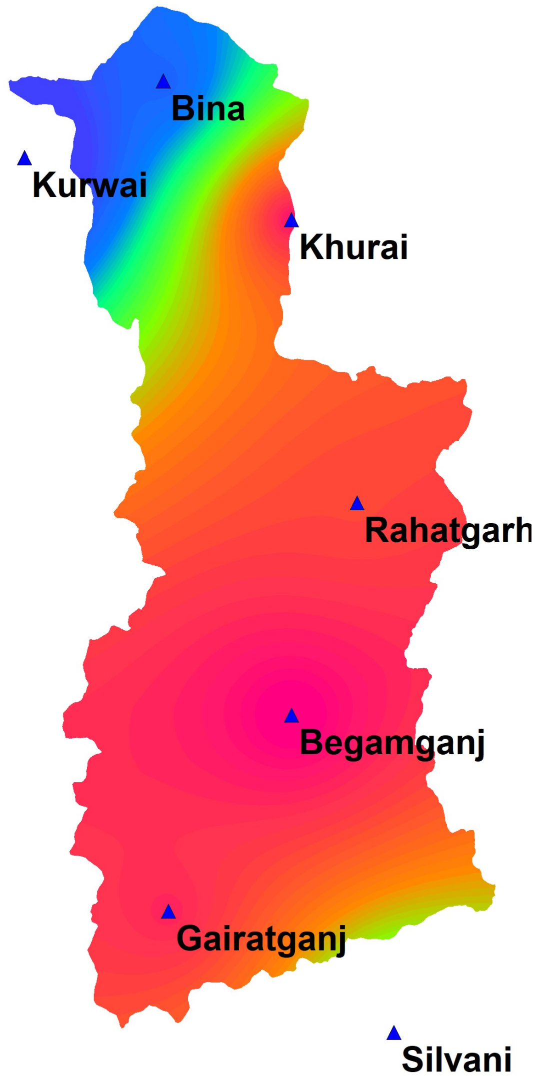
GIS BASED WATER BALANCE STUDY OF BINA RIVER BASIN



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PREFACE

Precipitation is the major source of input to the hydrologic system in semi-arid region. Division of rainfall into evapotranspiration and runoff is controlled by climate and catchment characteristics. The degree of control exerted by these factors varies with the spatial and temporal scales of processes being modelled. Understanding the relationship between catchment characteristics and climatic parameters is an important step in computation of water balance. However, this does not mean that one should try to incorporate every known process into a model. The interaction and co-evolution of these processes may manifest themselves in such a way that the overall behaviour of the catchment can be described by simple relationships. The Geographical Information System (GIS) is extremely useful in storing, retrieving, and manipulating the spatial as well as non-spatial data. GIS capability to generate landuse/land cover map, soils map and Thiessen polygon map used for computation of input parameters to the hydrologic models make it more expedient.

The Thornthwaite and Mather model for water balance was developed for the watershed, using estimates of monthly precipitation and potential evapotranspiration (PET) to estimate actual evapotranspiration (AET) and runoff, based on temperature, day length, rooting depth of plants and estimated soil storage capacity for the watershed. The Soil Conservation Service- Curve Number method is most widely used rainfall-runoff model developed for estimation of direct surface runoff using a single variable called Curve Number, which represents the catchment characteristics, viz. soil-cover complex of the watershed.

In the present study an attempt has been made to assess the water balance for Bina river watershed, a major tributary of Betwa river in Bundelkhand region of Madhya Pradesh. The water balance of the watershed has been carried out for three years, i.e. 2006, 2007 and 2008. I hope the study will be useful to the Water Resources Department, Sagar (M.P.) especially for planning and management of available water for the proposed Bina Complex – Multipurpose Project on Bina river.

Dr. Tejram Nayak, Scientist 'E' and team of Ganga Plains South Regional Centre, Bhopal have carried out the study under work program of 2013-14. The State Water Data Centre, Water Resources Department, Bhopal deserves our special thanks for supplying hydrologic data for this study.

(Raj Dev Singh)
DIRECTOR

ABSTRACT

The basic concept of Integrated Water Resources Management (IWRM) is to integrate not only the stakeholders but also put together various sources of supply to fulfil the demands. It is very obvious to have an idea about the water availability and water requirements for efficient use of water in a river basin. Therefore, water balance method is an important tool to provide quantitative information on water availability and water requirements. Precipitation is the main source of water in the river basins, which is not uniform over space and time. The surface water management requires the storage structures to be created on the rivers and rivulets at surplus locations during surplus periods. Further, the knowledge of availability of total water and peak flow are the major design criteria of any water resource structure, which becomes a difficult task for the ungauged catchments.

In the present study, an attempt has been made to compute the total volumetric runoff through the water balance of Bina river sub-basin, a tributary of Betwa river basin in Madhya Pradesh, using the Thornthwaite and Mather model. For the purpose of computation of peak flow and total runoff estimation, the SCS-CN method developed by soil conservation services (SCS) has also been applied to accomplish the above stated objective. The input parameters to the SCS-CN model and Water Balance model, i.e. landuse, soil texture, and hydro-meteorological data have been computed with the help of remote sensing and GIS techniques. Three years daily rainfall and runoff data from the year 2006 to 2008 have been used for evaluation of the SCS-CN model performance and monthly observed values of rainfall and runoff for the year 2007-2010 have been utilized for evaluation of the Thornthwaite and Mather model.

The results show that the yearly potential evapotranspiration in the watershed is 1229.31 mm. The actual evapotranspiration depends on the available soil moisture, viz. the duration and quantity of rainfall. The total runoff in the basin is about 45.5% of the total rainfall, which is high due to rocky & hilly terrain. The study reveals that the streams are generally dry in the months of November to June. Soil moisture recharge takes place during July, however July, August, September & October months are the period of water surplus.

The results of efficiency test carried out for the models show that the Nash-Sutcliffe Coefficient (E) varies between 0.60 to 0.86 and the Relative Volume Error (RVE) ranges from -1.8% to 9.3% for the three years for which surface runoff were computed. The RVE of SCS-CN model is within 5% range, hence it estimates the total volumetric runoff most accurately.

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S. No.	Abbreviation	Detail
1	AET	Actual Evapotranspiration
2	APWL	Accumulated Potential Water Loss
3	Avg.	Average
4	Avl.	Available
5	AWC	Available Water Capacity
6	Cal.	Calculated
7	DEF	Deficit
8	ESRI	Environmental Systems Research Institute
9	ET	Evapotranspiration
10	FC	Field Capacity
11	GIS	Geographic Information System
12	ILWIS	Integrated Land and Water Information System
13	Max.	Maximum
14	Min.	Minimum
15	Obs.	Observed
16	P	Precipitation
17	PET	Potential Evapotranspiration
18	PWP	Permanent Wilting Point
19	R.O	Runoff
20	STOR	Actual Storage of Soil Moisture
21	SUR	Surplus
22	Temp.	Temperature
23	Th.	Thiessen
24	TM model	Thornthwaite and Mather Model
25	US	United States
26	Wt.	Weighted

1.0 INTRODUCTION

It has been man's endeavor from time immemorial to utilize the available water resources as the existence of life primarily depends on water. Water is a mobile resource which is highly variable in space and time. Water is not only a commodity which is directly used by man but is also necessary for extensive economic development. With the growth of human civilization, man‘s requirement of water have increased manifold and it is being used for industries, power generation, irrigation, navigation, recreation, etc. apart from domestic supplies. The water is one of the important natural resources available to mankind. Due to its multiple benefits and the problem created by its excess and shortages and quality deterioration, the water has unique role as a resource and deserves special attention of development planners. Unprecedented increase in population, urbanization, agricultural expansion and industrialisation leads to higher levels of human activities. As water demand increases, issues on water availability and demand become critical. This makes the management of water resources (assessing, managing and planning of water resources for sustainable use) a complex task. The water on earth, whether as water vapor in the atmosphere, as surface water in the streams, lakes, as salty water in seas and oceans, or as ground water in the interstices of the subsoil, is not at rest, but in a continuous circulatory movement and never ending transformation from one state to another with sun as driving force. It undergoes various complicated process of interception, infiltration, unsaturated flow, saturated flow, evaporation, transpiration, overland flow, channel flow etc. All these process depend on space and time. Rainfall is the main source of water which is unevenly distributed spatially and temporally. Even though India is blessed with a higher average annual rainfall of 1,170 mm as compared to the global average of 800 mm, it faces the problem of water scarcity in most part of the year. (Jasrotia *et.al.* 2009).

In India, water resources are limited and are under severe and increasing pressure due to expanding populations, increasing per capita water use and irrigation. Recurrence of drought in many parts of the country in recent years caused unprecedented economic losses and great suffering to the affected areas. The systematic approach towards water resources management can be the key to mitigate the effect of water scarcity and droughts. Hence there is a need for water resources assessment, development and management to meet the challenges. The future availability of water for human use depends on how water resources are managed. Especially in water-shortage regions, pressures on management of water resources will become more important. According to an estimate by the World Resources Institute, 1–2.4 billion people (13–20% of the projected world population) will live in water-scarce countries by 2050 (http://www.wri.org/wri/water).

Water resources in Madhya Pradesh are mainly exploited for domestic and industrial water supplies and development of irrigation schemes. However, the state is facing the problem of water scarcity in rural areas as well as in urban areas to meet various water demands. In such circumstances, understanding the complex system of hydrological processes and the water availability in the river basins is needed for the sustainable water resources development of an area. The climatic and physiographic conditions, hydrologic response to rainfall and other characteristics of the catchment area are of vital importance for hydrological analysis for the purpose of water resources planning, flood forecasting, pollution control and many other applications. Major problems related to watershed management in rural area include water availability in streams during post-monsoon seasons, soil erosion, water stagnation in depressions and ground water recharge.

1.1 Water Balance of a River Basin

Sustainable water management in a river basin requires knowledge of the water availability and water requirements of the basin in the present and future for various purposes. The complexity of the water system in the region can be understood by calculating the regional water balance in a distributed scale considering the factors that affect it. Water balance is defined as the net change in water, taking into account all the inflows to and outflows from a hydrologic system. Spatial variation due to distributed landuse, soil texture, topography, groundwater level and hydrometeorological conditions should be accounted for in the water balance estimation.

River basin or watershed is generally considered as a spatial unit for preparation of any water resources management plan. Water balance study of a river basin is an important component of hydrology, on the basis of which development of water resource of a river basin for various beneficial uses is planned. Due to uneven distribution of precipitation in time and space, catchment characteristics and predominant hydro-meteorological factors in the watershed, all taken as the input, there is wide degree of variation in the water surplus and deficit. Therefore, water balance study in different time periods has to be carried out to conceive available water resource development project (Jenifa et al., 2010). From the hydrologic point of view, precipitation constitutes almost the entire water supply to any region, however its water potential can never be assessed from precipitation alone. It is necessary to know that whether the precipitation is greater than or less than the water need as determined essentially by the maximum amount of evaporation and transpiration or the evapotranspiration. When the precipitation is in excess of potential evapotranspiration, the region is wet and runoff takes place, while if the precipitation is lower than evapotranspiration, it is dry.

