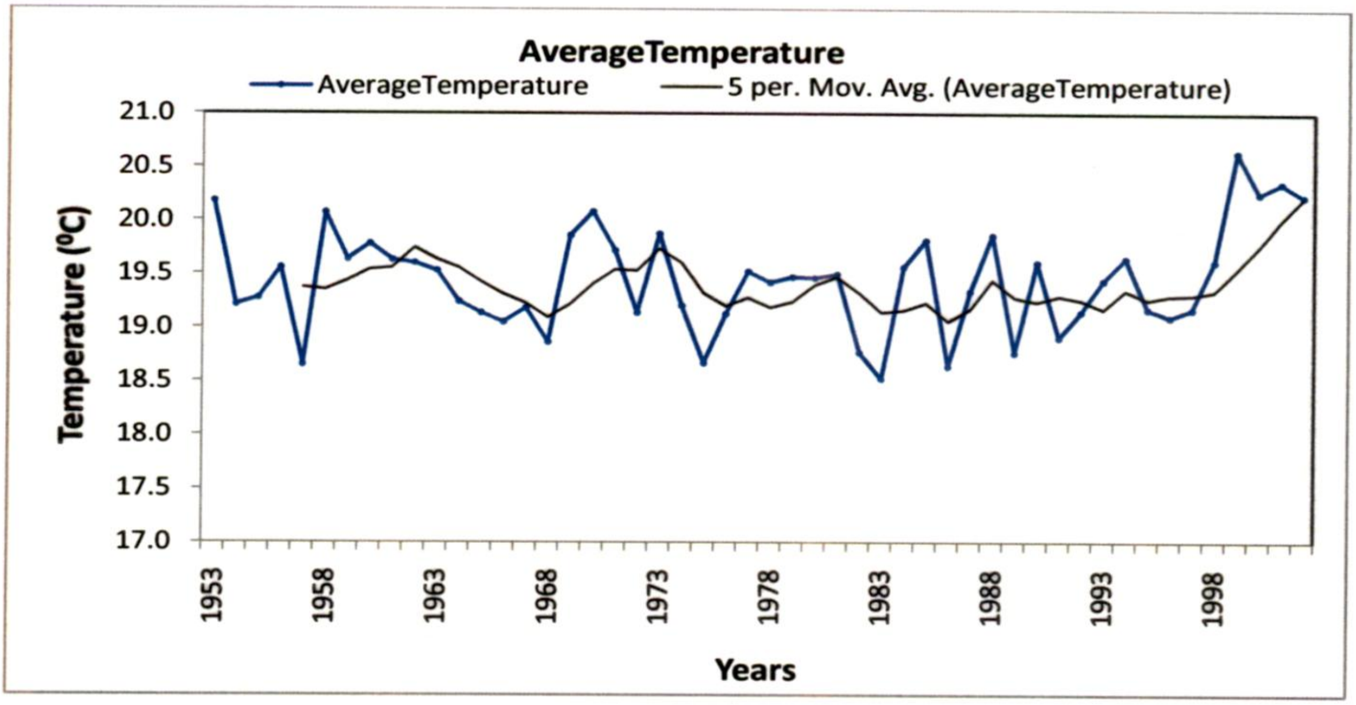

Fig. 5.1 Five years moving average annual temperature (1952-2002)

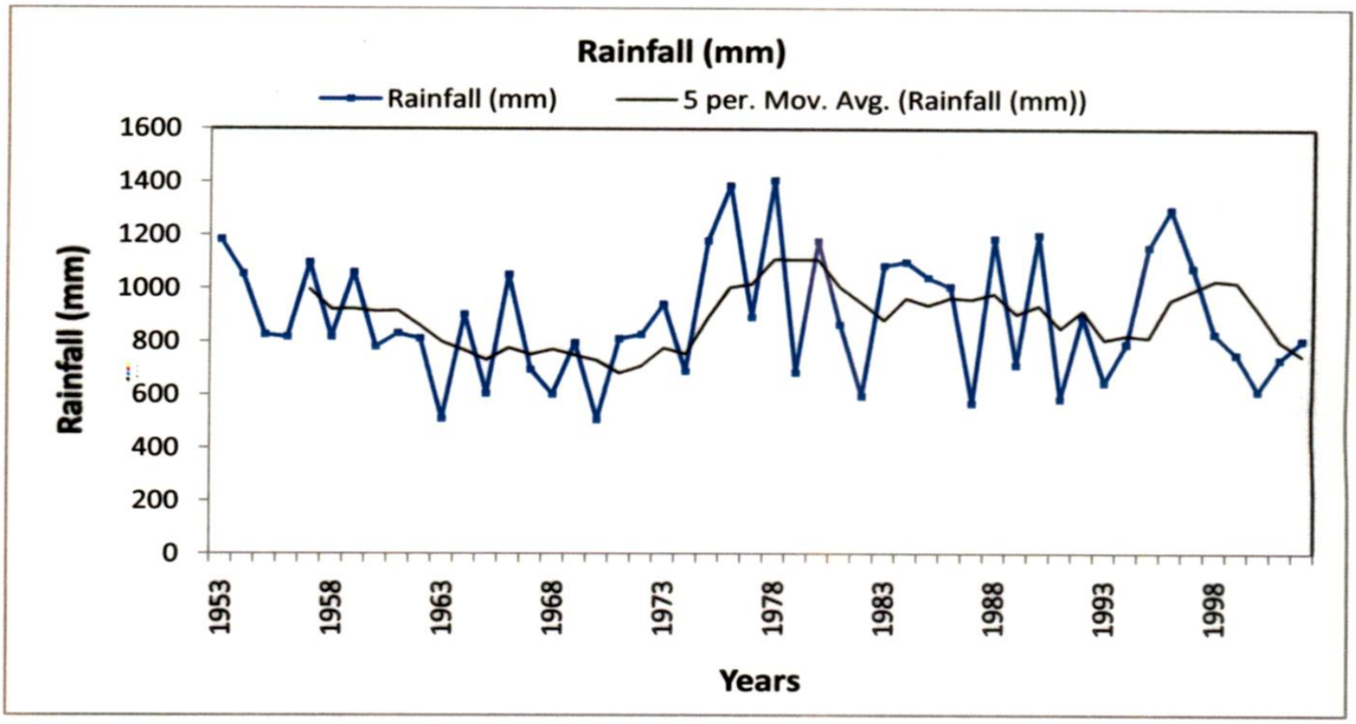

Fig. 5.2 Five years moving average annual rainfall (1952-2002)

5.2.1 Temperature Trend

The mean temperature varies from 1°C to 12°C in winter and from 30°C to 39°C in summer. Typical seasonal annual air temperature trends for the long term period (1953-2002) were analyzed using Mann-Kendall test.

The values of Mann-Kendall statistics Z_{mk} and Sen's slope in long term period for different months are given in Table 5.2. January and May gives the greatest slope 0.03°C, followed by December 0.02°C, February, April and November showed the smallest tendency, with slopes of 0.01°C. June gives the maximum negative trend -0.02°C, followed by July, August and September with slopes of -0.01°C while the months March and October shows no trend.

Table 5.2 Variations of the long term period temperature (°C) in The Barinallah Watershed

1953-2002		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mann Kendall	Z_{mk}	**2.21**	0.87	-0.38	0.67	1.92	-2.48	-1.15	-1.07	-1.16	0.38	1.69	1.80
Sen's Slope	Q	0.03	0.01	0.00	0.01	**0.03**	-0.02	-0.01	-0.01	-0.01	0.00	0.01	0.02

Generally, temperature slopes are positive during the winter season and are negative during the rainy season. But during the summer season the temperature have positive slopes in May and negative slope in June in the above table.

5.2.2 Rainfall Trend

The values of Mann-Kendall statistics Z_{mk} and Sen's slope in long term period for different months are given in Table 5.3. Long-term trend during fifty years period, in the rainfall is tested with Mann-Kendall (MK) methods. The values of Mann-Kendall statistics Z_{mk} and Sen's slope in long term period for different months is given in Table 5.3. It is seen that two months out of the twelve months showed a decreasing trend. October gives the greatest trend at -0.32 mm, December gives the trend at -0.11 mm. Two of the ten months showed an increasing trend. June gives the greatest trend at 0.75 mm, February gives the trend at 0.35 mm, May and August gives the trend at 0.15 mm, July gives the trend at 0.12 mm, January and April gives the trend at 0.09 mm, March gives the trend at 0.01 mm and November gives no trend.

In Monthly series, only month October is indicating downwards tendency and also showing a significant downward trend at the $\alpha = 0.05$ significant level, but month June is indicating upwards tendency. The Sen's slope is positive indicating upwards tendency (except for the month of October and December). The month of June and February are showing a significant upward trend at the $\alpha=0.05$ significant level.

Table 5.3 Variations of the long term period rainfall (mm) in Barinallah watershed

1953-2002		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mann Kendall	Z_{mk}	0.39	**1.57**	0.03	0.69	0.95	1.38	0.08	0.18	0.03	<u>-2.70</u>	0.54	-0.68
Sen's Slope	Q	0.09	0.35	0.01	0.09	0.15	**0.75**	0.12	0.15	0.04	<u>-0.32</u>	0.00	-0.11

5.3 Hydrological Modeling with ArcSWAT (2009)

As future changes, in watershed hydrology caused by global warming is important topic for water resource management, many researchers have studied the sensitivity of stream flow and hydrological elements to climate change. The Arc Soil Water Assessment Tools (ArcSWAT) was used in this study. In order to model the impacts of climate change on hydrological cycles in watershed, as many studies have been successfully made. Modeling simulation is done to predict the impact of land management on water, sediment over long periods of time in complex watersheds with different soil, land use, and management conditions with this tool. The process and result of this modeling tool are analyzed which are described in subsequent sections.

5.3.1 Model Set Up

To analyze the impact of different management practices and hydrologic conditions in the watershed for stream, firstly by preparing input database information and loading this information in the model. It is primarily step modelling. The following steps were followed to set up the model and load the input database:

5.3.1.1 Watershed Delineation

5.3.1.1.1 Digital Elevation Model (DEM) Set Up

In watershed delineation the Digital Elevation Model (DEM) (Fig. 5.3), which is used with 30x30 meter pixel size was loaded to the system in an ArcInfo grid format. The DEM properties were set up to verify the projection and the horizontal and vertical units of measure were verified. After the DEM was imported into ArcSWAT, the masking raster grid was created for the study area to focus only on the Barinallah watershed.

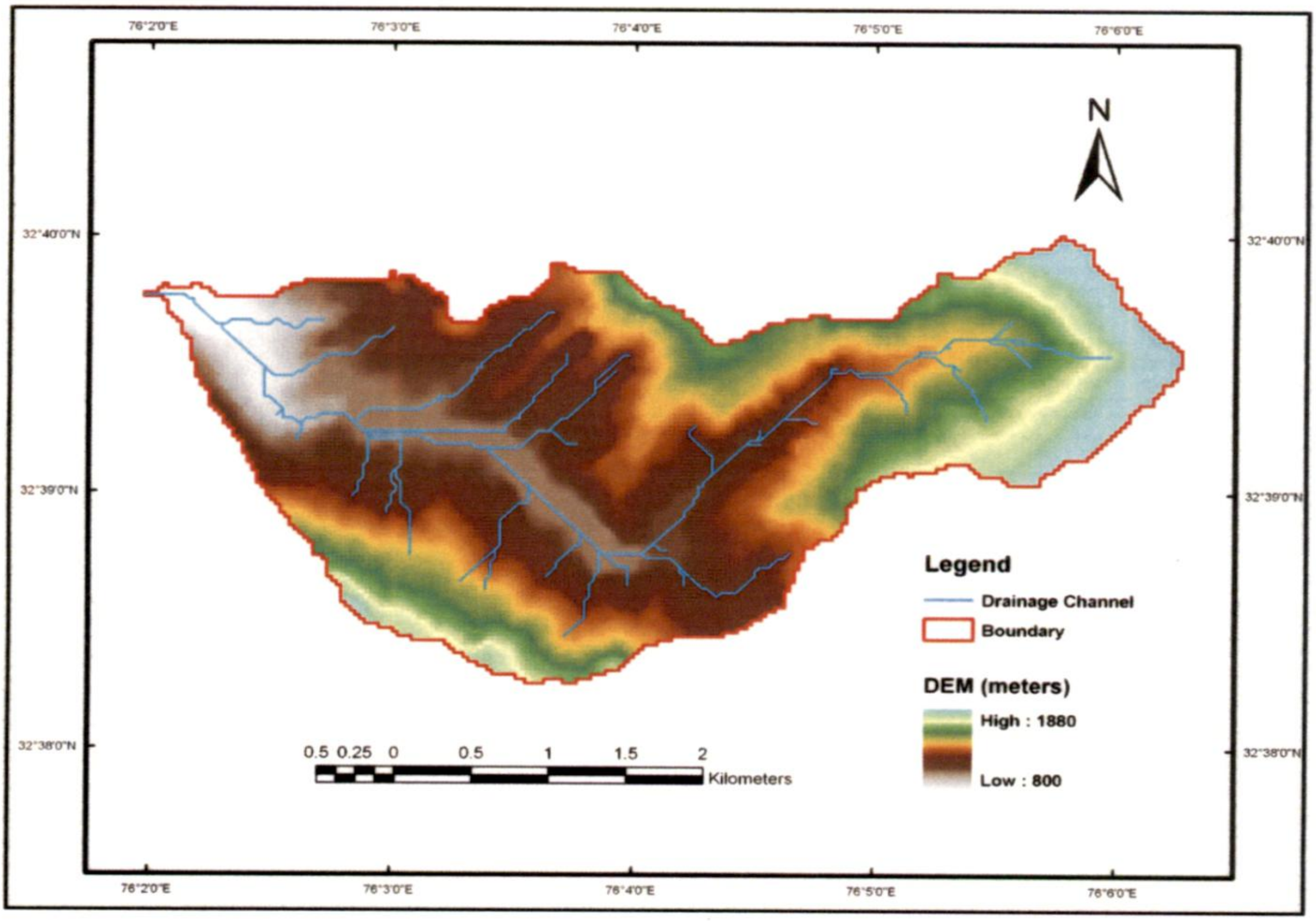

Fig.5.3 ArcSWAT Digital Elevation Model (DEM)