A water balance, applied to a particular spatial unit is an application of the law of conservation of mass which states that mass can neither be created nor destroyed. Balancing the availability and the demand in a spatial scale will be the best way to cope up with the present trend. To achieve this balance, the rate of change of storage of water within the spatial unit must be equal to the difference between its rates of inflow and outflow across the unit. Calculation of water balance is a basic approach for determining stocks of water in different components (air, soil, water bodies) of the hydrologic cycle and fluxes between these components. Knowledge of the quantity of water in different components of the water cycle serves in:

(a) Sustainable management of water resources and the protection against over exploitation and contamination

(b) Cropping pattern – irrigation and drainage practices

(c) Analysis of the effect of land use changes on water availability

(d) Analysis of the effect of climate changes on water availability

(e) Identification of recharge zones,

(f) Rainwater harvesting, etc.

The basic principle in hydrological modelling is that the model is used to calculate river flow based on meteorological data, which are available in a basin or in its vicinity. Hydrological models include subroutines for the most significant hydrological processes, such as precipitation at different locations, soil moisture dynamics, evapotranspiration, recharge of groundwater, runoff generation and routing in reservoirs and rivers. Most runoff models are based on the water balance, using precipitation as a driving variable and calculating the quantities directed as runoff, R, from the water balance equation:

$$R = P - E - \Delta S \tag{1.1}$$

where, P is precipitation, E evapotranspiration, and ΔS represents various storage terms. Water balance models are often divided into three categories; lumped models, distributed models, and stochastic models. However during floods the component E becomes insignificant and it has practically no effect on the predictions because the quantity of evapotranspiration is very less as compared to the river flow.

Water balance techniques, one of the main subjects in hydrology, are a means of solution of important theoretical and practical hydrological problems. On the basis of the water balance approach it is possible to make a quantitative evaluation of water resources and their change under the influence of man's activities. The study of the water balance structure of lakes, river basins, and groundwater basins forms a basis for the hydrological substantiation of projects for the rational use, control and redistribution of water resources in time and space (e.g. inter-basin transfers, streamflow control, etc.). Knowledge of the water balance assists the prediction of the consequences of artificial changes in the regime of streams, lakes , and ground-water basins. Current information on the water balance of river and lake basins for short time intervals (season, month, week and day) is used for operational management of reservoirs and for the compilation of hydrological forecasts for water management.

1.2 Remote Sensing and GIS Applications

Since last two decades, remote sensing has emerged as a powerful tool for natural resource management with the ability of obtaining systematic, synoptic, rapid and repetitive coverage. The thematic maps prepared for land use and soils class distribution in the watershed area by using digital image interpretation of satellite imageries provides spatially distributed inputs to the hydrological models. Geographic information systems (GIS) have made remote sensing a unique technology and widened the spectrum of remote sensing applications on natural resources management. GIS focuses on proper integration of user and machine for providing spatial information to support operations, management, analysis and decision making. Since, GIS does not directly land itself to time varying studies, its features are utilised in hydrological studies by coupling it with hydrological models. Two types of approaches are possible for this purpose. In the model driven approach, a model or set of models is defined and thus the required spatial (GIS) input for the preparation of the input data and output maps. The other approach is the data driven approach. It limits the input spatial data to parameters which can be obtained from generally available maps, such as topographic maps, soil maps, landuse maps etc. In the development of any modeling strategy, the data base management used to be a serious limitation. However, in recent times GIS and Remote Sensing (RS) techniques have alleviated this difficulty. Remote sensing data provides spatial information on the meteorological and hydrological data and catchment characteristics required in the hydrological model.

The possibility of rapidly combining data of different types in a GIS has led to significant increase in its use in hydrological applications. It also provides the opportunities to combine a data from different sources and different types. One of the typical applications is use of the digital terrain model (DTM) for extraction of hydrologic catchment properties such as elevation matrix, flow direction matrix, ranked elevation matrix, and flow accumulation matrix. GIS also provides the ability to analyze spatial and non-spatial data simultaneously. A GIS can bring spatial dimensions into the traditional water resource data base, and it has the ability to present an integrated view of the world. This is accomplished by combining various social, economic and environmental factors related to spatial entities of a water resources problem and making them available for use in a water balance model. In the development of any modeling strategy, the data base management used to be a serious limitation. The availability of GIS tools, together with national and global databases grant the researchers and practicing hydrologists have an opportunity to access and use enormous quantities of spatial and temporal data. With the exponential increase in computing power it is feasible to apply high resolution distributed hydrological models to a range of water resource problems including water balance of a river basin. Integrated Water and Land Information System (ILWIS) has the capabilities of GIS and Image Processing. The satellite imageries can be used for preparation of thematic maps, such as Land use by using Digital Image Processing module in ILWIS.

1.3 Objectives of the Present Study

In the present study efforts have been made to analyze meteorological and hydrological aspects of water availability in Bina river basin which is a tributary of Betwa River in Madhya Pradesh. The area under Bina river basin falls in the drought prone Bundelkhand region and is characterized by water scarcity, increasing water demand and over exploitation of the available water resources. Lack of suitable water management measures in the basin leads to most of the precious water flow down the river during the monsoon months without being tapped causing more dependence on groundwater resources to fulfil the agricultural and domestic demands during the post-monsoon months. In the present study, climatic factors have been thoroughly analyzed. Considering all these aspects, an attempt has been made to study the water balance of Bina river watershed in Madhya Pradesh using the Thornthwaite and Mather model with the help of remote sensing and GIS techniques. Subsequently, the computed monthly runoff was compared with the observed monthly runoff.

The volumetric runoff, one of the water balance components has also been computed by the Curve Number method developed by the Soil Conservation Service, USDA in 1969. The daily direct runoff in the Bina river basin at Rahatgarh gauging station have been computed by using SCS-CN model develop for the Bina river basin and subsequently total monthly volume of surface runoff was summed up. Finally, the monthly available for runoff, i.e. surplus moisture computed by using Thornthwaite Mather method have been compared with those of the volume obtained from the SCS-CN model.

2.0 REVIEW OF LITERATURE

The scope of hydrological applications has broadened dramatically over the past five decades after the advent of fast computing machines and techniques. The development of various water resources management and modelling techniques were emphasized during the latter half of the last century and the main thrust was on improvement in the model efficiency. In this chapter a review of literature of various methods and techniques involved in water balance of a spatial unit (watershed and river basin) are presented.

Subrahmanyam (1983) presented the principles and procedures of drought climatology employing the water balance concepts. Identification and categorization of drought years have been made using Thornthwaite's index of aridity. Using the soil as a reservoir with limited water holding capacity, a comparison of water supply by precipitation with the water need was done, with the help of the water budgeting to evaluate potential evapotranspiration, actual evapotranspiration, the water surplus and the water deficit.

Pimenta (1999) wanted to identify the desertification prone areas for Portugal so he used the Thornthwaite and Mather’s approach to compute the number of months of water stress conditions and amounts of water involved in the different components of the hydrologic cycle with a monthly time step, using GIS. **Kumar (2001)** computed the normal water balance of Krishna basin. The monthly water balance computations were done using the procedure of Thornthwaite (1948) to estimate the elements of water balance; viz., actual evapotranspiration (AET), water deficit, & water surplus.

Zlomke (2003) developed a Thornthwaite-type water balance model for Carneros Creek Watershed, Napa County, California. Input Data used include long term monthly average rainfall and estimated monthly average values of PET. PET values were multiplied by a landscape coefficient. AET was estimated on the basis of PET by use of the original Thornthwaite’s method. The model distinguishes between quick runoff, which runs off immediately without infiltration, and slow runoff, which contributes to soil moisture recharge before it enters the runoff stream. The final conclusion was that the model showed a tendency to over predict the total runoff, which was due to the inclusion of groundwater recharge in runoff.

Killingtveit (2004) through his study found that the water balance for the two catchments at Svalbard has an average residual term close to zero, so in this sense the water balance measurements were good. But there were large errors in individual years with positive and negative deviations. So he concluded that the individual terms in the water balance were not known well enough; the largest errors were probably due to insufficient knowledge of precipitation corrections and glacial balance. He suggested that even if evaporation is not a dominant factor in the water balance, it would be useful to include evaporation from both bare ground and snow.

Singh, *et al.* (2004) conducted a water balance study in Nana Kosi watershed, in the district of Almora (Uttranchal) using the Thornthwaite and Mather (TM) model with the help of Remote Sensing and GIS. Besides showing the seasonal pattern of precipitation, actual evapotranspiration (AET), potential evapotranspiration (PET) and runoff, he indicated the periods of moisture deficit and soil moisture recharge.

Jasrotia, *et al.* (2006) computed the runoff in the catchment area along the NH-1A between Udhampur and Kud using Remote Sensing data and GIS techniques. Using the US Soil Conservation Service curve number method, the estimated runoff potential was classified into five levels—very low, low, moderate, high, and very high. **Victoria, *et al.* (2006)** simulated the monthly water balance for the Ji-Parana river basin, in the Western Amazonian state of Rondonia using Thornthwaite–Mather climatological model. The Ji-Parana river basin was divided into 10 sub-basins where discharges were available. And finally the observed data were compared with the modeled results, which indicated an under estimation of basin ET and an excess water surplus. It was suggested that these results could be due to underestimation of PET, rooting depth estimates, or a combination of both. But an increase in PET improved modeled results.

Jasrotia, *et al.* (2009) assessed the water balance of Devak–Rui watershed of Kandi region in Jammu district using the Thornthwaite and Mather (TM) model with the help of Remote Sensing and GIS. The runoff potential map was generated with the help of GIS from the runoff values which were calculated from the TM model. The runoff potential map was classified into low, moderate, and high runoff potential zones. And finally the moderate runoff potential zone were suggested as suitable zone for rainwater harvesting structures such as check dams, percolation tanks, etc.

Jenifa, *et al.* (2010) observed that traditional approach of calculating the water balance using a spatially and temporally lumped scale does not give very accurate estimate of the water volume in a hydrological component. A spatially semi distributed, GIS based hydrological model was developed on a sub watershed scale using mean monthly hydro-meteorological data. Surface runoff and evapotranspiration were estimated using land use, soil texture, topography, and hydro-meteorological parameters in Amaravathi River Basin.