5.3.1.1.2 Stream Definition

In this section, the initial stream network and sub-basin outlets are defined. Delineation of stream network from raster DEM is based on the eight-pour point algorithm. Flow vector grid is created filling the sinks (raising the elevation of the sink until overflows occurs). The flow accumulation grid is created by counting the number of contributing cells to each unit in the grid (cells whose flow path eventually passes through them). Cells which are potentially part of a stream network will have a larger flow accumulation value, whereas cells near watershed boundaries and where overland flow dominates will have a low accumulation value. The detailed study area of the watersheds is 12.02 km^2 for 66 sub-watersheds (Fig. 5.4).

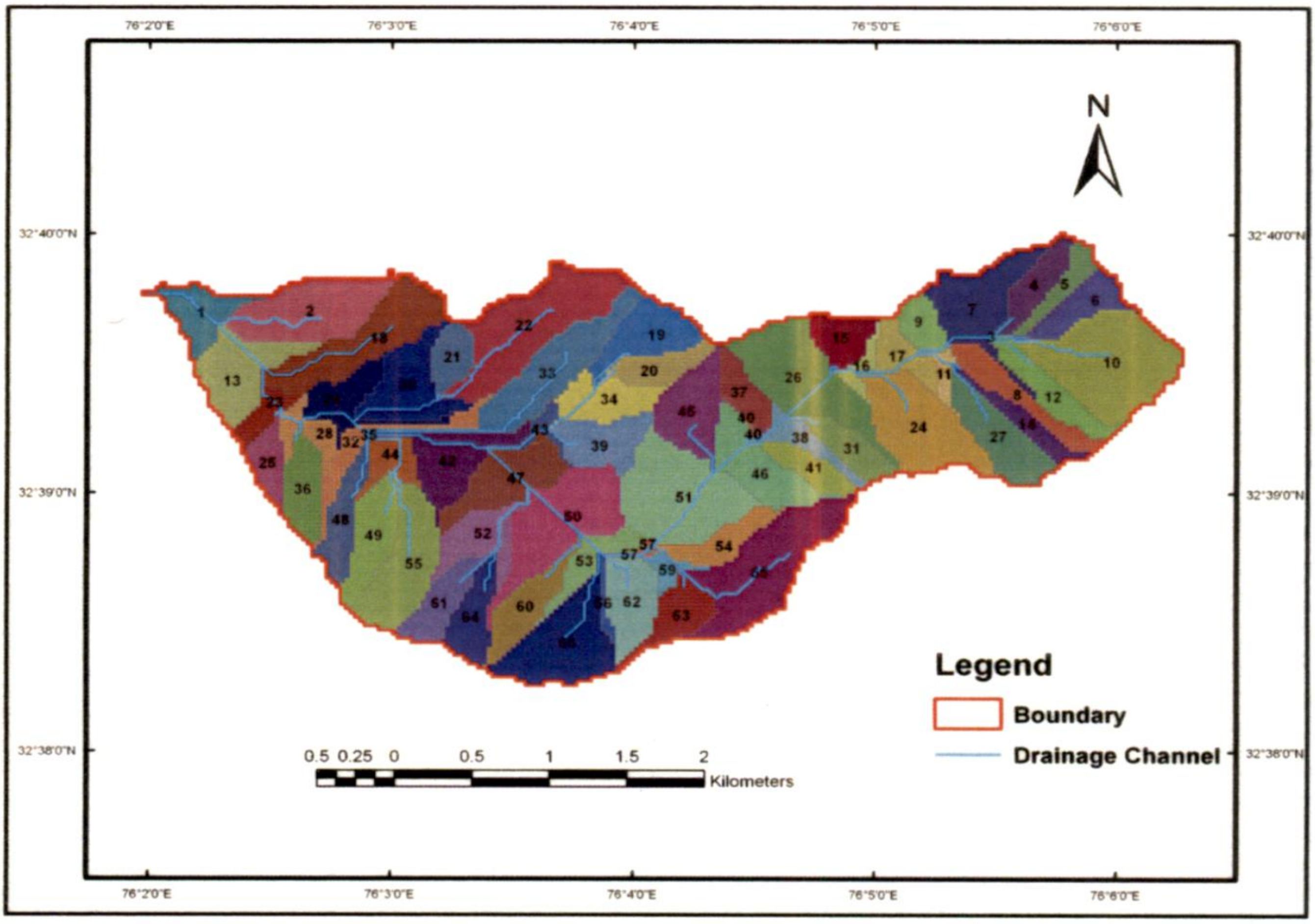

Fig.5.4 ArcSWAT Sub-watershed Map

5.3.1.1.3 Outlet and Inlet Definition

In this section the outlet points were added which helped to compare the measured and simulated flows and loads for some monitoring stations. For these outlet points, the coordinate of flow measurement points were used to define the outlet points of each micro watershed.

5.3.1.1.4 Main Watershed Outlets Selection and Definition

After setting all parameters described above, a map of watershed, sub watershed and stream network restricted to the watershed was obtained when the interface has completed the watershed delineation (Fig. 5.5). The total ArcSWAT area of the basin after delineation is 12.02km^2.

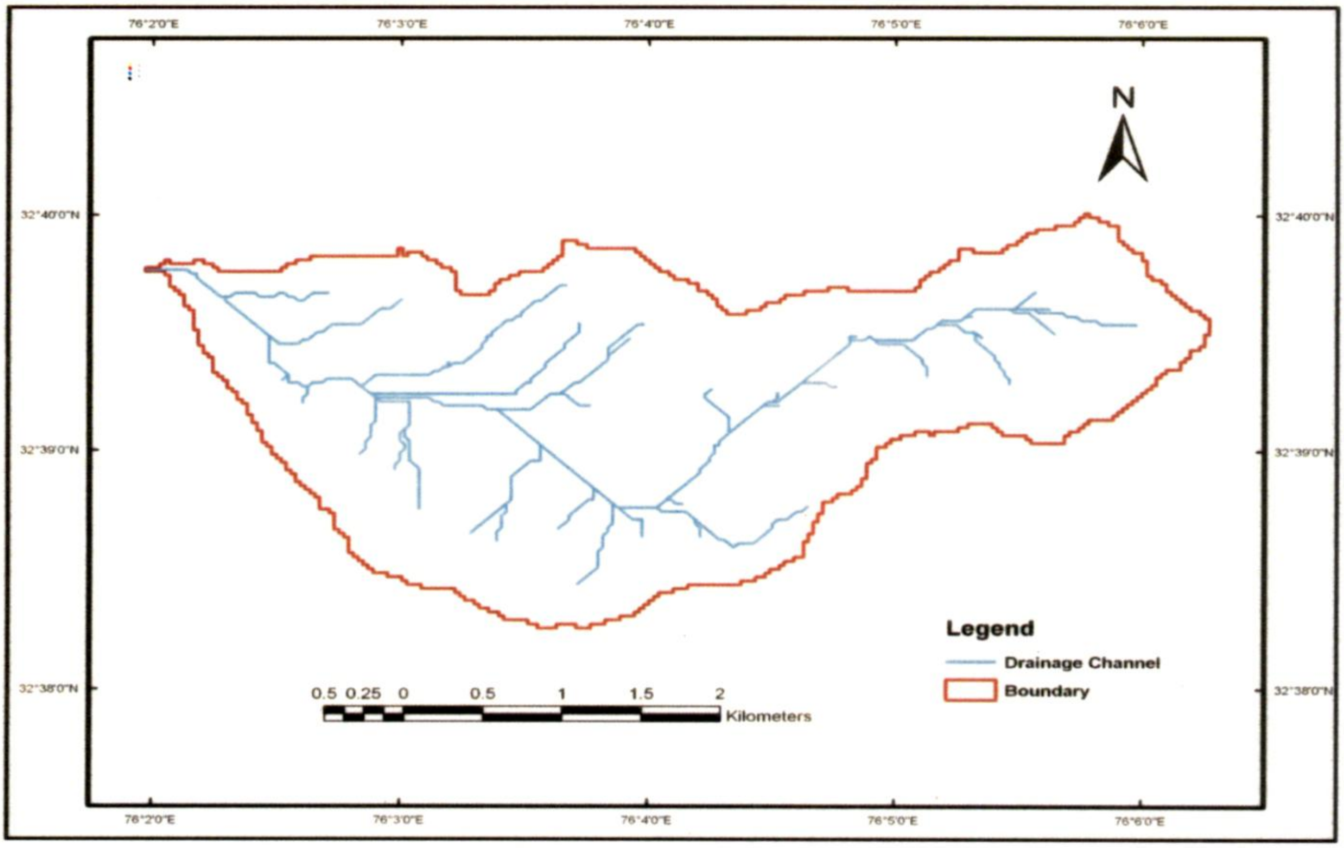

Fig.5.5 ArcSWAT Drainage Channel Map

5.3.1.2 Land Use and Soil Characterization

The movement of water depends on the soil type and vegetation cover. The amount of rain lost due to interception storage on the plants depends on the type of vegetation and has a significant effect on the infiltration capacity of the soil. As vegetation covers decrease, the surface runoff increases and results to reduce groundwater recharge. Soil infiltration capacity depends on the soil texture, the highest infiltration rates are observed in sandy soil, which indicates the surface runoff is higher in clay or in a soil which has low infiltration rates.

5.3.1.2.1 Land Use/ Soil/ Slope Definition and Overlay

a. Land Use Map

The land use map for the study areas was prepared on the basis of the ground truth by using the field area and the percentage of the land cover found in the area of study. The type of land use was delineated into four different class used as the ArcSWAT input (Fig. 5.6), and the corresponding areas are given in Table 5.4.

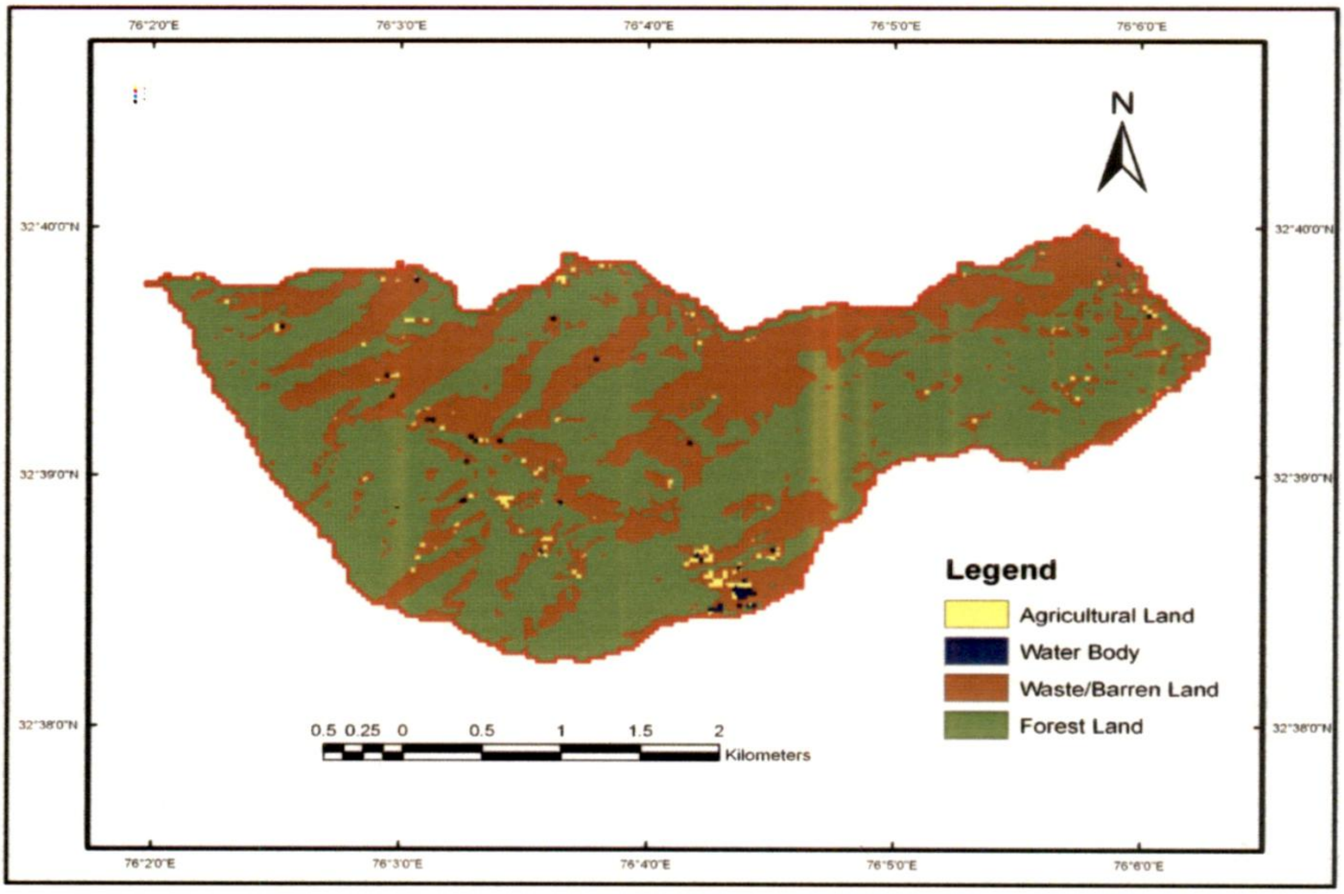

Fig.5.6 ArcSWAT Land Use Map

Table 5.4 Description of ArcSWAT land use and area covered

S. No.	Land Use	Area (Km^2)	% Area
1	Agricultural Land	0.10	0.84
2	Water	0.04	0.29
3	Fallow Land	4.51	37.50
4	Forest	7.37	61.37

Source: ArcSWAT model output

b. Soil Map

The soil map was taken from The Department of Agriculture, Himachal Pradesh is used for the ArcSWAT input. After overlaying over the land use map the distribution of soil type by ArcSWAT in the Barinallah watershed is shown in Fig. 5.7 and Table 5.5. The main soils in this area are sandy loam, loam and sandy clay loam.

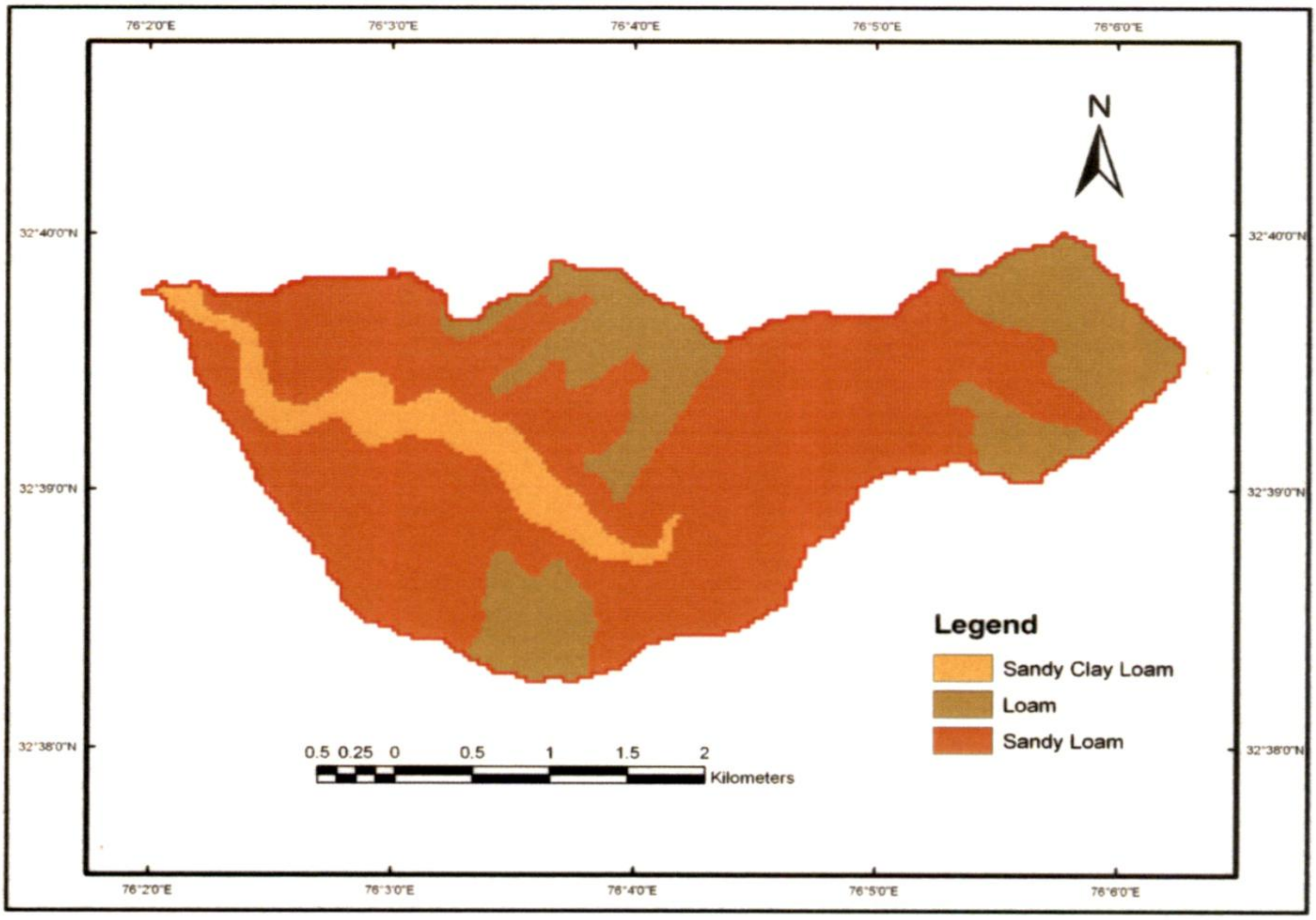

Fig.5.7 ArcSWAT Soil Map

Table 5.5 Distribution of ArcSWAT soil types and area covered

S. No.	Soil Type	Area (Km^2)	% Area
1	L o a m	2.96	24.61
2	Sandy Clay Loam	0.99	8.23
3	Sandy Loam	8.07	67.16

Source: ArcSWAT model output

c. Slope Map

After land use map and soil map overlaid, the next input was slope range. Slope map of the area was prepared from the digital elevation map. Slope of the area study were classified by ArcSWAT into three groups as shown in Fig.5.8 and Table 5.6. Most of the area has range is greater than 5%, which is consist of high land hilly area above 800 meters in altitude.

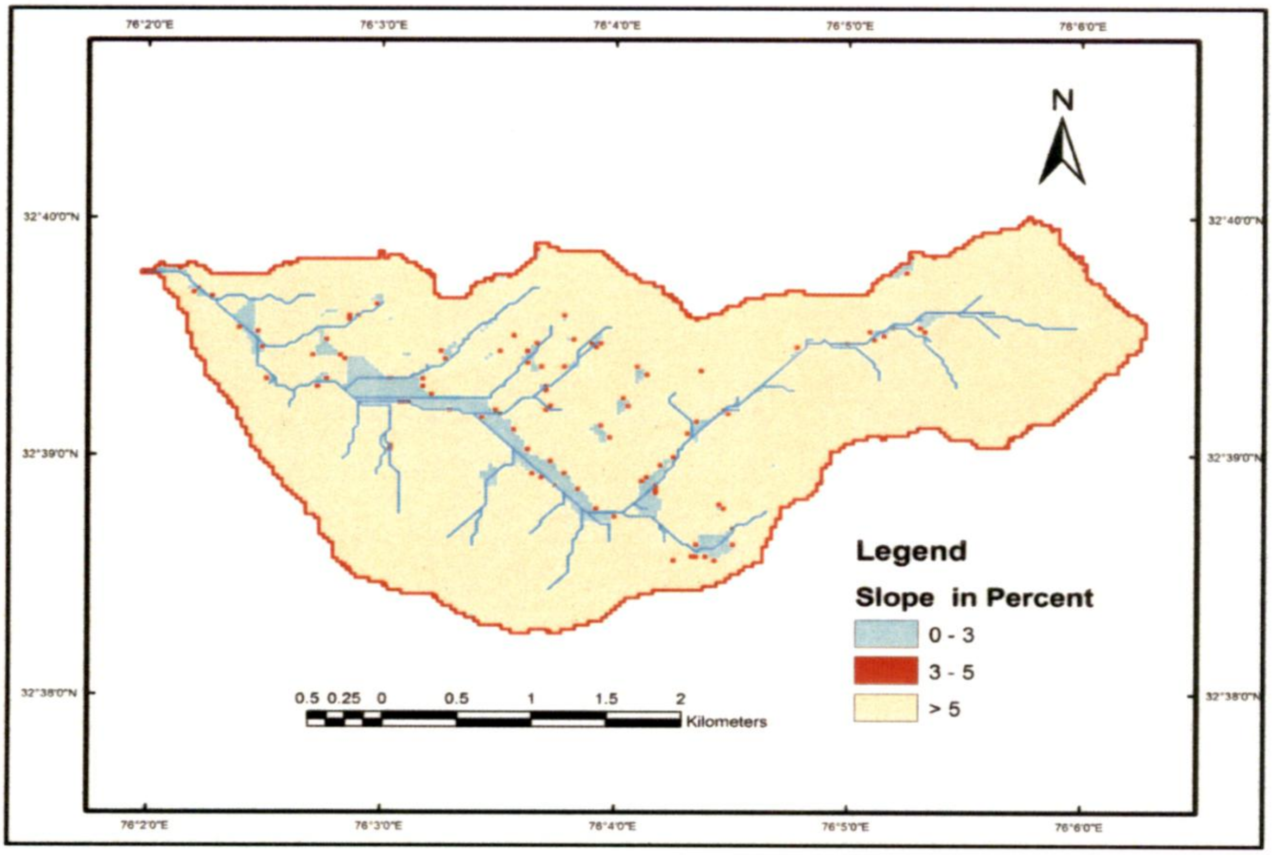

Fig.5.8 ArcSWAT Slope Map

Table 5.6 Distribution of ArcSWAT slope range and area covered

S. No.	Slope Range (%)	Area (Km^2)	% Area
1	0 - 3	0.66	5.50
2	3- 5	0.12	0.97
3	> 5	11.24	93.52

Source: ArcSWAT model output

5.3.1.3 Hydrologic Response Units (HRU) Distribution

Subdividing the watershed into areas having unique land use and soil combinations enables the models to reflect differences in evapotranpiration and other hydrologic condition for different land cover/crops and soil (Neitsch, 2002).

The load prediction will be good and accurate if each HRU is considered obtaining the total effect of different land cover and soils. In this study, for the aim to by multiple hydrologic response unit, the percentage threshold for land use and soil over the area were set 0 % in order to get much better description for all combination land use and soil over the area.

5.3.1.4 Climate Data

One of the main sets of input for simulating the watershed in Arc SWAT is climate data. Climate input consists of daily rainfall, maximum and minimum daily temperature, wind speed, solar radiation, and relative humidity. The daily rainfall and temperature records (2000-2010) were used to develop the climate-input files required for the model. The remaining climate inputs were generated internally within Arc SWAT using monthly climatic statistics. The rainfall station and temperature station is about 8 km away from the outlet of the watershed area.

5.3.1.5 Model Input Set Up

After simulating the climate data, the next step was to set-up inputs required for running the ArcSWAT model. These inputs were management data, soil data and weather generation data.

5.4 Model Calibration and Validation

5.4.1 Model Calibration

Model calibration was performed for the year 2002-2003 (Fig.5.9) and graphically compared the model output with observed discharge data recorded during these years. It is observed that the model discharge closely matched the observed discharge consistently in both the calibrated years. The calibration was done with the average daily discharge in a month for the whole year.

The regression analysis was performed between the observed and simulated discharge and the best fit line is also shown for the calibrated year 2002-2003. The coefficient of correlation (R^2) is 0.9385 and which shows a close relationship between the observed and simulated discharge.

Further, the efficiency of the model for simulating the runoff was also tested using established index (Table. 5.7). It is observed from the overall standard deviation and mean that the model over predict during the year 2002-2003. A high value of Nash–Sutcliffe efficiency and index of agreement shows that there is a good relationship between the model and observed discharge during the calibration. The linear correlation of coefficient of the observed and simulation mean monthly discharge in scatter plot is shown in Fig. 5.10.

Table 5.7 Statistical analysis of model and observed monthly discharge during calibration.