Jain (2012) believed that evapotranspiration (ET) estimate for India (as per few studies) is much lower than what may be expected as per the India's climate and land use. So, he tried to find out the reason for this. Based on the estimates of range of ET for the areas which are hydrometeorologically similar to India, it was found that ET for India is under estimated. ET values for the Ganga and Brahmaputra basins appear to be unreasonable because these trans-boundary basins bring in large quantities of flow that has been generated beyond the borders by surface and sub-surface routes. Thus it would be necessary in ET computations to consider only that part of the flow which has been generated in the Indian portion of the catchment, since all other water balance components pertain only to the catchment area in India. **Roy, *et al.* (2012)** attempted to find a solution of water shortage problem in Paramount farm in Southern San Joaquin Valley, California, the world's largest supplier of almonds. The resources were estimated by a water balance assessment approach using the Thornthwaite and Mather (TM) model.

Karsili (2013) conducted a study to model the water balance of the Mediterranean Region to understand the impacts of climate change. The aim was to calculate potential evapotranspiration of the Mediterranean region in order to develop a water balance model by using the ArcGIS (created by ESRI, US) Model Builder, which is a tool that allows to create models, and was used here to calculate storage, storage change, surplus, deficit and actual evapotranspiration, with a model mainly based on the Thornthwaite's methodology. This study spans different time periods which are for the past, present and future. Because of changes that have already occurred in climate, the model produces different results for the three periods. This study only focused on temperature rise in the future, holding precipitation the same as in the present period. According to the model results, there are not sufficiently increased surpluses in the region. One possible reason for this result is the use of unchanged precipitation data in the future analysis. With decreased precipitation, there will be more water scarcity and lesser surpluses in the future. Even without the inclusion of this factor, the model predicts more deficits than surpluses in the future. **Eamus, *et al.*** discussed the water balance of a catchment and showed that rainfall alone does not always represent the only significant input of water. He highlighted the importance of solar radiations in determining evapotranspiration. [http://www.eolss.net/sample-chapters/ c07/e2-09-01-04.pdf]

Zhang, *et al.* used a top-down approach (moving from mean annual to shorter time scale) to explore the effects of climate and catchment characteristics on water balance over variable time scales. At mean annual scale, the water balance is dominated by climatic factors such as average precipitation and potential evapotranspiration. At annual time scale, results from this study showed that the inter-annual variability of water balance in many Australian catchments can be reasonably well estimated from the dryness index (ratio of potential evapotranspiration to precipitation). At monthly time scale, the effects of soil moisture dynamics has to be considered on water balance.

3.0 STUDY AREA

Bina river is a major tributary of River Betwa in Bundelkhand region of Madhya Pradesh, which originate from Begumganj block of Raisen district and enters Sagar district at Rahatgarh block and traverse through Khurai and Bina tehsil before confluence with river Betwa near Basoda town in Vidisha district. Presently, domestic water supplies to Rahatgarh, Khurai and Bina town; railways requirement at Bina Railway Junction and industrial supplies for Bina Refinery and proposed JP power project is met from this river beside limited irrigation from the river by direct pumping. "Bina Complex- Irrigation and Multipurpose Project" has been proposed. Under this project, four dams are proposed, the Madia dam and Chakarpur dam-cum-pickup weir on Bina river and one each on Dehra and Dhasan rivers, which are the tributaries of river Betwa. The study area is located partly in Sagar, Vidisa and Raisen districts of Madhya Pradesh. Various maps of Bina Basin are shown below. The geographical area of the Bina basin up to Rahatgarh Gauge-Discharge is about 1139 Km^2. Bina river basin which traverses through the fertile plains of Madhya Pradesh, is one of the important tributary of Betwa River, which is one of the important basin of Yamuna River. Bina river basin is situated at 24° 10' N to 24° 42' N latitudes and 78° 09' E to 78° 23' E longitudes. The study area is located in Survey of India toposheet Nos. 55I/2, 3, 6, 7 and 11 on 1:50,000 scale. Water balance study was carried out for the watershed upto Rahatgarh G&D site in Bina river as shown in Figure 3.1.

The catchment area is highly undulating and covered by forests, barren lands and localized rain-fed agriculture. The drainage density is more in the upper catchment as compared to the lower part of the Bina river basin, the later is mostly gently sloping to plain topography mostly covered with agricultural fields. The streams are dry after the monsoon months despite enough rainfall; the average annual rainfall in recent years over the basin is 1016.37 mm and 980.35 mm during monsoon months, i.e. June to October. Therefore groundwater is exploited for domestic and agricultural uses during Rabi season causing depletion of the water table in most of the area.

3.1 Water Resources Issues of Bina River Basin

Bina river is a major tributary of River Betwa in Bundelkhand region of Madhya Pradesh, which originate from Begumganj block of Raisen district and enters Sagar district at Rahatgarh block and traverse through Khurai and Bina tehsil before confluence with river Betwa near Basoda town in Vidisha district. The Bina river watershed experience very heavy rainfall during monsoon but due to lack of water conservation and management practices the river goes dry by the end of November or mid December, depending on the departure of monsoon in this region. Another, major issue is land use change, farmers intend to grow more water required crops, like wheat as the availability of electric supply is improved and advancement in technology for deep bore-wells. This practice has resulted into

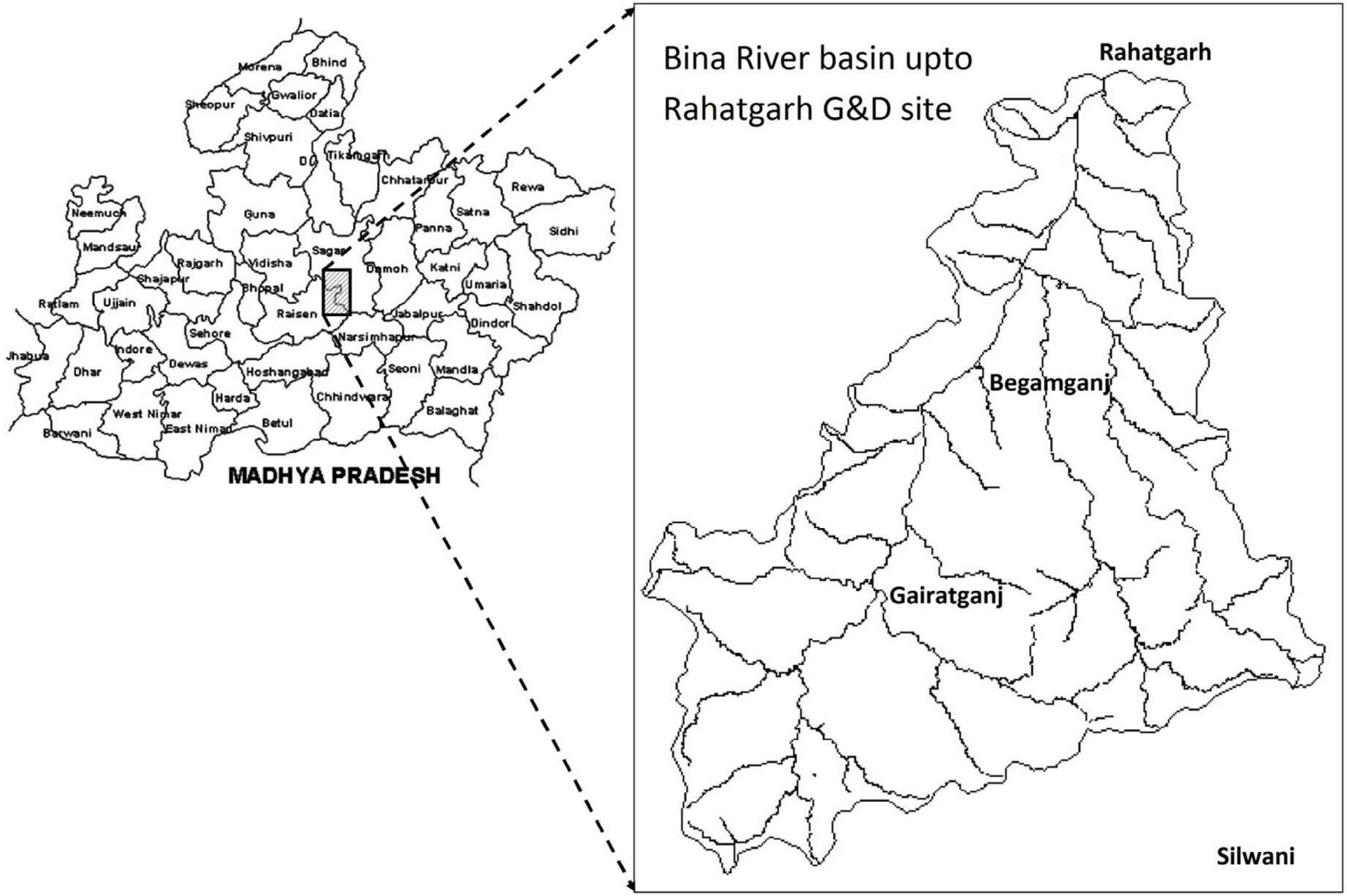

Fig. 3.1: Index Map Showing Location of Bina River Watershed upto Rahatgarh Site

depletion of groundwater in the region. The depletion of groundwater has intensified the drinking water problem in rural areas and also led to rapid reduction in vegetation cover (forest cover). Three medium cities, namely Rahatgarh, Khurai and Bina, and about 150 villages fall in the jurisdiction of Bina river basin. The lower part of the basin has good fertile lands which produce the best quality wheat. Recently, there is rapid growth in industrial development after commissioning of the Bina Refinary Project, otherwise agricultural practices are the main source of livelihood for the population in the basin. The large populations in the basin come under weaker socio-economic group, for which safe drinking water should be ensured, apart from the need of domestic water supply in cities/towns.

Presently, domestic water supplies to Rahatgarh, Khurai and Bina town; railways requirement at Bina Railway Junction and industrial supplies for Bina Refinery and proposed JP power project is met from this river beside limited irrigation from the river by direct pumping. "Bina Complex-Irrigation and Multipurpose Project" has been proposed by the Water Resources Department, Govt. of Madhya Pradesh is an ambitious project of the region for irrigation, power generation, industrial and domestic water supply etc. Under this project, four dams are proposed- two on river Bina and one each on Dehra and Dhasan rivers, which are the tributaries of river Betwa. The Madia dam and Chakarpur dam-cum-pickup weir are proposed on river Bina, Dhasan diversion on river Dhasan and Dehra dam on river Dehra, a tributary of Bina river.

3.2 Bina Complex-Irrigation and Multipurpose Project

The base map showing the Bina Project Complex showing all four structures, catchment area and command area is given in Figure 3.2. The main Madia dam of the project is proposed near village Madia on river Bina at about 42 km away from the Sagar district Head Quarter. The catchment area of Madia dam is 1139 sq. km. To exploit the power potential of Madia dam, underground Power House having two units of each 11 MW is proposed on this location. The tail water releases from Madia power house will be stored in another dam namely, Chakarpur dam in Bina river, which is about 55 km away from Sagar and having independent catchment area of 187 sq. km. In the project, Dhasan diversion dam near Bhainsa village at 25 km from Sagar has been proposed on Dhasan river mainly to divert water from river Dhasan to river Bina to overcome the excess demand in Bina basin. The catchment area of Dhasan diversion dam is 464.50 sq. km. The Dehra dam of Bina Project Complex is proposed on river Dehra which is a tributary of river Bina. It is about 36 km away from Sagar with independent catchment area of 62.50 sq. km. The water stored in Dahasn diversion will be diverted to Dehra dam through a feeder canal of 5 km length. To exploit the hydro-electric potential of Dhasan and Dehra, water stored in Dehra dam will be used for generation of 10 MW power through two units of each 5 MW surface Power House.

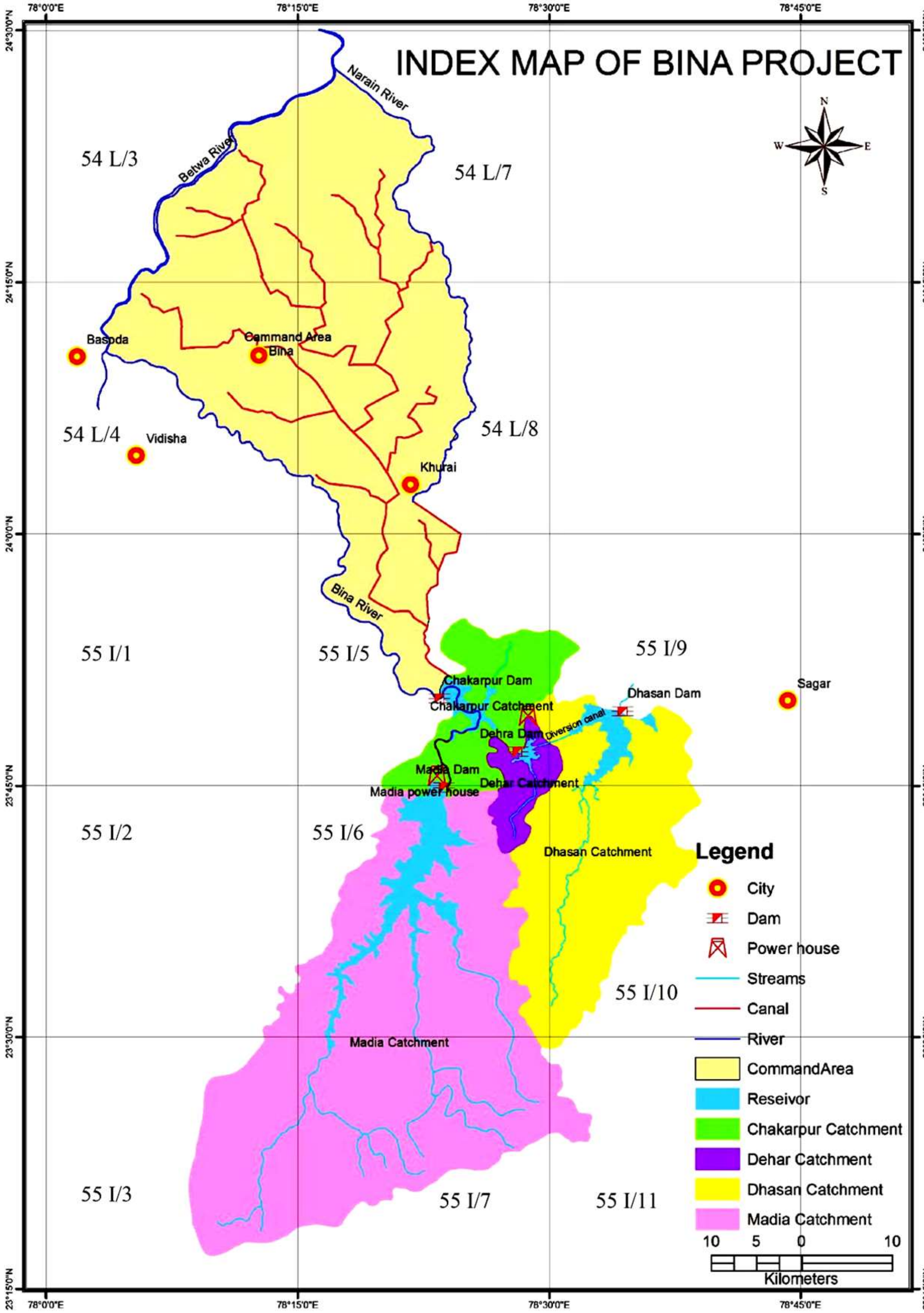

Fig. 3.2: Catchments and Command Area of Bina Complex Project

The Detailed Project report for "Bina Complex - Irrigation and Multipurpose Project" has already been submitted for approval from various ministries at Central Govt. and State Govt. The Bina complex project envisages /total irrigation potential of 97,747 ha in 70,000 ha cultivated land. The salient features are shown in Table 3.1. Line diagram is given at Figure 3.3 showing the Dams, Diversion structures, link channel and water demands.

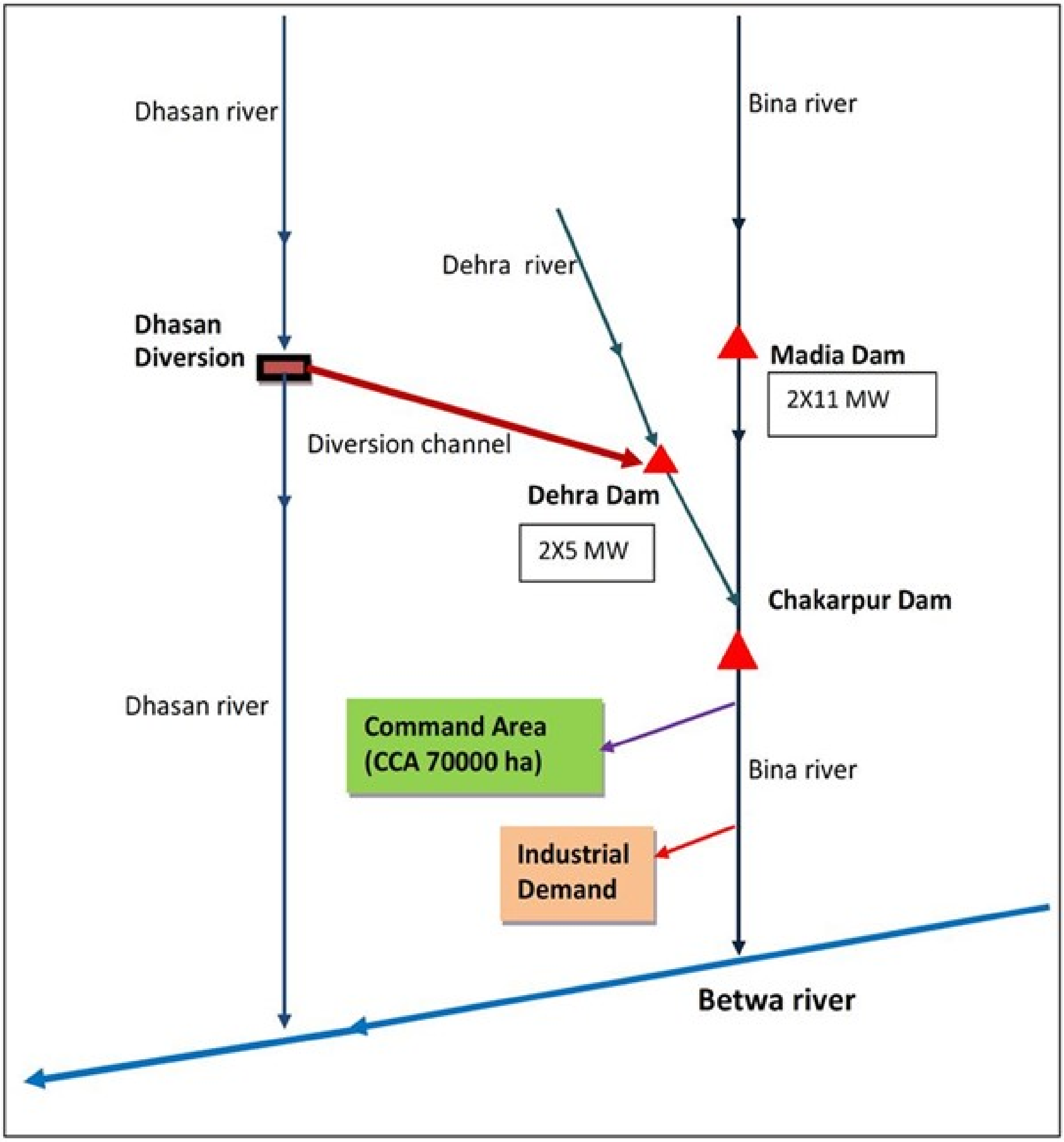

Fig. 3.3: Flow Diagram of Bina Complex-Irrigation and Multipurpose Project

Table 3.1: Salient Features of Bina Complex-Irrigation and Multipurpose Project

Particulars	Madia dam	Dhasan diversion	Dehra dam	Chakarpur dam
LOCATION				
Village	Madia	Bhainsa	Shikarpur	Bhulna Bhangarh
Latitude	$23^0$50'34"	$23^0$50'01"	$23^0$48'34"	$23^0$50'27"
Longitude	$78^0$22'32"	$78^0$34'07"	$78^0$26'20"	$78^0$23'16"
HYDROLOGY				
Catchment area (sq. km)	1139.00	464.50	62.50	187.00
Water yield (MCM)	496.98	199.25	34.92	104.59
Gross storage (MCM)	313.11	86.47	72.36	74.31
Live storage (MCM)	310.44	80.55	72.255	72.89
LEVELS				
River bed level (m)	482.00	482.00	459.00	430.00
Minimum water level (m)	487.79	492.12	467.49	437.79
Lowest power intake level(m)	488.00	-	473.96	-
Full supply level (m)	501.20	498.50	491.60	451.50
Maximum water level (m)	501.60	498.60	492.00	452.50
Height of dam (m)	23.50	21.60	35.00	25.00
Length of dam (m)	2069.694	7402.00	3509.00	751.682
Diversion channel	From Dhasan diversion to Dehra dam is 5 Km.			
POWER GENERATION				
Capacity (MW)	2X11	-	2X5	-
Maximum head (m)	39.75	-	35.32	
IRRIGATION				
Canal length (km)	533			
No. of canal structures	251			
Gross command area (ha)	78535			
Cultivable command area (ha)	70000			
Irrigation capacity	Rabi-70000 ha and Kharif-27747 ha (97747 ha)			

3.3 Physiography

The study area falls under Bundelkhand plateau as per broad physiographical classification. The topography of the area is rolling to undulating. The land slope is characterized by flat topped hillocks. The valley land is moderately to poorly drain. The uplands having dendrite drainage pattern have limited natural drains and very low drainage density. The region has fairly extensive network of rivers which are mostly seasonal. Bundelkhand region has network of rivers like Dhasan, Bebas, Bina, Bamner and Sonar etc.