Parameters	**Discharge**	
	Model	**Observed**
Mean	0.0112	0.0098
Standard Deviation	0.0087	0.0082
Maximum	0.0303	0.0285
Total	0.2690	0.2344
Coefficient of correlation (R^2)	0.9385	
Nash-Sutcliffe efficiency (NSE)	0.8958	
d	0.9755	
RE	0.1477	

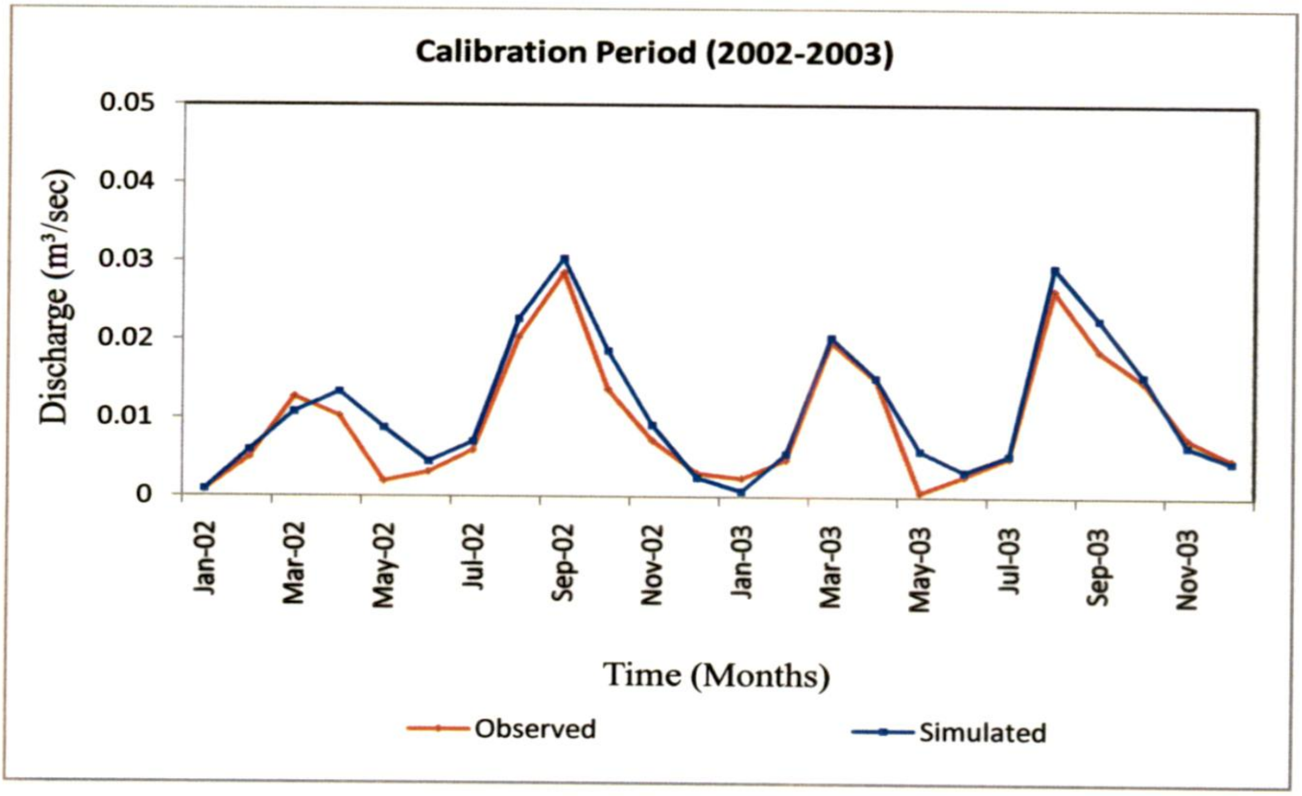

Fig 5.9 Mean monthly simulated and observed discharges in Barinallah watershed for calibration period

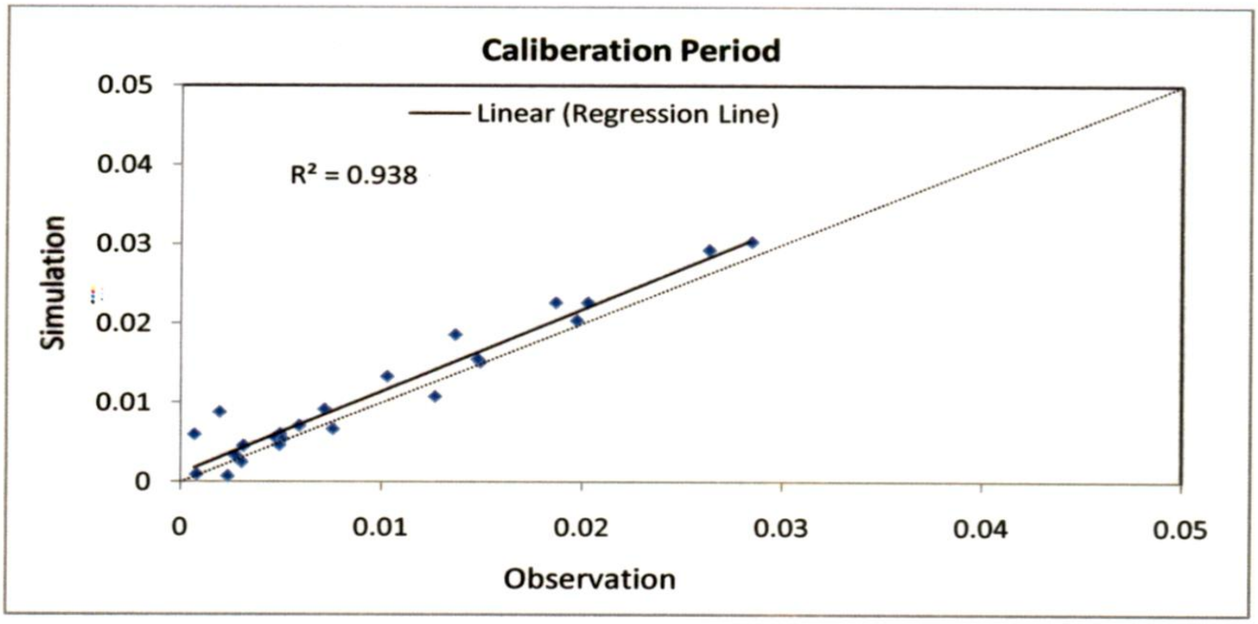

Fig. 5.10 Scatter plot of monthly simulated and observed discharge during the calibration

5.4.2 Model Validation

Validation of a model is required to evaluate the performance of the model and is achieved by running the model without changing any parameter and with a different set of input data. Calibrated model was validated using the discharge data recorded. For this purpose the model was continuously run from 2000 to 2004 and for evaluation, results of 2002 to 2004 were used as the observed discharge data is available for these years. The validation was tested for the year of 2004 and also for the years of 2002-2004 (3 years).

Model validation was performed for the year 2004 (Fig. 5.11) and graphically compared the model output with observed discharge data recorded. It is observed that the model discharge closely matched the observed discharge consistently. The regression analysis was performed between the observed and simulated discharge and the best fit line is also shown. The model slightly over predicted the high value of discharge (Fig. 5.12). The coefficient of correlation (R^2) is 0.9361 shows a close relationship between the observed and simulated discharge.

Further, the efficiency of the model for simulating the runoff was also tested using the efficiency index (Table. 5.8). A few high value of discharge during the monsoon were slightly over predicted. The value of Nash-Sutcliffe value (0.8229), index of agreement 'd' (0.9600) and a lower value of relative error 'RE' (0.2589) indicates that there is a good relationship between the observed and simulated discharge during the validation. Figure 5.9 describes the scatter plot of monthly simulated and observed discharge during the validation period.

Table 5.8 Statistical analysis of model and observed monthly discharge, 2004

Parameters	Discharge	
	Model	**Observed**
Mean	0.0141	0.0112
Standard Deviation	0.0104	0.0096
Maximum	0.0400	0.0345
Total	0.1693	0.1345
Coefficient of correlation (R2)	0.9361	
Nash-Sutcliffe efficiency (NSE)	0.8229	
d	0.9600	
RE	0.2589	

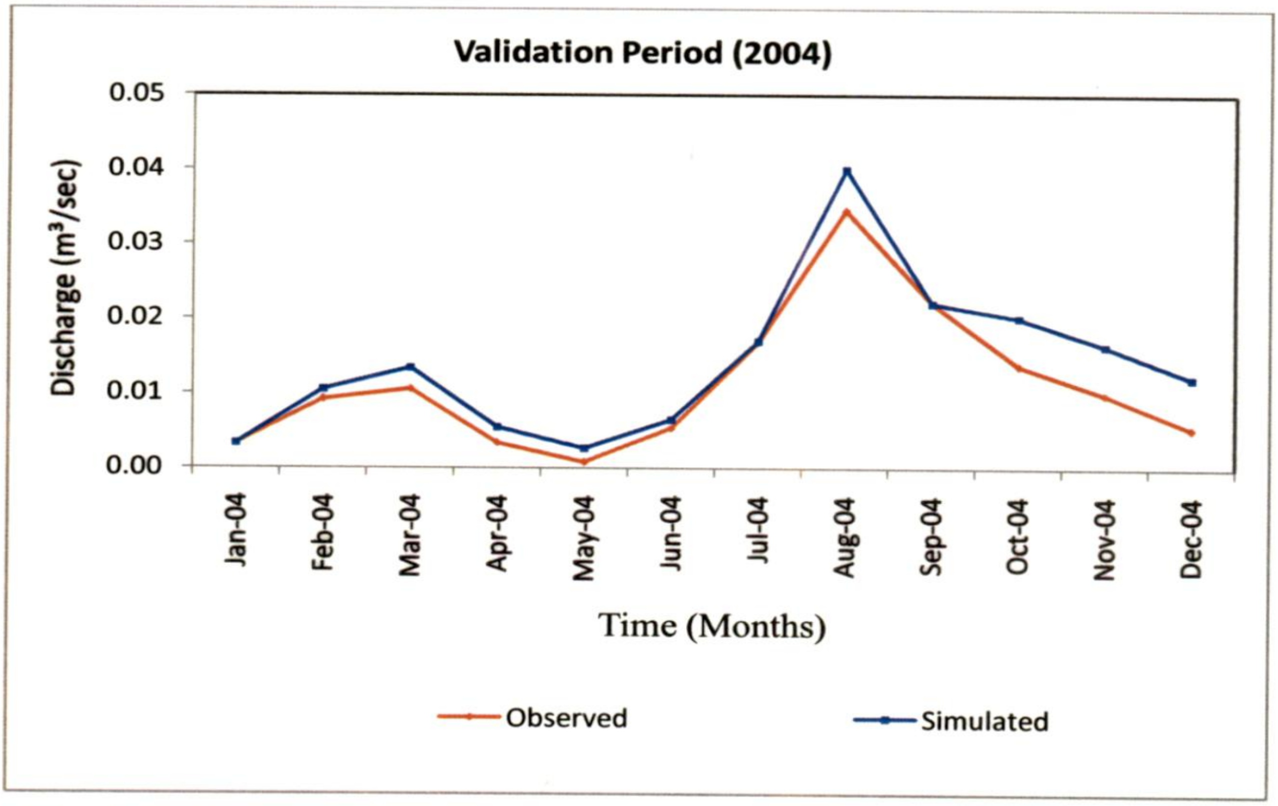

Fig. 5.11 Mean monthly simulated and observed discharges in Barinallah watershed for validation period

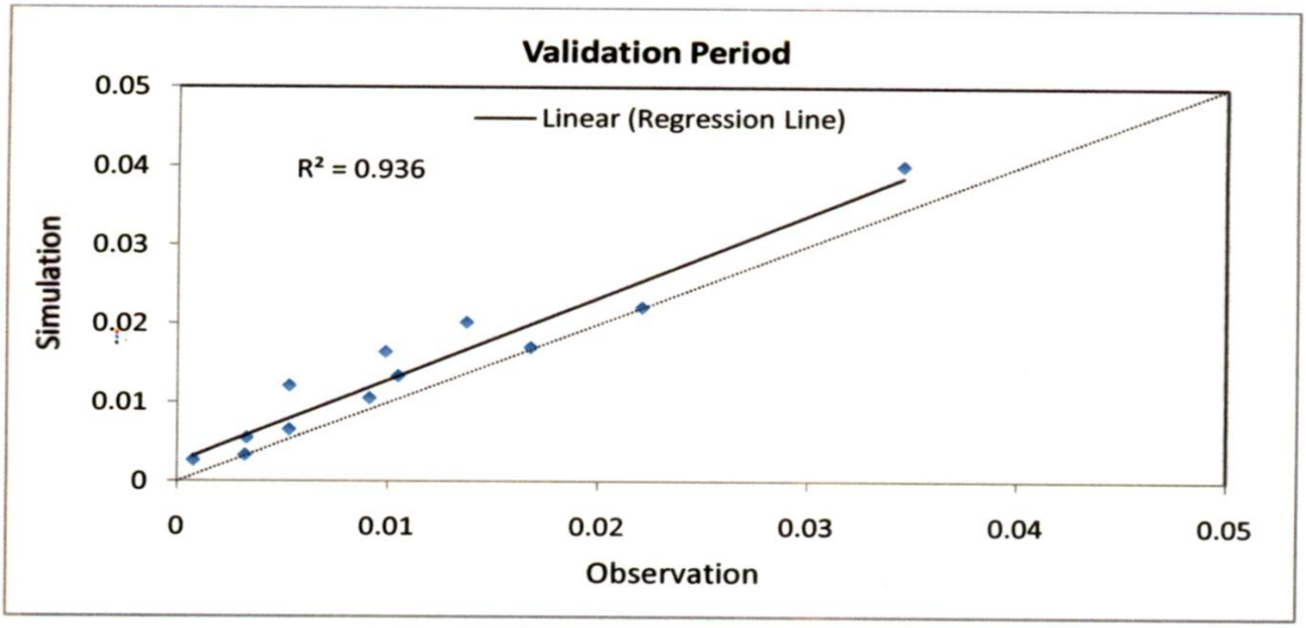

Fig. 5.12 Scatter plot of monthly simulated and observed discharge during the validation

The high R^2 and NSE in the calibration and validation suggest that the calibrated model can describe the stream flow of the watershed. Thus we can be confident the calibrated model with set of optimized parameters can be applied to examine the hydrological responses of the basin under the land-cover change and climate change scenario.