3.4 Climate

The average normal annual rainfall of the area is 1204.55 mm and about 90% of the annual rainfall takes place during the southwest monsoon period i.e. June to October, only 5.5% of annual rainfall takes place during winter and about 4.5% of rainfall occurs during the summer season. The maximum monthly rainfall occurs during the month of July followed by August. The climate of study area can be classified mainly into three seasons: Winter season starting from middle of November to end of February; March to May constitutes the summer season whereas the monsoon season starts from second week of June to end of September. During winter season the January is the coldest month with the average minimum temperature of 11.5˚C whereas the hottest month is May with average maximum temperature up to 40.9˚C.

3.5 Geology

The study area falls under the Vindhyan region, important rocks found in this area are sand stone, Quartizitic sand stone, lime stone and Deccan traps, called basalt. Basalt rocks overlie the Vindhyan sand stone. Lower Vindhyan is represented by quartizitic sand stone and shale where as upper Vindhyan consists of sand stone and shale with subordinate limestone. Lameta lime stone is also found in lower ridge area.

3.6 Soil and Crops

The area around Bina river basin is mostly fertile black cotton soil and some area under red soil. The main crops grown in Kharif season are soyabeen, urad and paddy and main crops grown in Rabi season are wheat, red gram. Other staple crops like linseed, chickpeas, sorghum, oilseeds are also grown in the study area. The area around Bina river basin is mostly fertile black cotton soil and some area under red soil. The main crop grown in in kharif season Soyabeen, Urad and paddy and main crop grown in Rabi season are wheat red gram. Other staple crops like linseed, chickpeas, sorghum, oilseeds and grown are also grown in the study area. As per the demographic information collected for villages in catchment area, around 40% of area in Rabi season is under wheat cultivation. The area under wheat cultivation varies from 36% in Dehra to 47% in Dhasan villages. Gram is grown in around 38% of area cultivated in Rabi. The area covered under gram cultivation in the villages of different dams is in the range of 35-45%. Less than 20% area in rabi season is under lintel cultivation. Lintel is grown more in Madia villages with around 25% of the total Rabi season.

3.7 Drought Prone Area

Drought is an extended shortfall of precipitation that results in water supplies insufficient to meet the needs of humans and the environment (Wilhite and Buchanan-Smith, 2005) and occurs routinely as part of the natural hydrologic cycle. So the occurrence of drought event does not scale the proneness of that particular area. The probability of occurrence of rainfall equivalent to the 75% of the normal seasonal and annual rainfall along with the identification of drought proneness of these stations is depicted in Table 8.6 and 8.7 respectively. Probability distribution of annual rainfall helped in identifying the drought prone blocks in study area. The probability of occurrence is 80.86% at Begamganj which indicating that, it is not a drought prone area. The probability of occurrence of annual rainfall at Rahatgarh and Jaisinagar were 78.87 % and 70.04 % respectively, come under drought prone area. The probability of occurrence of seasonal rainfall at Rahatgarh, Jaisinagar and Begamganj were 78.58%, 69.73% and 76.57% respectively, fall under drought prone region.

4.0 METHODOLOGY AND DATA USED

The water balance of a physical unit, such as watershed or administrative block essentially means balancing the inflow, outflow and changes in storage of the hydrological unit. In hydrology, a water balance equation can be used to describe the flow of water in and out of a system. A system can be one of several hydrological domains, such as a column of soil or a drainage basin.

4.1 Thornthwaite and Mather's model

Analysis of water availability in the Bina river watershed is based on the Thornthwaite methodology. This method mainly calculates potential evapotranspiration (PET). Since the measurement of temperature is much easier than many other climatic variables and one of the most common methods to estimate PET is the Thornthwaite approach, so it is preferred for use in this study. According to the PET results and using Thornthwaite and Mather's model, water storage, storage changes, actual evapotranspiration, surplus and deficit can be calculated. The inputs are temperature, precipitation, day length hours as a function of latitude and available water capacity of the soil (Figure 4.1). Thornthwaite's water balance concept is applicable for any area, from smaller regions to continents, countries etc. In a steady-state world, incoming water (precipitation) should be equal to outgoing water (evapotranspiration). However this is not the case in the real world over all durations. There are water deficiencies as well as surpluses in many parts of the world. The first step for calculating water balance is the derivation of potential evapotranspiration (PET). PET is important because actual evapotranspiration (AET) can be calculated from it, by using it together with precipitation, and hence by subtracting AET from PET, water shortages can be determined.

4.1.1 Potential Evapotranspiration

Thornthwaite (1948) correlated mean monthly temperature with evapotranspiration as determined from water balance for valleys where sufficient moisture water was available to maintain active transpiration. According to Thornthwaite (1948) potential evapotranspiration (PET) is the ability of soil and vegetation to remove water from the surface by evaporation and transpiration with available energy. It gives an idea about the situation if there would be enough water under available energy (temperature) which is often different from the current situation (Thornthwaite, 1948). In order to clarify the existing method, the Thornthwaite's equation is discussed.

$$PET = 16\left(\frac{L}{12}\right)\left(\frac{N}{30}\right)\left(\frac{10\,T_a}{I}\right)^{\alpha} \tag{4.1}$$

Where,

PET is the estimated potential evapotranspiration (mm/month)

T_a is the average daily temperature (degrees Celsius; if this is negative, use 0) of the month being calculated

N is the number of days in the month being calculated

L is the average day length (hours) of the month being calculated

$$\alpha = (6.75\times10^{-7})I^3 - (7.71\times10^{-5})I^2 + (1.792\times10^{-2})I + 0.49239$$

$$I = \sum_{i=1}^{12}\left(\frac{T_{ai}}{5}\right)^{1.514}$$

T_{ai} is a heat index which depends on the 12 monthly mean temperatures.

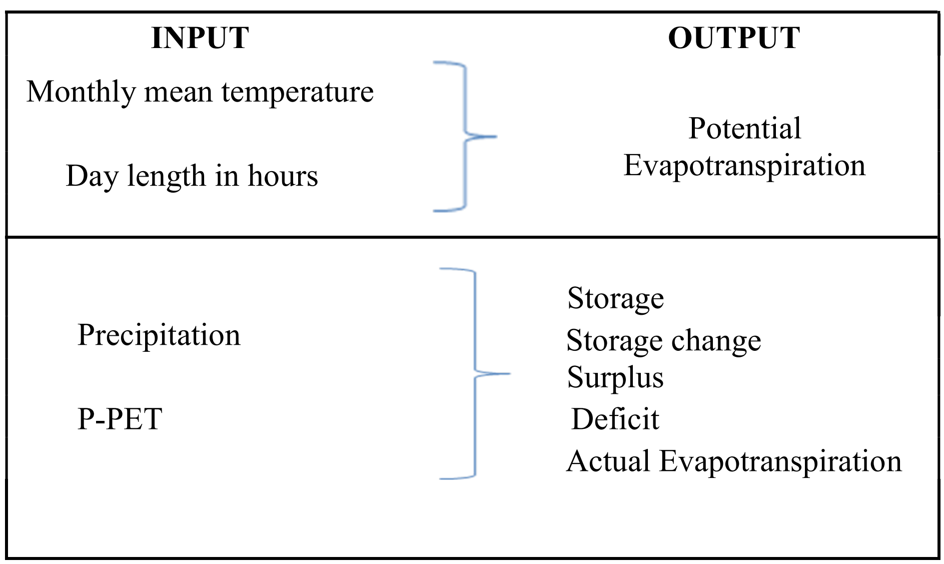

Fig. 4.1: Inputs and outputs for Thornthwaite and Mather's model

Precipitation is an important input to the water balance model in order to determine if the water supply is meeting vegetation demand, resulting in evapotranspiration and some water left over in soil storage. Precipitation must supply actual evapotranspiration, surplus and soil moisture storage all together. If precipitation is higher than evapotranspiration (P > PET) water is stored in the soil until it reaches its holding capacity. After a while water infiltrates from larger pores and the water that remains in the soil after downward movement, which is for the use of vegetation by means of transpiration and for the soil by means of evaporation, is called “field capacity” or “storage capacity”. This is the water stored in the soil available for the access of plant roots (Christopherson, 2006). Storage is equal to the field capacity if precipitation is higher than evapotranspiration (P > PET). However, storage changes over the whole year. While the storage is charging itself during the wet seasons, it does the opposite in the dry months, viz. mostly in summer.

4.1.2 Storage

As per the Thornthwaite and Mather’s model next step is to calculate (P – PET), which is an estimation of the quantitative water excess (+) or deficit (–) with P as precipitation. Then the accumulated values of (P – PET), i.e. the accumulated potential water loss (APWL) for each month, are calculated. This will be zero for months having positive (P – PET) and starting with the first month having a negative value after the monsoon. Then the actual storage of soil moisture (STOR) for each month is calculated as follows:

$$STOR = AWC \times e^{(APWL / AWC)} \tag{4.2}$$

Where, AWC is the moisture storage capacity (i.e. the available water capacity) of the soil. This is calculated based upon the land use, soil texture and rooting depth as suggested by Thornthwaite & Mather (1955, 1957).

4.1.3 Storage Change

When evapotranspiration exceeds precipitation, soil loses water so storage decreases in the soil until precipitation is higher again and it starts increasing until it is completely refilled again. This change is called the storage change of the soil. Changes of actual storage (ΔSM) for all the months are calculated as:

$$\Delta SM_{month} = STOR_{month} - STOR_{previous\,month} \tag{4.3}$$

A negative value of ΔSM implies subtraction of water from the storage to be used for evapotranspiration, whereas a positive value of ΔSM implies infiltration of water into the soil and its addition to the soil moisture storage.

4.1.4 Actual Evapotranspiration

Actual evapotranspiration (AET) is the combination of evaporation and transpiration, which is actually moving upwards from soil and vegetation to the atmosphere under current conditions

(Christopherson, 2006). The actual evapotranspiration (AET) is computed for all the months, as given in the following equations;

$$AET = \Delta SM + P \quad ; \Delta SM < 0 \tag{4.4 a}$$

$$AET = PET \quad ; \Delta SM > 0 \tag{4.4 b}$$

In a place or a region if there is lesser precipitation than PET, this means incoming water is not matching outgoing water (Thornthwaite, 1948).