5.4.3 Validation with Discharge Data of 2002 to 2004 Combined

The performance of the model was checked by statistical analysis (Table. 5.9). Model validation was performed for the year 2002-2004 (Fig. 5.13) and graphically compared the model output with observed discharge data recorded. It is observed that the model discharge closely matched the observed discharge consistently. A regression analysis was performed between the observed and simulated discharge and the best fit line is also shown (Fig. 5.14). It is observed that the model discharge data are distributed uniformly along the 1:1 line.

The efficiency of the model for simulating the runoff was also tested using the efficiency index (Table. 5.9). A high value of coefficient of determination (0.9337) indicates a close relationship between the observed and model discharge data exist. A close relationship between the means and standard deviation of the observed and model data shows that the frequency distribution is similar. The value of Nash-Sutcliffe value (0.8424), index of agreement 'd' (0.9636) and a lower value of relative error 'RE'

(0.1882) indicates that there is a good relationship between the observed and simulated discharge during the calibration and validation period.

Table 5.9 Statistical analysis of model and observed monthly discharge, 2002-2004

Parameters	**Discharge**	
	Model	**Observed**
Mean	0.0122	0.0103
Standard Deviation	0.0093	0.0086
Maximum	0.0400	0.0345
Total	0.4383	0.3689
Coefficient of correlation (R2)	0.9337	
Nash-Sutcliffe efficiency (NSE)	0.8676	
d	0.9695	
RE	0.1882	

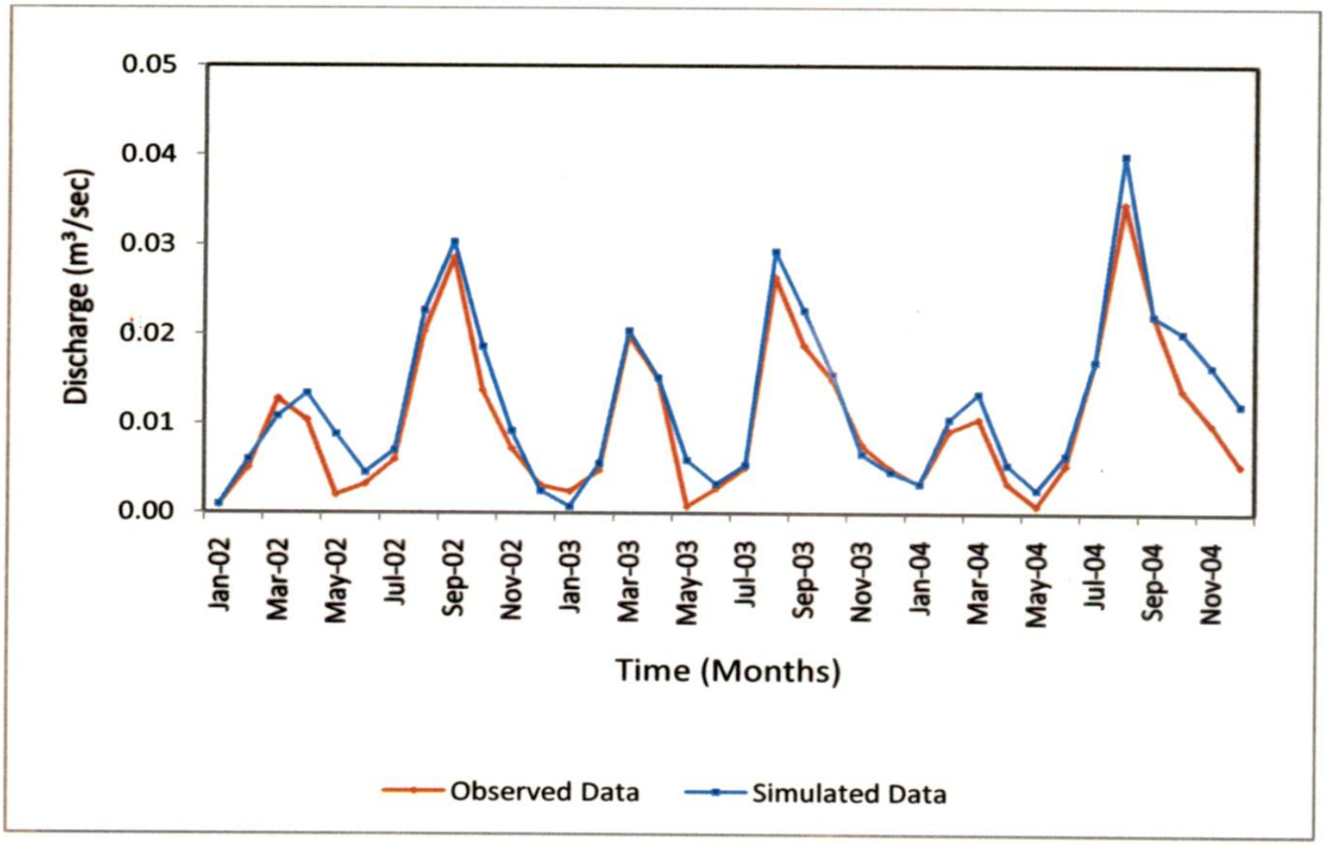

Fig. 5.13 Mean monthly simulated and observed discharges in Barinallah watershed for calibration and validation period

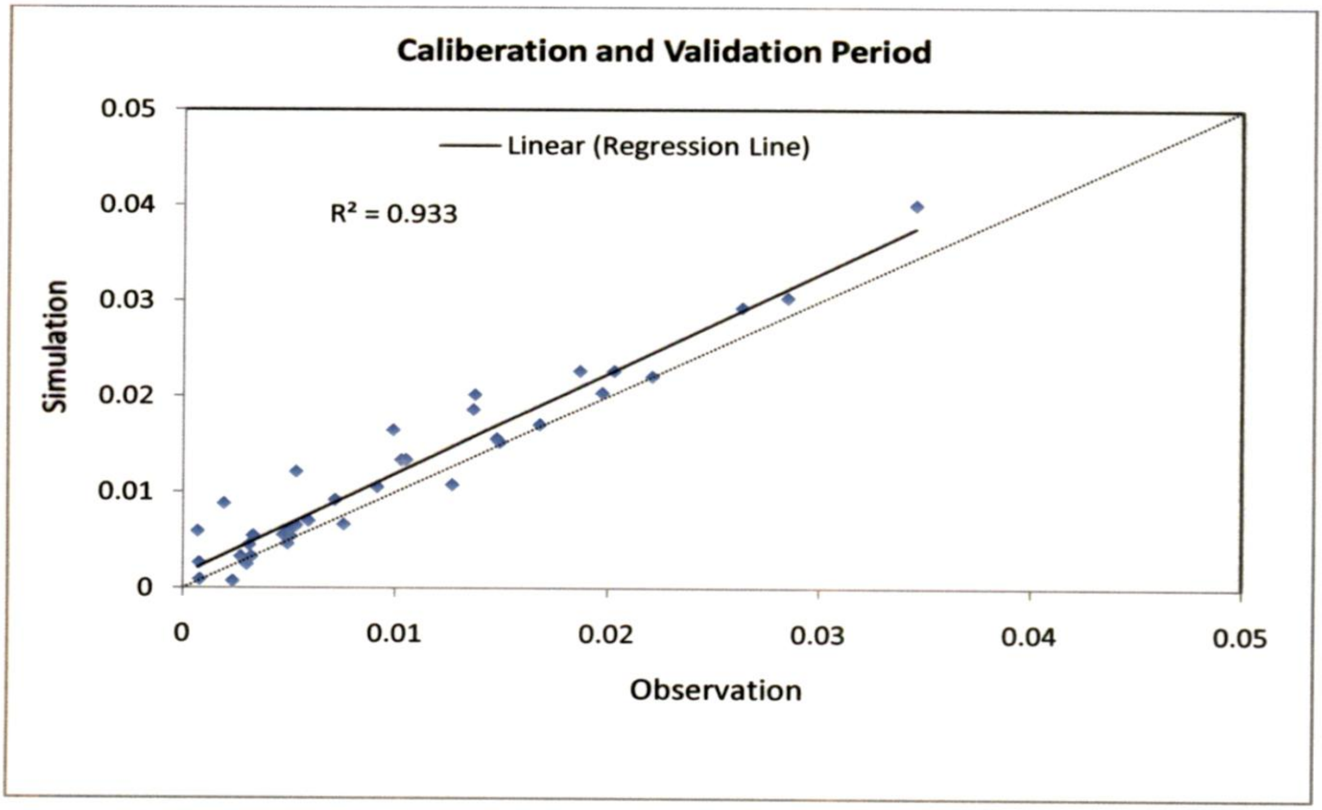

Fig. 5.14 Scatter plot of monthly simulated and observed discharge during calibration and validation

5.5 Sensitivity Analysis

The sensitivity analysis in ArcSWAT of different parameters was carried out to know how different parameters of ArcSWAT influence the model output. The analysis was done, based on the hydrological simulation at the catchment outlet by varying the various parameters one by one and comparing the deviation in the flow simulated.

Sensitivity analysis was carried out using those model parameters which were used for calibration of the watershed within their recommended range. The calibrated value of each parameter is selected as the base value for the sensitivity analysis. The base value of the each parameter is varied by replacing the values of the parameters within their recommended range. The parameters considered for sensitivity analysis are: Threshold depth of water in shallow aquifer required for return flow to occur (Gwqmn), Soil evaporation compensation factor (Esco), Channel effective hydraulic conductivity, Ch_K_2, Base flow recession alpha (Alpha_Bf), Manning's coefficient 'n' for channel (Ch_N2). The various parameters and their range considered for sensitivity analysis are present in table (Table. 5.10).

Table 5.10 Input ArcSWAT parameter for sensitivity analysis for Barinallah watershed

S. No.	Parameters	Short form	Range
1	Threshold depth of water in shallow aquifer required for return flow to occur	Gwqmn	0 - 5000
2	Soil evaporation compensation factor	Esco	0.01 - 1
3	Channel effective hydraulic conductivity	Ch_K_2	0 - 150
4	Base flow recession alpha	Alpha_Bf	0 - 1
5	Manning's coefficient 'n' for channel	Ch_N_2	0 - 1

Source: ArcSWAT model output

5.6 Identification of Suitable Sites and Design of Check Dam

In the present study, information about various themes such as land use/cover, drainage, soil, slope etc. were integrated in the GIS environment to arrive at a decision regarding sites suitable for conservation measures. Survey of India toposheet of the watershed with a scale of 1:50000 and contour interval of 40 m was used to compute the DEM. From DEM, slope grid was generated for the study area, which was again reclassified according to the Integrated Mission for Sustainable Development (IMSD) guidelines (NRSA, 1991).

Satellite data was used for generation of land use/cover map. In addition to that quantitative morphometric analysis was carried out for all the sixty six sub- watersheds independently for determining their linear aspects. GIS represents the most effective mechanism for utilizing remotely sensed data and also enhancing the effectiveness of this data through correlation of remote sensing input already stored in a GIS environment. Integration of Remote Sensing and GIS techniques provide reliable, accurate and updated database on land and water resources, which is a prerequisite for any integrated approach in identifying potential zones and to identify suitable sites for water harvesting such as farm ponds, check dams and percolation tanks etc. The analysis was carried out by ArcGIS software. The decision rule was formulated for selection of sites for various water conservation structures as per the guidelines suggested by the Integrated Mission for Sustainable Development (IMSD, 1995) and Indian National Committee on Hydrology (INCOH). Table 5.11 and Table 5.12 provide the slope and site selection criteria respectively. The details of the procedures followed for identification of suitable sites are given below:

1. Drainage layer was overlaid on the slope, soil and land use map.
2. The drainage pattern, slope, soil and land use map of the watershed area were carefully studied.
3. The structures were located where the ground is fairly level below steeply sloped upstream land, the drainage path is nearly straight and the soil is fairly thick.
4. The relationship of the water harvesting structures to high-priority sub-watershed was determined considering the priority sub watershed and morphological parameters.
5. The water harvesting structures should be located along the streams and near the settlement and cultivated area. Therefore, a buffer of 500 m was considered between the settlement and proposed structures.

Table 5.11: Slope categories used for design of soil and water conservation structures

Sl. No.	Slope Category	Slope (Percent)
1.	Nearly level	0-1
2.	Very gently sloping	1-3
3.	Gently sloping	3-5
4.	Moderately sloping	5-10
5.	Strongly sloping	10-15
6.	Moderately steep to steep sloping	15-35
7.	Very steep sloping	35-50
8.	Extremely steep	>50

Table 5.12 Site selection criteria for soil and water conservation structures

Name of structure	Slope	Land use	Catchment area
Check dams	Nearly level to gentle slope	River stream (Nearby agricultural land)	Upto 25 ha
Percolation tank	Nearly level to very gentle	Open land /Waste land	>5 ha
Nallah bunds	Nearly level to very steep	Open land/Waste land	>20 ha

5.7 Water Demand Assessment Based on Population Growth

An assessment is made on the population growth vis-a-vis water requirement in the region. Accordingly, total water requirement in the area based on the population is estimated considering per capita water requirement per day as 70 liters per day. Table 5.13 gives the population of the study area since 1971 to 2011 (as per census) and 2021 to 2031 (as per projection @ 1.75% increase per year). Figure 5.15 shows the graphical representation of population in different years. Estimated water requirement in the region based on population count is given in Table 5.14.

Table 5.13 Year-wise population in the study area

Villages / Year	Pranohin	Dular+ Behra	Karor	Loni+ Bhuman	Pukhri	Total
1971	279	320	227	450	454	1730
1981	328	431	262	532	606	2159
1991	326	510	330	608	673	2447
2001	346	567	397	684	776	2770
2011	388	636	445	767	870	3106
2021	462	757	530	913	1035	3697
2031	549	900	630	1086	1231	4396

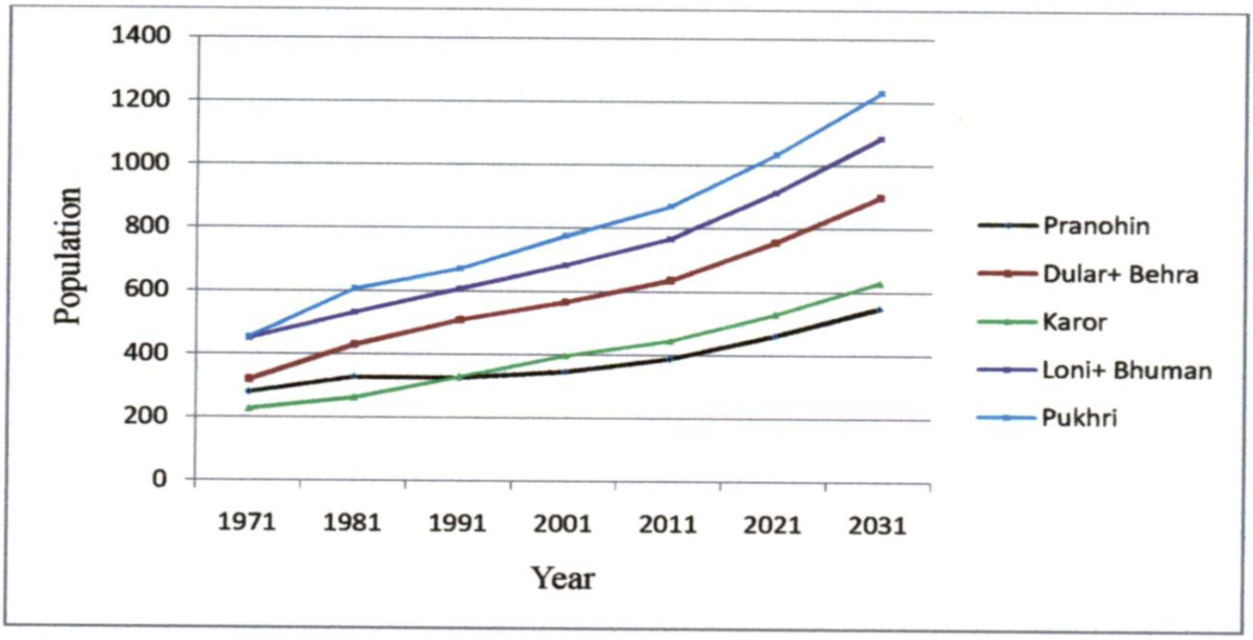

Fig. 5.15 Year-wise population in the study area

Table 5.14 Estimated water requirement based on population growth in litre per day

Villages / Year	Pranohin	Dular+ Behra	Karor	Loni+ Bhuman	Pukhri	Total
1971	19530	22400	15890	31500	31780	121100
1981	22960	30170	18340	37240	42420	151130
1991	22820	35700	23100	42560	47110	171290
2001	24220	39690	27790	47880	54320	193900
2011	27160	44520	31150	53690	60900	217420
2021	32340	52990	37100	63910	72450	258790
2031	38430	63000	44100	76020	86170	307720

5.8 Design Methodology of Check Dam

5.8.1 Gravity Dam

The gravity dams are of small heights of about 4 to 5 m and are proposed to be constructed. As these are very small dams, section of which have been chosen in accordance to the guide lines given in Bureau of Indian Standards (IS-6512, IS-1893 and Small Dams, USBR Publications). Top width of check dam has been proposed as 1 m and side slopes have been considered as 0.9H: 1V till it meets the natural ground level. The details on the design aspect are given in Annexure I.

Sample design of check dam has been carried out for two selected watersheds, viz. sub-watershed No. 17 and 43, the detail of which are given in Table 5.15 . Design of check dam for subwatershed No. 17 and 43 revealed that height of the check dam may be 4.50 m. Total catchment area of the check dam for sub-watershed No. 17 and 43 is found to be 1.97 km^2 and 0.69 km^2. For this design discharges were 0.041 m^3/s and 0.026 m^3/s respectively.

Table 5.15 Calculation of capacity of Check Dam for sub-watershed No. 17

Area (m^2)		Interval (m)		Volume (m^3)	Cumulative Volume (m^3)
A1	12.025				
A2	20.450	h1	0.50	8.1188	8.1188
A3	28.320	h2	0.50	12.1925	20.3113
A4	38.520	h3	0.50	16.7100	37.0213
A5	48.260	h4	0.50	21.6950	58.7163
A6	68.750	h5	0.50	29.2525	87.9688
Total			2.50	**87.9688**	

Table 5.16 Calculation of capacity of Check Dam for sub-watershed No. 43

Area (m^2)		Interval (m)		Volume (m^3)	Cumulative Volume (m^3)
A1	6.100				
A2	14.250	h1	0.50	5.088	5.088
A3	20.540	h2	0.50	8.697	13.785
A4	28.550	h3	0.50	12.273	26.058
A5	38.860	h4	0.50	16.852	42.910
A6	45.640	h5	0.50	21.125	64.035
Total			2.50	**64.035**	

5.8.2 Surplus Escape

The surplus escape is a concrete structure proposed at the said location to release the design flood from the Check dam without causing harm to the other components of the head works of the scheme. Clear water way has been provided to release the excess water. The following formulae suggested by Varshany et al. (1993) has been considered to release the design flood over the broad crested weir is

$$Q = C\,L\,H^{3/2}$$

where, Q is in m^3/s, C is a constant taken as 1.76, L = length of water way in meter and H = head over the crest in meter.

The upstream and downstream water level has been calculated corresponding to the design flood and accordingly the crest level has been fixed. Fixing of crest level also depends upon the pond level and Maximum Water Level (MWL) of the reservoir. Provision of shutters of size about 1.00 m x 1.00 m have also been considered to create the pond level intact, so that the water can release comfortably to the command area. The automatic falling shutters are to be so designed that if the water rises above the pond level the shutters automatically fall down to release the discharge quickly.

Upstream cut off and downstream cutoffs have also been considered to control seepage beneath the structure as well as to protect the structure from scouring effect. Lacey's scour depth below the water level has been estimated as follows:

$$R = 1.35\ q^{2/3} / f^{1/3}$$

where "R" is maximum probable scour depth in m, "q" is discharge intensity in cumec and "f" is the silt factor. A factor of safety of 1.5 in upstream cutoff and 2.00 in downstream cut off have also been taken into consideration.

One stilling basin has also been proposed at the downstream end of the crest so as to dissipate the quantum of energy acquired by the high velocity flowing water. Because of the provision of stilling basin, the downstream end of the structure is protected from scouring effect and the less velocity water is release to the drainage channel downstream. USBR type of stilling basin has been adopted (Small Dams, USBR Publications and IS 4997/1968).

The side retaining walls as well as upstream and downstream return walls have also been designed with its top level above the maximum water level and suiting to the embankment of dam's top level with its slope. Further, stability analysis has been performed for its safety considerations.

5.8.3 Head Regulators

Depending upon the topographic condition and permissible limit of the contours, the head regulators have been proposed at the banks of the Nallah so as to release the water to the downstream area. As these are located at the high ground level, very simple structures are designed as retaining structure with a passage in between. Provisions of shutters are to be made to control the flow to the downstream for command area. These are concrete structures provided with cutoffs at both upstream and downstream and as per the requirements of command area waterways are provided through these control structures.

5.9 Spacing of Contour Trenches:

The slope of the sub-watershed Nos. 36, 52 and 61 is more than 40%. The average slope stands at 50% in the area. Here, the spacing of contour trenches is calculated using average slope of 50% as per the following equation:

$$\text{Vertical Interval (V.I.)} = 0.305\ (XS+Y),$$

Using,

X = 0.40 (Rainfall factor)

S = 50% (Land slope %)

Y = 1.0 (Soil infiltration factor)

$$\text{V.I.} = 0.305\ (0.40 \times 50 + 1.0)$$

$$= 6.405 \text{ m}$$

The horizontal interval between two bunds is calculated as

$$\text{Horizontal Interval (H.I.)} = \text{V.I.} \times 100/\text{Slope}$$

Using,

V.I. = 6.405 m

S = 50%

$$\text{H.I.} = 6.405 \times 100 / 50$$

$$= 12.81 \text{ m.}$$

$$\text{Contour trenching/ Bunding Intensity} = 100 * S/VI$$

$$= 100 * 50/6.405$$

$$= 780.64 \text{ m/ hectare.}$$

5.10 Model Response to Future Climate Data

The impact of future climate were assessed by running the calibrated model for the period 2011-2031 by keeping the DEM, soil map, slope map and land use/ cover map same. The predicted surface runoff for the years 2011, 2021 and 2031 has the average monthly changes as 2.45 %, 7.91 % and 16.95 % respectively which are shown in Fig.

5.16. The surface runoff decreases throughout the year except for the months of June, July and August for the year 2011 (Fig. 5.17). For the year 2021, the surface runoff has decreased in January to May and October to December (Fig. 5.18) and increased in June to September. The surface runoff has decreased in January to May and November to December and increased in June to October for the year 2031 as shown in Fig 5.19.