4.1.5 Deficit

Deficit occurs if the water cannot satisfy the demand of PET. Deficit is one the reasons for the water shortages in a region which hence bring stresses on the water resources.The water deficit (DEF) for crop evapotranspiration in each month is calculated for the months having negative (P – PET) as follows:

$$DEF = PET - AET \tag{4.5}$$

4.1.6 Surplus

The amount of excess water that cannot be stored is denoted as moisture surplus (SUR). If soil capacity is saturated with water and further water is added onto the soil, this water will be surplus that can be collected in rivers and lakes or infiltrate to the water table. When storage reaches its capacity, SUR is calculated using equation given below:

$$SUR = P - PET \tag{4.6}$$

When the soil storage is not at its capacity, no surplus exists. In a month in which the soil moisture storage capacity is just satisfied, SUR is obtained using equation given below:

$$SUR = P - (AET + \Delta SM) \tag{4.7}$$

Where, ΔSM is the change in actual soil moisture storage.

The runoff is calculated using the formulae given below:

$$R.O_{month} = (0.5 \times SUR_{month}) + (0.5 \times SUR_{previous\,month}) \tag{4.8}$$

Where, R.O is runoff for any month.

Thus we can say that it is assumed that the surplus generated in a month gets divided equally into the current month and the next month as runoff.

The annual amount of actual evapotranspiration and runoff from the watershed is calculated considering the area under different land use and the respective values from the monthly water balance table. Thus, the monthly actual evapotranspiration and runoff from the watershed are area-weighted values. The figure below shows the input and output parameters of Thornthawaite and Mather's concept.

4.2 Derivation of SCS-CN Model

The method is based on an assumption of proportionality between retention and runoff in the following form:

$$\frac{P-Q}{S}=\frac{Q}{P} \tag{4.9}$$

Where,

P = Total Storm Rainfall or Potential Runoff (mm)

Q = Actual Direct Runoff (mm)

S = Potential Maximum Retention by soil (mm)

Equation 4.9 states that the ratio of actual retention to potential retention is equal to the ratio of actual runoff to potential runoff. This assumption generates the conceptual basis of the runoff curve number method.

For practical applications, the above equation is improved by reducing the potential runoff by an amount equal to the initial abstraction. The initial abstraction consists mainly of interception, infiltration and surface storage, all of which occur before runoff begins. Moreover, the initial abstraction depends upon antecedent moisture condition (AMC).

Thus,

$$\frac{P-I_a-Q}{S}=\frac{Q}{P-I_a}$$

Where I_a is initial abstraction.

Solving for Q,

$$Q=\frac{(P-I_a)^2}{P-I_a+S} \tag{4.10}$$

Equation 4.10 is physically subjected to the restriction that $P \geq I_a$ (i.e. the potential runoff minus the initial abstraction cannot be negative). To simplify the Equation 4.10, initial abstraction (I_a) is related to potential maximum retention (S). The general relationship is given as:

$$I_a=\lambda.S \tag{4.11}$$

4.2.1 Initial Abstraction

Generally for all practical applications, λ is taken as 0.2. However, in Indian context pertaining to the black soil region the value of λ is taken as follows (NIH, 98):

1. For black soil region (Antecedent Moisture Condition I) and for all other regions:

$$I_a = 0.3S \tag{4.12}$$

2. For black soil region (Antecedent Moisture Condition II & III):

$$I_a = 0.1S \tag{4.13}$$

Eq. 4.12 & 4.13 are used with the assumption that the cracks are typical of black soil when in dry conditions which get vanished in wet conditions due to the expansive characteristics of the black soils. The potential maximum retention by the soil is given by relating it to a dimensionless factor that is the curve number (CN) that depends upon the hydrologic soil groups, antecedent moisture conditions as well as land use land cover factors in the catchment area.

$$S = \frac{25400}{CN} - 254 \tag{4.14}$$

Thus the value of Q that is the net runoff depth depends on the factors like precipitation depth, and the Curve Number chosen for the specific catchment. Equation 4.10 provides the depth of direct surface runoff, if we put depth of precipitation and the curve number. The total volume of direct runoff is computed by multiplying the depth of runoff with the area of the watershed.

4.2.2 Hydrologic Soil Group

Classification of hydrologic soil group is made based on the infiltration rate, which is given in Table-4.1.

Table 4.1 Hydrologic Soil Groups and the Infiltration Rates

Hydrological Group	**Minimum Infiltration Rate (in/hr)**	**Soil Texture**
A	0.30 - 0.45	Sand, Loamy Sand or Sandy Loam
B	0.15 - 0.30	Silt Loam or Loam
C	0.05 - 0.15	Sandy Clay Loam
D	0 - 0.05	Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay or Clay

4.2.3 Antecedent Moisture Condition (AMC)

The antecedent moisture condition (AMC) is the index of the soil condition with respect to runoff potential before the storm. NEH-4 (SCS, 1984) showed an appropriate Antecedent Moisture Condition (AMC) level based on a 5-day antecedent rainfall for dormant and growing seasons. The average curve numbers are the median values used to represent the average response of a site for given soil, cover and surface conditions. Hence, the observed variability of rainfall-runoff response was represented by the AMC parameter (Ponce and Hawkins, 1996). The curve numbers were developed by SCS for AMC I (dry conditions), AMC II (average conditions) and AMC III (wet conditions). For applications of the SCS-CN method to ungauged watersheds, NEH-4 related the above three antecedent moisture conditions with the amount of antecedent 5-day rainfall and the crop season and are defined as follows:

AMC I: Dormant season antecedent soil moisture less than 12 mm, Growing season antecedent soil moisture less than 36 mm.

AMC II: Dormant season antecedent soil moisture between 12 and 28 mm, growing season antecedent soil moisture between 36 and 53 mm.

AMC III: Dormant season antecedent soil moisture greater than 28 mm, growing season antecedent soil moisture greater than 53 mm.

The values of Curve Number for common land use class and hydrological soil groups have been provided in Table 4.2.

4.2.4 Computation of Average Curve Number

The area weighted average curve number of a watershed may be calculated by knowing the land use and hydrologic soil group of the region. To calculate the area weighted average curve number for a watershed, following steps were adopted:

i. Preparation/Import of landuse and soil map and stored in raster format in ILWIS GIS
ii. Superimposition of land use map and the soil map in ILWIS GIS platform to get polygons with unique land use class and hydrologic soil group.
iii. Attribute the superimposed map with appropriate CN value for AMC II, i.e. CN values were assigned to each polygons
iv. The geographical area and respective CN value were multiplied w.r.t. each polygon
v. Step (iii) and (iv) were repeated by taking CN values for AMC I and III conditions
vi. Finally, sum of the product of polygon area and respective CN values is divided by the total catchment area to get area weighted average CN value of the watershed for AMC-I, II & III.

Table 4.2 Curve Number for different landuses and hydrologic soil groups

Land use class	Hydrologic Condition	Hydrologic Soil Group			
		A	B	C	D
Woods And Forest	Poor	45	65	76	82
	Fair	36	60	73	79
	Good	30	55	70	77
Scrub with Cultivation		45	66	77	83
Pasture,grassland,or range-continuous forage for grazing	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Agricultural Land (row crops)	Poor	72	81	88	91
	Good	67	78	85	89
Agricultural Land (Fallow)	Poor	76	85	90	93
	Good	74	83	88	90
Built Up area (Residential/Commercial/ Industrial)	High Density (Urban)	77	85	90	92
	Med. Density	57	72	81	86
	Low Density (Rural)	46	66	78	83
Impervious	> 95 %	98	98	98	98
Water bodies (River/Stream Lakes/ponds)		100	100	100	100

*Source: from detail table of SCS (1986) or NRCS

4.3 Integrated Land and Water Information System (ILWIS) GIS

A geographic information system (GIS) is a computer software for collecting, storing, retrieving, analyzing, and displaying of spatial data. The increasing volume of available environmental information with all its complexity and subsequent demand for its storage, analysis and display, have lead to the rapid development in the application of computer to environment and natural resources data handling. Effective utilization of large volumes of spatial data depends on the existence of efficient data handling and processing system such as GIS, which is capable of transforming these data into usable information. The data to be entered in a GIS are of two types; spatial and associated non-spatial attribute data. The spatial data represent the geographic location of features, which are input using points, lines, and areas. Non-spatial (attributes) data supplies respective values or descriptions associated with the spatial data. Spatial data can be of vector or raster formats. In the vector representation, the objects in the real world are denoted by points and lines, whereas raster models consist of regular grids of square or rectangular cells. Besides the other applications of GIS, it can be used in Hydrology for:

- Land use planning and management
- Natural resources mapping and management
- Land information system
- Urban and regional planning
- Management of well log data

The GIS software used in the study is ILWIS (Integrated Land and Water Information System) 3.0, developed at International Institute of Aerospace Survey and Earth Sciences (ITC), Enschede, Netherland. ILWIS provides user with state of art of data gathering, data input, data storage, data manipulation and analysis, and data output capabilities. ILWIS is a Window based, integrated GIS and Remote Sensing application consisting of:

- Display of raster and multiple vector maps in map window
- Display of tables in tables window
- Interactive retrieval of attribute information
- Image processing facilities
- Manipulation of maps in map window

ILWIS functionality for vectors includes; digitizing with mouse/digitizer, interpolation from isolines or points, calculation of segment or point density, pattern analysis. ILWIS functionality for raster includes: distance calculation, creation of Digital Elevation Model (DEM), calculation of slope/aspect, deriving attribute maps, classifying maps, manipulating maps with iff-statements, with Boolean logic, crossing maps, etc.

For satellite imagery: creation of histograms, colour composites, sampling and classification, filtering, multi-band statistics. Furthermore, it provides import and export routines, editing of point, segment, polygon, and raster maps, change of projection/coordinate systems of maps, and output possibilities with annotation. Analog data can be transferred into vector format by means of digitizing program. Complex modeling of features can be executed by map calculation. It includes an easy to use modeling language and the possibility of using mathematical functions and macros. It integrates tabular and spatial database. Tabular and spatial databases can be used independently and on an integrated basis. Calculation, queries, and simple statistical analyses can be performed by table calculator. The process of database creation for an area in ILWIS involved collection of relevant data, including converting these data into digital format, digitization, error checking and correction, polygonization of segment files and finally conversion of data acquired in vector structure to raster format or from raster to vector format.