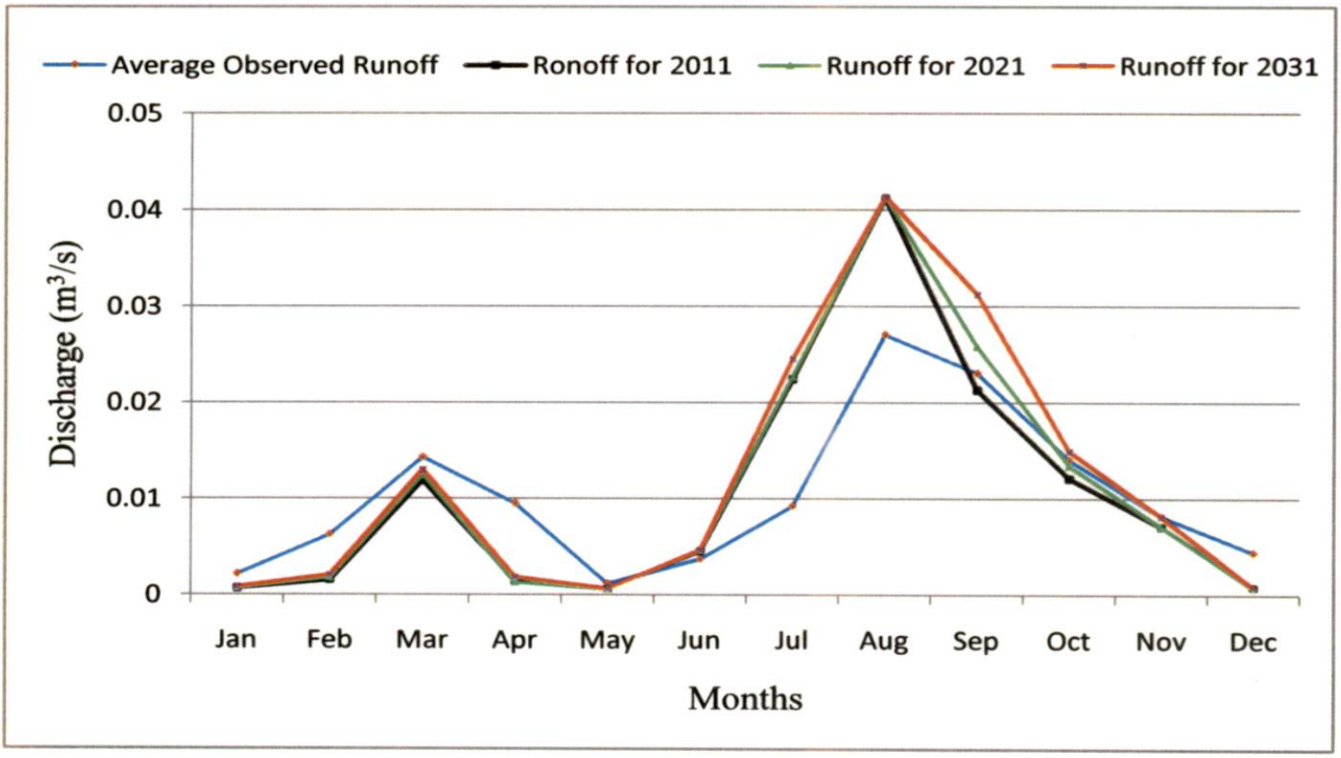

Fig.5.16 Monthly change in surface runoff in Barinallah watershed

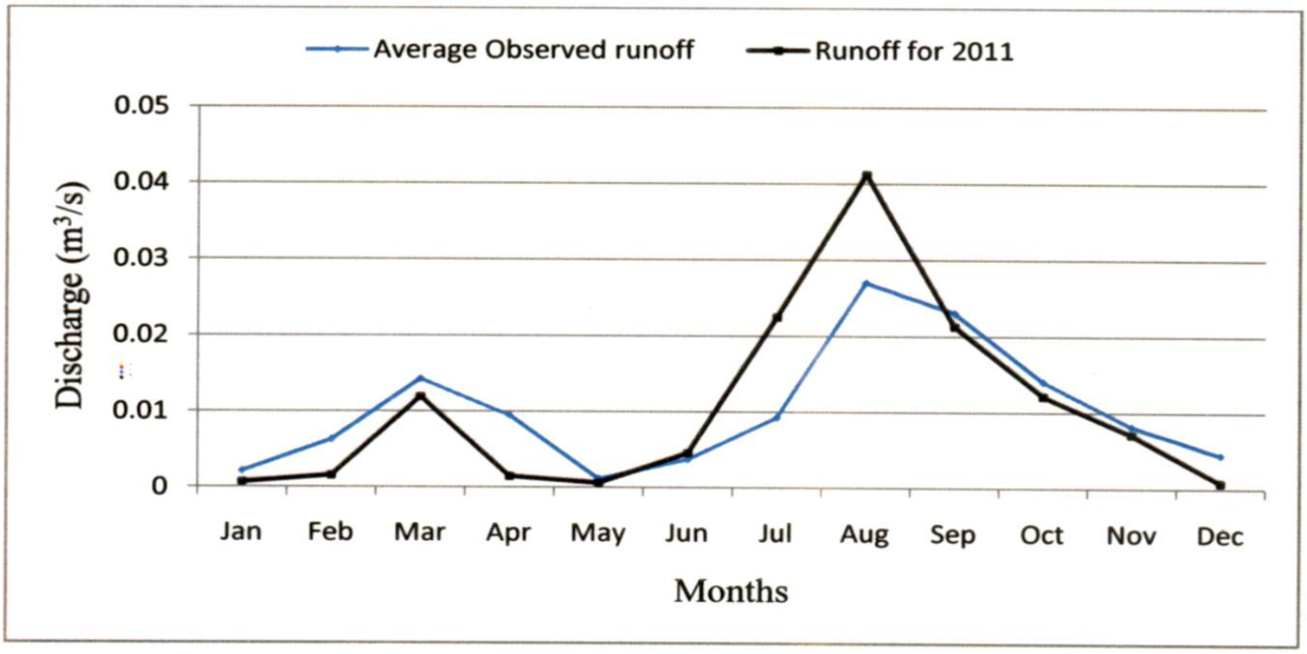

Fig.5.17 Monthly change in surface runoff in Barinallah watershed for 2011

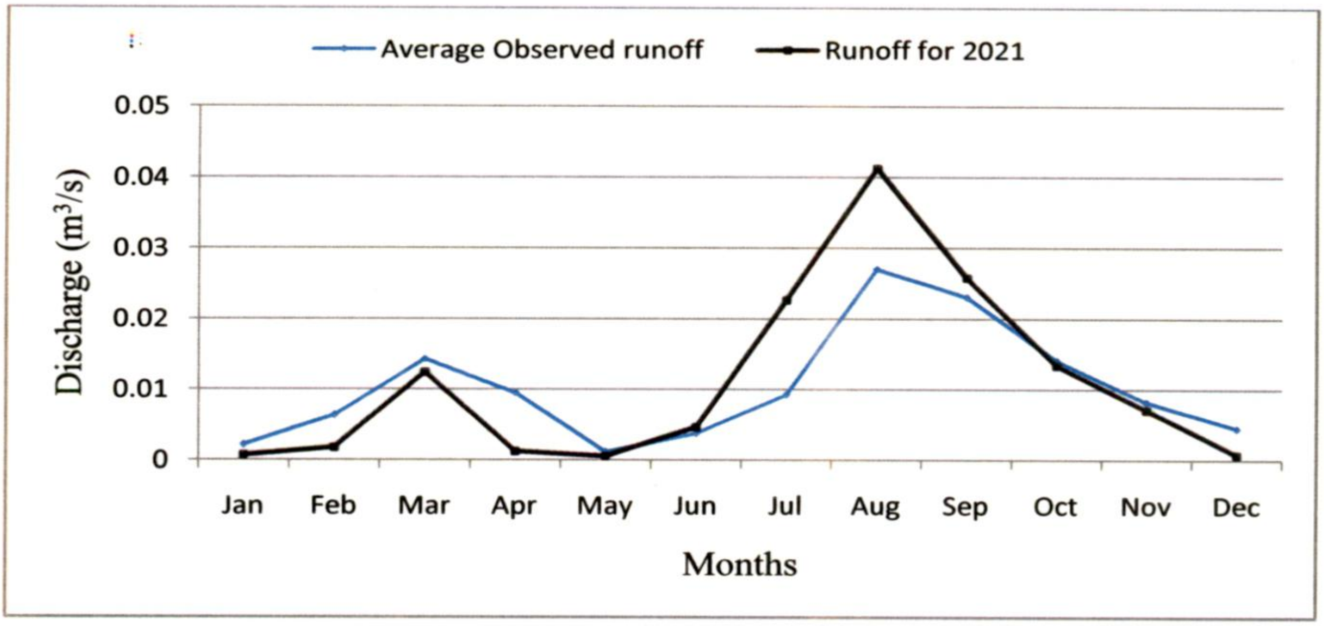

Fig.5.18 Monthly change in surface runoff in Barinallah watershed for 2021

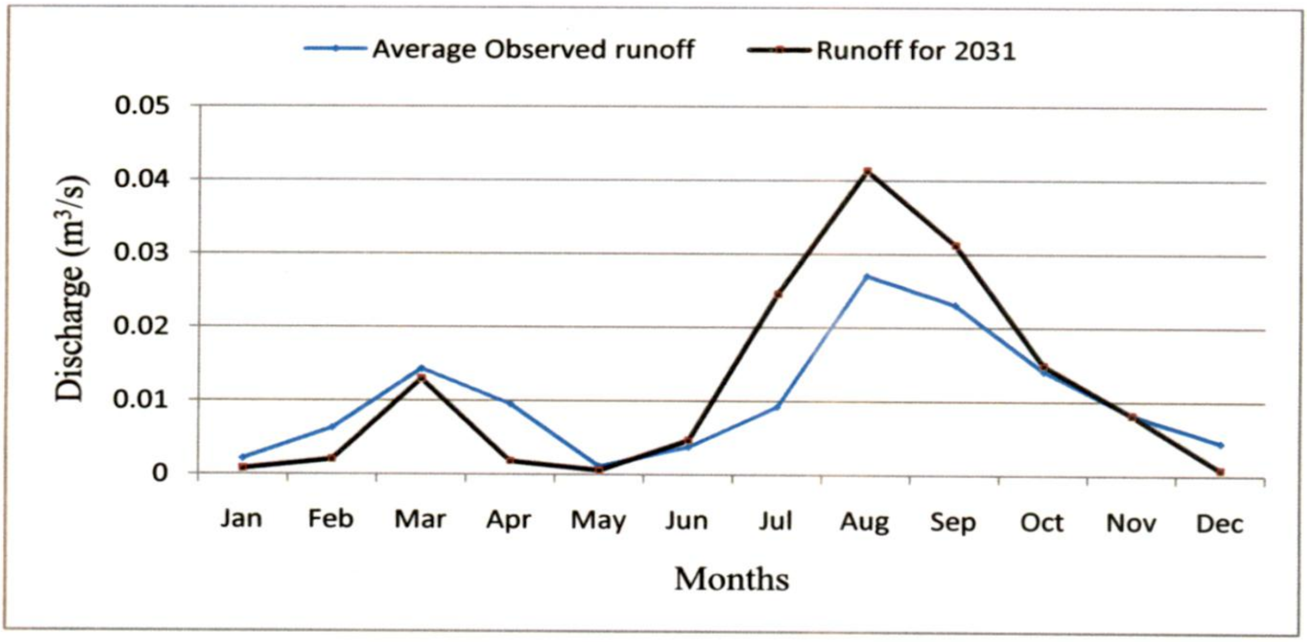

Fig.5.19 Monthly change in surface runoff in Barinallah watershed for 2031

At present none of the existing streams in the watershed are being treated with water restoration structures such as check dams, gabions and contour trenches etc. However, based on the population growth and model response to future climate data, it is suggested to undergo water restoration plan in the region to mitigate climate change. Table 5.17 presents the water restoration plan of the area for the period 2011 and 2031 through proposing structures in the suggested streams considering climate change as well as in normal condition.

Table 5.17 Watershed Restoration Plan considering Climate Change

Sl. No.	Structure Type	Present Position	Water Restoration Plan	
			In 2011 (without climate change)	In 2031 (with climate change)
1	Check Dam for Sub-watershed No. 17	Not existing	7.83 m^3	71.72 m^3
2	Check Dam for Sub-watershed No. 43	Not existing	27.00 m^3	58.59 m^3
3	Gabions for Sub-watershed No. 17	Not existing	3 Nos	3 Nos
4	Gabions for Sub-watershed No. 43	Not existing	1 No.	1 No.
5	Contour Trenching for Sub-watershed No. 36	Not existing		780.64 m per hectare.
6	Contour Trenching for Sub-watershed No. 52	Not existing		780.64 m per hectare.
7	Contour Trenching for Sub-watershed No. 61	Not existing		780.64 m per hectare.

5.11 Concluding Remarks

The hydrological parameters based on the analysis revealed an increasing trend in precipitation and temperature. The catchment modelling was carried out using the ArcSWAT model. ArcSWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The ArcSWAT model divides the watershed into sub-watersheds which allow accounting of land uses and soil properties impact on hydrology. Model calibration was performed manually by adjusting five (5) parameters (within their prescribed range) until the model output matches the observed discharge. The gauge discharge for a period of 2002 and 2003 was used for calibration.

The validation of the ArcSWAT model was performed by comparing the observed and model simulated discharge by comparing them graphically and the model performance was also evaluated using four indices *viz.*, Coefficient of determination (R^2), Nash and Sutcliffe Efficiency (E), index of agreement (d), relative error of the stream flow volume (RE). The model performance was evaluated for the year 2002-2003. Further, validation was also carried out for the year 2004 along with the calibration period (2002-2003).

Finally, three different types of structures viz. check dam, gabions and contour trench have been identified using GIS technique and then suggested for implementation with their design details within the watershed. A plan for the restoration of water resources is prepared considering the climate change.