4.4 Data Used

The requirements of data for water balance analysis of Bina river watershed are rainfall, runoff, temperature, sunshine hour, soils and land use & land cover. These data were collected from various departments/organizations in both spatial and non-spatial format. These data were stored in ILWIS 3.0 GIS and further analyzed. A brief description of various data collected from different sources and its analysis is given in the following paragraphs.

4.4.1 Meteorological Data

Most of the area of Bina river watershed falls in Sagar district, therefore the climatic parameters of observatory at Sagar have been used. The average values of meteorological data such as temperature and sunshine hours, for the period from 1st January 1972 to 31st December 2008 of Sagar observatory was collected from the India Meteorological Department (IMD), Pune.

4.4.2 Rainfall Data

The daily rainfall data of four rain gauge stations Begamganj, Gairatganj, Rahatgarh and Silvani falling in and around Bina river watershed up to Rahatgarh G/D site are collected from State Water Data Centre, Water Resources Department, Government of Madhya Pradesh, Bhopal and Superintendent of Land Record, district- Sagar (M.P.). The daily rainfall data of the above mentioned rain gauge stations for the period of 1st January 2006 to 31st December 2008 were collected and used for the analysis. The location of raingauge stations and Thiessen polygon map has already been shown in Fig. 3.4.

4.4.3 Discharge Data

The Water Resources Department of Madhya Pradesh envisaged to construct a dam across the river Bina near Rahatgarh town in Sagar district as a part of the Bina Complex Project as discussed earlier. For the purpose, daily gauge and discharge observations were started in the year 2005 at Rahatgarh. The daily gauge and discharge for the period from 1st January 2006 to 31st December 2008 of Rahatgarh gauge-discharge (G/D) site on Bina river was collected from State Water Data Centre, Water Resources Department, Government of Madhya Pradesh.

4.4.4 Soil Map

The moisture holding capacity of soil depends on the soil texture. The soil maps of Madhya Pradesh published by the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Indian Council of Agricultural Research (ICAR), Government of India, Nagpur pertaining to the study area was digitized and stored in raster format map 'soil'. The soil class map was created based on the information on soils classification and organic matter contents described in the report on 'Soils of Madhya Pradesh for Optimizing Land Use' and 'Soil Series of India' published by NBSS & LUP, Nagpur.

4.5 Data Processing

4.5.1 Computation of Average Rainfall

The Thiessen polygon map has been created by performing few steps in ILWIS. For the purpose, the point map containing the locations of raingauge stations is required as input to the said module and by applying the minimum distance filter, we get the Thiessen polygon map of the desired rectangle enveloping the study area. Finally the study area is masked out from the rectangular map. The average rainfall of the study area is calculated using Thiessen Polygon Method, which takes into account the weights of the respective rain gauge station on the basis of the area represented by each station. The average rainfall of the study area is calculated using equation given below:

$$P = \frac{\sum_{i=1}^{i=n} (AP)_i}{A} \tag{4.15}$$

Where,

$(AP)_i$ = Product of area of each station with its respective precipitation in the order 1 to n

P = Mean rainfall of the study area

A = Total area of the study area

4.5.2 Preparation of Land Use/Land Cover Map

The Indian Remote Sensing Satellite Resourcesat-1, LISS-III sensor and Path 98-Row 56 covering the entire catchment area has been used for preparation of first level Landuse map. The digital image processing of LISS-III data of the year 2009-10 was carried out to prepare the land use map of the Bina watershed. Maximum Likelihood Classification (MLC) was adopted. The forest cover may be clearly delineated from the imageries of the month of August and September whereas, the February and March month's imageries give the spread of agricultural lands in the catchment area. Total nine categories of landuse class could be identified in the Bina river sub-basin based on the ground truth survey and digital classification. The land use classes include two types of agriculture, current fallow, scrubs/bushes, barren/grazing lands, dense forest, open forest, settlements and water bodies. Following steps were adopted to prepare the landuse/land cover map.

To Create a Map list:

A map list is a container object which stores the names of a set of raster maps, for example of the multi-spectral bands of a satellite image that are to be classified. A map list may also store the names of several raster maps of a time series which can be displayed as a slide show. All raster maps in a map list must have the same domain and georeference.

- To create a map list, open the File menu in the Main window and select the Create Map List command. We can also expand the Create item in the Operation-tree and double-click the New Map List command, or double-click the New Map List item in the Operation-list. Furthermore, we can also create a map list when we start an operation which requires a map list as input, and click the create button in the operation's dialog box.
- In the appearing Create Map List dialog box, enter a name and description for the map list, and select the raster maps which are to be add to the map list. Remember that all raster maps in a map list should use the same domain and the same georeference.

Operations on map list:

Usually, a map list is created during sampling to obtain a sample set with which a supervised classification can be performed in a later stage.

Sampling-

Sampling creates a sample set which is needed for a multi-spectral image classification. Sampling is the assignment of class names to groups of pixels which have similar spectral values and that are supposed to represent the classes that we want to obtain from the classification. The sampled pixels or training pixels are thus supposed to be characteristic for a certain type of a natural resource. For instance, to perform a land use classification, we might sample the classes: forest, grass land, etc.

Requirements-

For sampling an image is needed which can be easily interpreted (e.g. a color composite), a map list, that is the set of images which we want to classify in a later stage, and a class domain containing the set of class names that we want to assign to training pixels. All maps must have the same georeference.

Sample set-

A sample set stores training pixels for supervised classification. Prior to an image classification, sample pixels or training pixels have to be selected in a sample set. A map list, containing the set of images used for classification and a background map on which we can locate training pixels and a class domain have to be specified. Then, during sampling, class names need to be assigned to groups of pixels that are supposed to represent a known feature on the ground and that have similar spectral values in the maps in the map list. A sample set consists of:

- A reference to a map list, which is the set of images we want to classify in a later stage. The spectral values of the images in the map list, at the position of the training pixels provide the basis on which decisions are made in the classification. During sampling, these values can be inspected in the sample statistics of a certain class of training pixels, and can be visualized in feature spaces. Usually, we use a set of satellite images in the map list.
- A reference to a class domain, which is the collection of class names that we want to assign to the training pixels and that are the classes that we want to obtain from the classification. The representation of this domain determines in which colors the training pixels are displayed during sampling. We can also add classes to the domain during sampling, or delete classes;
- A reference to a raster map which is automatically created and obtains the same name as the sample set. This so-called sample map contains the locations of the training pixels and the class names assigned to them.

A sample set is used as input in the Classify operation. The Maximum Likelihood Classifier (MLC) has been used to create the landuse/land cover map of Bina river watershed.

4.5.3 Cross Map of Landuse / Land Cover and Soil Map

The Cross operation performs a task of overlaying of two raster maps. Pixels on the same positions in both maps are compared; the occurring combinations of class names, identifiers or values of pixels in the first input map and those of pixels in the second input map are stored. These combinations give an output cross map and a cross table. The cross table includes the combinations of input values, classes or IDs, the number of pixels that occur for each combination and the area for each combination.

4.5.4 Computation of Average CN Values

The map showing landuse and soil group has been further attributed with a table containing the corresponding CN values and stored as CN-value map in raster format, which is a value map in raster format showing the curve numbers of each pixel.

The statistics of CN values generated from the raster map was transferred in MS-Excel worksheet to compute the area weighted average CN values for Antecedent Moisture Condition-II (AMC-II). The CN values for AMC-I and AMC-III were then computed by knowing the CN values for AMC-II. The area weighted average curve number $\overline{(CN)}$ is calculated by dividing the sum of the product of CN value and area of the corresponding polygons with total area of the watershed:

$$\overline{CN} = \frac{\sum_{i=1}^{n}\left(CN_i * A_i\right)}{A} \qquad (4.16)$$

where, CNi is the curve number for the identical polygons having geographical area Ai. The average curve number is calculated for all the three AMC conditions.

Hjelmfelt (1991) developed a relationship between the CN values for AMC class-II with AMC class-I and class-III and suggested the following equations:

$$\mathrm{CN_I} = \frac{4.2\mathrm{CN_{II}}}{(10 - 0.058\mathrm{CN_{II}})} \qquad (4.17\ a)$$

$$\mathrm{CN_{III}} = \frac{23\mathrm{CN_{II}}}{(10 + 0.13\mathrm{CN_{II}})} \qquad (4.17\ b)$$

5.0 RESULTS AND DISCUSSION

The study has been conducted in the Bina river watershed up to Rahatgarh G/D site, where a dam is proposed. The study area is located in Sagar and Raisen districts of Madhya Pradesh. An attempt has been made to create a digital database, mainly of soil and landuse/ land cover to estimate the water balance of the Bina watershed. GIS acts as a useful media to provide a spatial dimension. At the same time, it integrates maps from various sources encompassing various vistas. Spatial assessment of water balance analysis requires an integration of soil data and land use/ land cover data in GIS environment to generate output for water resource planning projects. Various outputs were generated in both tabular and map forms. The following section deals with the major results and outcomes of the study for the year 2006-2008.

An attempt has been made to create a digital database, mainly of watershed area, soils and land use/land cover to assess the water balance of the Bina basin using toposheet and satellite remote sensing data in GIS environment to generate output in tabular form for water balance computations. The inputs to the SCS-CN model are Curve Number and rainfall. The curve number is function of the soil-cover complex and antecedent moisture condition (AMC). Thornthwaite and Mather equation for computation of available water capacity (AWC) also require landuse class and textural soil class as input in terms of rooting depth and moisture holding capacity respectively.

5.1 Rainfall

The study area is covered by four rain gauge stations, namely Rahatgarh, Begamganj, Gairatganj and Silvani. The State government agency has ordinary rain gauges installed in these locations and the rainfall for last 24 hours (daily rainfall) is collected and measured at 08.00 AM every day. In absence of automatic weather station or self recording raingauge, the quality of data collected may not be upto the mark. But for the purpose of daily/monthly analysis through hydrological modelling, the observed daily rainfall data may be used. The four raingauge stations were marked on the basin map and digitized as point map. Using the Point Interpolation operation and choosing the Nearest Point option in ILWIS 3.0, the Thiessen Polygon map was created from the point map in raster format. The Thiessen Polygon map of Bina watershed up to Rahatgarh G/D is shown in Fig 5.1. The weights of each influencing stations in the study area were estimated and are given in Table 5.1. The average daily rainfall over the watershed is calculated by Thiessen Polygon method for the year 2006-2008 and used in SCS-CN model. The daily values are summed up to get the monthly rainfall for calculations in Thornthwate & Mather model, which is shown in Table 5.2, Table 5.3 and Table 5.4. The rainfall is concentrated mostly in the months of June to October.