CONCLUSIONS

6.1 Conclusions

Based on the present study the following conclusions can be drawn:

- The study assesses the water availability in the region. Based on the interpretation of meteorological data for the last 11 years, it is concluded that the region is facing water scarcity during peak summer. The discharges from natural springs, nallah, etc are at minimal.
- Trend analysis was done using Mann-Kendall test, Sen's Slope Estimator and Moving Average method. Trend analysis of temperature and rainfall for 50 years (1953-2002) confirms changing climate in the region. The annual mean temperature in the region is increasing gradually. Dry spell in the region is also frequent. Rainfall pattern is becoming erratic with high intensity rainfall.
- It is observed during trend analysis that temperature is showing an increasing tendency in six months out of twelve months of the year. January and May gives the greatest slope 0.03°C, followed by December 0.02°C, February, April and November showed the smallest tendency, with slopes of 0.01°C. June gives the maximum negative trend -0.02°C, followed by July, August and September with slopes of -0.01°C while the months March and October shows no trend. Temperature slopes are positive during the winter season and are negative during the rainy season.
- Rainfall trend when analyzed, it is observed that two months i.e. October and December out of the twelve months witnesses decreasing trend with values -0.32 mm and -0.11 mm respectively. However, remaining months in the year witnesses increasing trends excepting November showing no trend.
- Satellite image was regenerated into land use map for the region using supervised classification algorithm. The land use in the region is predominantly covered by forest (61.37%) followed by fallow land (37.50%), agricultural land (0.84%) and water bodies (0.29%) out of the total area of 12.02 km^2.
- Average monthly discharge data for three years (2002-2004) was calibrated and validated using ArcSWAT model. It is observed from the overall standard deviation and mean that the model over predict during the year 2002-2003. A high

value of Nash–Sutcliffe efficiency and index of agreement shows that there is a good relationship between the model and observed discharge during the calibration.

- Model validation was performed for the year 2004 and graphically compared the model output with observed discharge data recorded. It is observed that the model discharge closely matched the observed discharge consistently. The regression analysis was performed between the observed and simulated discharge and the best fit line is also shown. The model slightly over predicted the high value of discharge. The coefficient of correlation (R^2) is 0.9361 showing a close relationship between the observed and simulated discharge.
- The efficiency of the model for simulating the runoff was also tested using the efficiency index in the study. A few high value of discharge during the monsoon were slightly over predicted. The value of Nash-Sutcliffe value (0.8229), index of agreement 'd'(0.9600) and a lower value of relative error 'RE' (0.2589) indicates that there is a good relationship between the observed and simulated discharge during the validation.
- Two suitable sites were identified using satellite image and GIS technologies in the region where check dam is proposed for storing and recharging runoff.
- A suitable plan has been prepared for the restoration of water resources within the study area considering climate change.

6.2 Scope for Further Study

- Study should be performed with more field data particularly the discharge data of springs.
- LANDSAT Satellite image passing in the year 2006 with a resolution of 30m x 30m has been used in the study to generate the land use/ land cover as well as identification of suitable sites. In future, high resolution latest satellite image can be taken for research.

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APPENDIX

DESIGN OF CHECK DAM

Data required :

D/S face of Dam	=	0.90 Horizontal :	1 Vertical
Rectangular Height	=	4.50 m	
Roadway width	=	1.00 m	
D/S triangle height	=	3.39 m	
D/S Triangle width	=	3.05 m	
Unit Weight of Water	=	10.00 KN/m^3	
Unit Weight of Material	=	24.00 KN/m^3	
Free board Height	=	1.00 m	
Tail race height	=	0.00 m	
Horizontal distance of tail race	=	0.00 m	
Assumed Maximum reservoir level	=	4.00 m	
Silt level	=	0.00 m	
Total base of Dam	=	4.05 m	
Centre of gravity of Base	=	2.03 m	

A) **<u>Calculation of Dead weight</u>**

i) D/S Triangular Portion

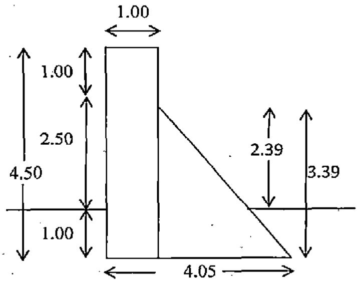
W_1 = 124.03 KN

Lever Arm = 0.01 m

ii) Rectangular portion

W_2 = 108.00 KN

Lever Arm = 1.525 m



B) **<u>Calculation of Water Pressure in NRL condition</u>**

Horizontal:

i) U/S water pressure

W_{w1} = 61.25 KN

Lever Arm = 1.17 m

ii) D/S water pressure

W_{w2} = 0.00 KN

Lever Arm = 0.00 m

C) **<u>Calculation of Water Pressure in MRL condition</u>**

Vertical:

i) U/S Rectangular portion

W_{w1} = 0.00 KN

Lever Arm = 2.025

ii) D/S Triangular portion

W_{w2} = 0.00 KN

Lever Arm = 2.025 m

Horizontal:

i) U/S water pressure

W_{w3} = 80.00 KN

Lever Arm = 1.33 m

D) **<u>Calculation of Uplift Pressure (NRL)</u>**

Vertical:

U1 = 54.00 KN Lever Arm = 0.68 m

E) **<u>Calculation of Uplift Pressure (MRL)</u>**

Vertical:

U1 = 54.00 KN Lever Arm = 0.68 m

LOADS AND MOMENTS ACTING ON DAM

Sl. No.	Description of Load	Symbol	Load in KN Horizontal	Load in KN Vertical	Lever arm in m	Moment in KN-m
1	Dead Load	W1		+ 124.03	+ 0.010	+ 1.24
		W2		+ 108.00	+ 1.525	+ 164.70
		Total		232.03		165.94

$$P \text{ minimum 'a'} = \frac{\sum W}{T} - \frac{6*\sum M}{T^2}$$

= 57.2914 - 60.701 = -3.41 KN/m² < 420 KN/m² (Safe)

$$P \text{ maximum 'b'} = \frac{\sum W}{T} + \frac{6*\sum M}{T^2}$$

= 57.291 + 60.701 = 117.99 KN/m² < 3000 KN/m² (Safe)

Sl. No.	Description of Load	Symbol	Horizontal	Vertical	Lever arm in m	Moment in KN-m
2	Reservoir Water Pressure in NRL U/s (Horizontal)	Ww1	- 61.25		+ 1.17	- 71.46
		Total		0.00		71.46

$$P \text{ minimum 'a'} = \frac{\sum W}{T} - \frac{6*\sum M}{T^2}$$

= 0 - 26.139 = -26.14 KN/m²

$$P \text{ maximum 'b'} = \frac{\sum W}{T} + \frac{6*\sum M}{T^2}$$

= 0 + 26.139 = 26.14 KN/m²

Sl. No.	Description of Load	Symbol	Horizontal	Vertical	Lever arm in m	Moment in KN-m
3	Uplift Pressure in NRL	U1		- 54.00	+ 0.68	- 36.45
		Total		- 54.00		- 36.45

$$P \text{ minimum 'a'} = \frac{\sum W}{T} - \frac{6*\sum M}{T^2}$$

= -13.333 - -13.333 = 0.00 KN/m²

$$P \text{ maximum 'b'} = \frac{\sum W}{T} + \frac{6*\sum M}{T^2}$$

= -13.333 + -13.33 = -26.67 KN/m² < 420 KN/m² (Safe)

Sl. No.	Description of Load	Symbol	Horizontal	Vertical	Lever arm in m	Moment in KN-m
4	Uplift Pressure in MRL	U1		- 54.00	+ 0.68	- 36.45
		Total		- 54.00		- 36.45

$$P \text{ minimum 'a'} = \frac{\sum W}{T} - \frac{6*\sum M}{T^2}$$

= -13.333 - -13.333 = 0.00 KN/m²

$$P \text{ maximum 'b'} = \frac{\sum W}{T} + \frac{6*\sum M}{T^2}$$

= -13.333 + -13.33 = -26.67 KN/m² < 420 KN/m² (Safe)

Calculation of capacity of Check Dam for Sub-watershed No. 17

Population	Per capita demand	Water requirement	
Persons	LPD	LPD	Cum per day
870	70	60900	0.000705

Month	Averge monthy discharge in cumec	Water Demand in cumec	Departure in cumec	Cumulative excessive down stream flow demand in cumec	Cumulative excessive flow in cumec
Jan	0.00069965	0.00070	-0.00001	-0.00001	0.00000
Feb	0.00156963	0.00070	0.00086	-0.00001	0.00086
Mar	0.01193395	0.00070	0.01123	-0.00001	0.01209
Apr	0.00148369	0.00070	0.00078	-0.00001	0.01287
May	0.00061941	0.00070	-0.00009	-0.00010	0.01287
Jun	0.00457507	0.00070	0.00387	-0.00010	0.01674
Jul	0.02247251	0.00070	0.02177	-0.00010	0.03851
Aug	0.0412434	0.00070	0.04054	-0.00010	0.07905
Sep	0.02130127	0.00070	0.02060	-0.00010	0.09965
Oct	0.01213062	0.00070	0.01143	-0.00010	0.11108
Nov	0.00711945	0.00070	0.00641	-0.00010	0.11749
Dec	0.00081242	0.00070	0.00011	-0.00010	0.11760
Total				-0.00010	

Required storage capacity = 86400 x 0.0001

8.64 m^3

Population	Per capita demand	Water requirement	
Persons	LPD	LPD	Cum per day
1231	70	86170	0.000997

Month	Averge monthy discharge in cumec	Water Demand in cumec	Departure in cumec	Cumulative excessive down stream flow demand in cumec	Cumulative excessive flow in cumec
Jan	0.00077151	0.00100	-0.00023	-0.00023	0.00000
Feb	0.00201822	0.00100	0.00102	-0.00023	0.00102
Mar	0.01297874	0.00100	0.01198	-0.00023	0.01300
Apr	0.00181417	0.00100	0.00082	-0.00023	0.01382
May	0.00060163	0.00100	-0.00040	-0.00063	0.01382
Jun	0.00467196	0.00100	0.00367	-0.00063	0.01749
Jul	0.02453468	0.00100	0.02354	-0.00063	0.04103
Aug	0.0413337	0.00100	0.04034	-0.00063	0.08137
Sep	0.03121688	0.00100	0.03022	-0.00063	0.11159
Oct	0.01491499	0.00100	0.01392	-0.00063	0.12551
Nov	0.00814646	0.00100	0.00715	-0.00063	0.13266
Dec	0.00078882	0.00100	-0.00021	-0.00084	0.13266
Total				-0.00084	

Required storage capacity = 86400 x 0.00084

Required storage capacity = 72.576 m^3

Calculation of capacity of Check Dam for Sub-watershed No. 43

Population in 2011	Per capita demand	Water requirement	
Persons	LPD	LPD	Cum per day
636	70	44520	0.000515

Month	Averge monthy discharge in cumec	Water Demand in cumec	Departure in cumec	Cumulative excessive down stream flow demand in cumec	Cumulative excessive flow in cumec
Jan	0.00030621	0.00052	-0.00021	-0.00021	0.00000
Feb	0.00192722	0.00052	0.00141	-0.00021	0.00141
Mar	0.00670321	0.00052	0.00619	-0.00021	0.00760
Apr	0.00454796	0.00052	0.00403	-0.00021	0.01163
May	0.00058805	0.00052	0.00007	-0.00021	0.01170
Jun	0.00041181	0.00052	-0.00010	-0.00031	0.01170
Jul	0.01355553	0.00052	0.01304	-0.00031	0.02474
Aug	0.01213252	0.00052	0.01162	-0.00031	0.03636
Sep	0.02038524	0.00052	0.01987	-0.00031	0.05623
Oct	0.00918477	0.00052	0.00867	-0.00031	0.06490
Nov	0.00465182	0.00052	0.00414	-0.00031	0.06904
Dec	0.00071898	0.00052	0.00020	-0.00031	0.06924
Total				-0.00031	

Required storage capacity = 86400 x 0.00031

Required storage capacity = 26.784 m^3

Population in 2031	Per capita demand	Water requirement	
Persons	LPD	LPD	Cum per day
900	70	63000	0.000729

Month	Averge monthy discharge in cumec	Water Demand in cumec	Departure in cumec	Cumulative excessive down stream flow demand in cumec	Cumulative excessive flow in cumec
Jan	0.00051018	0.00073	-0.00022	-0.00022	0.00000
Feb	0.00253972	0.00073	0.00181	-0.00022	0.00181
Mar	0.00735675	0.00073	0.00663	-0.00022	0.00844
Apr	0.00117658	0.00073	0.00045	-0.00022	0.00889
May	0.00027008	0.00073	-0.00046	-0.00068	0.00889
Jun	0.00152402	0.00073	0.00079	-0.00068	0.00968
Jul	0.01865042	0.00073	0.01792	-0.00068	0.02760
Aug	0.01839438	0.00073	0.01767	-0.00068	0.04527
Sep	0.0256798	0.00073	0.02495	-0.00068	0.07022
Oct	0.00733647	0.00073	0.00661	-0.00068	0.07683
Nov	0.00268292	0.00073	0.00195	-0.00068	0.07878
Dec	0.00088673	0.00073	0.00016	-0.00068	0.07894
Total				-0.00068	

Required storage capacity = 86400 x 0.00068

Required storage capacity = 58.752 m^3