Table 5.1: RG Stations Thiessen weights in Bina watershed

S. No.	Station Name	Area (Sq.Km.)	Thiessen Weight
1	Begamganj	503.08	0.44
2	Gairatganj	406.44	0.36
3	Rahatgarh	93.85	0.08
4	Silvani	135.66	0.12
	Total	1139.03	1.00

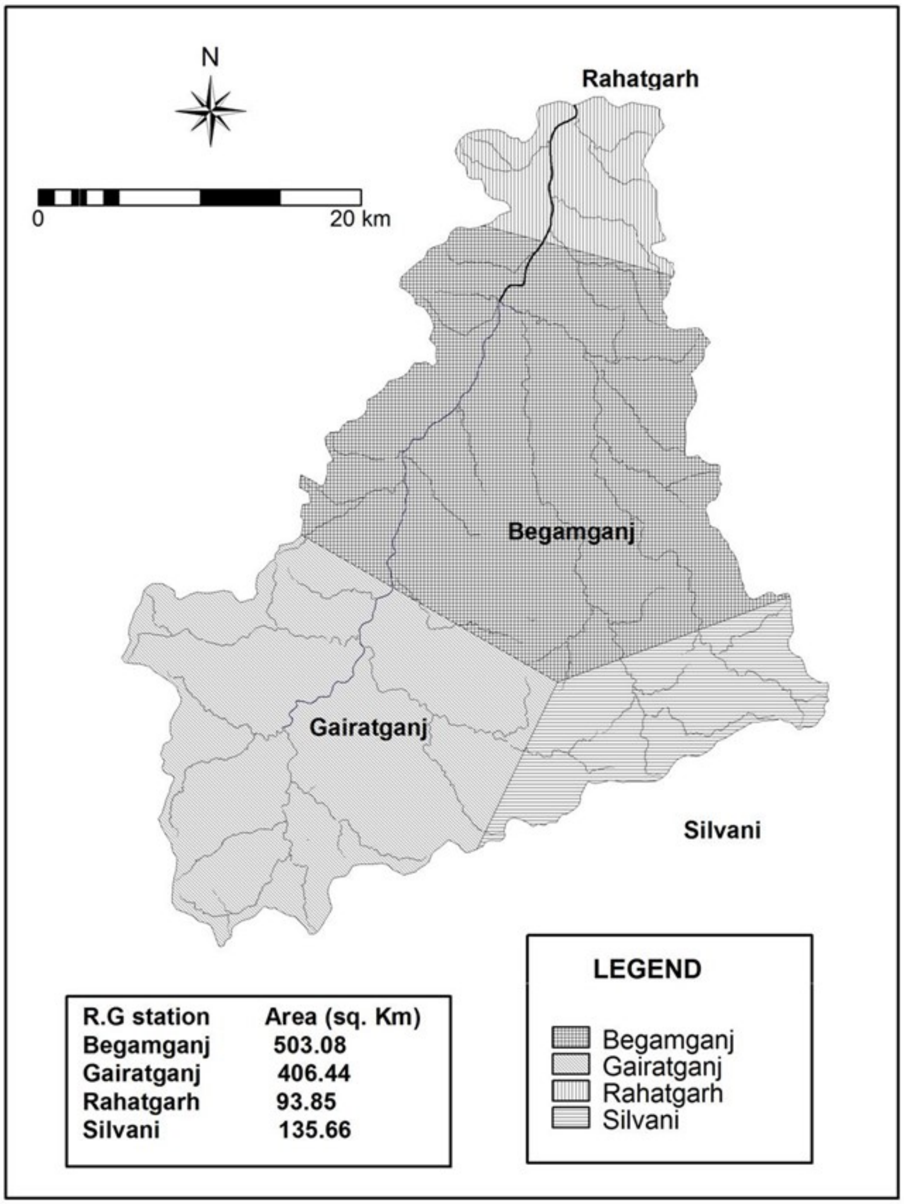

Fig. 5.1: Location of rain gauge stations and Thiessen Polygons in Bina Watershed

Table 5.2: Monthly Rainfall in Bina Watershed (2006)

Month	Station name (Thiessen wt.)				Avg. Rainfall (mm)
	Begamganj	Gairatganj	Silvani	Rahatgarh	
Year (2006)	(0.44)	(0.36)	(0.12)	(0.08)	
Jun	11.84	0.36	10.12	49.08	10.14
Jul	225.80	297.00	271.20	421.40	272.53
Aug	428.30	438.00	394.80	494.60	433.08
Sept	218.80	284.60	199.80	208.40	239.38
Oct	0.00	8.00	0.00	0.00	2.88
Total	**885.18**	**1028.32**	**876.04**	**1173.56**	**958.01**

Table 5.3: Monthly Rainfall in Bina Watershed (2007)

Month	Station name (Thiessen wt.)				Avg. Rainfall (mm)
	Begamganj	Gairatganj	Silvani	Rahatgarh	
Year (2007)	(0.44)	(0.36)	(0.12)	(0.08)	
Jun	92.74	110.36	120.72	76.68	100.81
Jul	358.80	408.00	389.50	339.30	378.64
Aug	165.60	246.30	219.20	171.30	201.54
Sept	159.60	173.60	251.20	140.00	174.06
Oct	0.00	0.00	0.00	0.00	0.00
Total	**777.18**	**938.62**	**980.74**	**727.36**	**855.05**

Table 5.4: Monthly Rainfall in Bina Watershed (2008)

Month	Station name (Thiessen wt.)				Avg. Rainfall (mm)
	Begamganj	Gairatganj	Silvani	Rahatgarh	
Year (2008)	(0.44)	(0.36)	(0.12)	(0.08)	
Jun	0.44	0.36	0.12	0.08	0.00
Jul	298.00	363.20	232.80	0.00	308.43
Aug	211.90	147.40	344.40	0.00	215.18
Sept	111.10	159.20	193.00	0.00	144.80
Oct	4.20	28.00	36.80	0.00	19.29
Total	**626.08**	**698.52**	**807.24**	**0.16**	**687.70**

5.2 Soil

Total four categories of soil based on infiltration rate and textural class were found in the Bina river watershed, namely clayey loam, fine clay, fine loam, and loamy clay. The soil map obtained from NBSSLU&P, Nagpur in hardcopy was first digitized and converted into raster format.

The map showing the soil class is given at Fig. 5.2 and its spatial distribution is given in the Table 5.5 below:

Table 5.5: Different soil types present in Bina watershed

S. No.	Soil type	Area covered (sq. km)
1	Clayey loam	56.40
2	Fine clay	883.85
3	Fine loam	102.05
4	Loamy clay	96.73
	Total	**1139.03**

5.3 Land Use

The land use map of the Bina watershed was prepared by adopting the Maximum Likelihood Classifier, Digital Image Processing technique of the satellite imageries as described in previous chapter. Nine land use classes could be identified in the Bina watershed on the basis of sample set assigned to different objects (landuse classes) in the imagery. The land use classes include dense forest, open forest, agriculture-1 (wheat), agriculture-2 (mustard/gram), current fallow land, barren land, settlements, water body and land with shrubs. The land use map thus classified from satellite imagery was stored in GIS platform in raster format. The spatial distribution of landuse/land cover of Bina watershed is shown in the Fig. 5.3 and statistical distribution is given in Table 5.6.

Table 5.6: Different land use patterns in Bina watershed

S. No.	Land use	Area (sq.km.)
1	Agricultural-1 (wheat)	26.02
2	Agricultural-2 (mustard/gram)	159.52
3	Dense forest	35.60
4	Open forest	297.55
5	Current fallow	212.02
6	Barren land	55.42
7	Settlement	33.85
8	Water body	2.03
9	Shrub land	317.02
	Total	**1139.03**

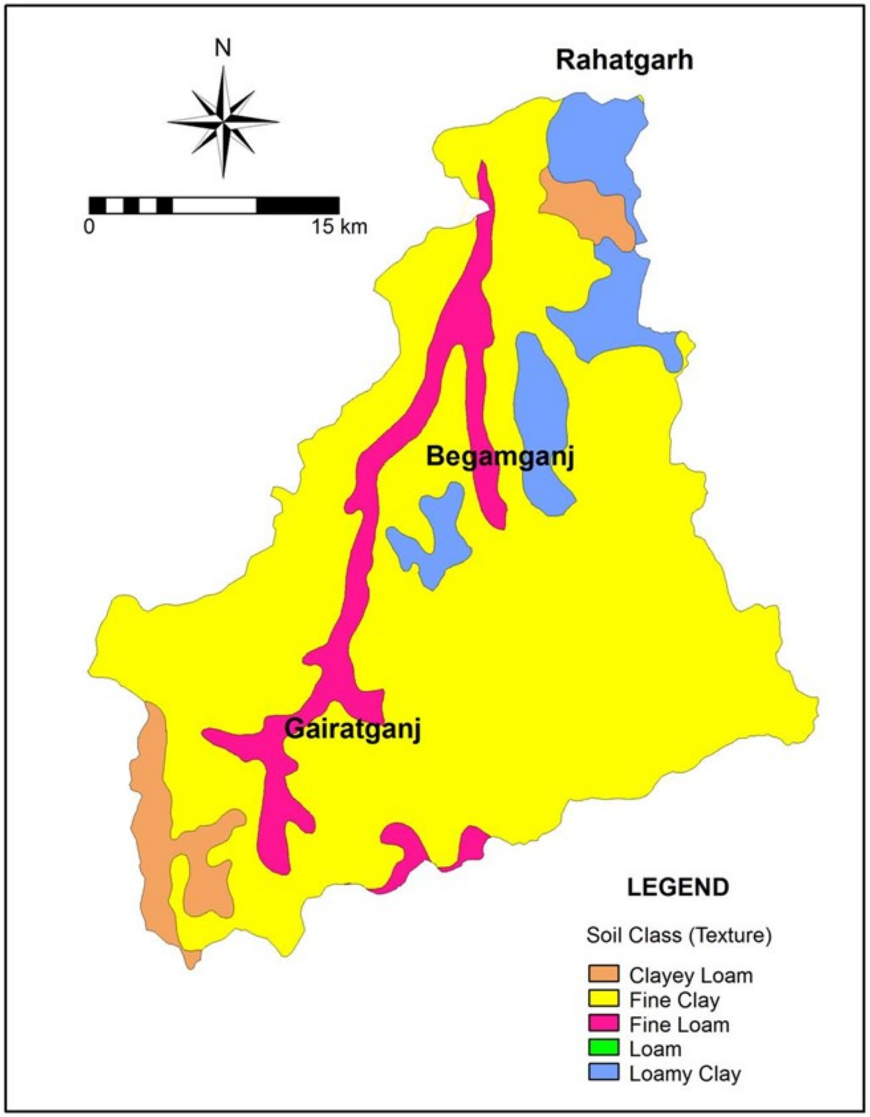

Figure 5.2: Soil Map of Bina River Watershed

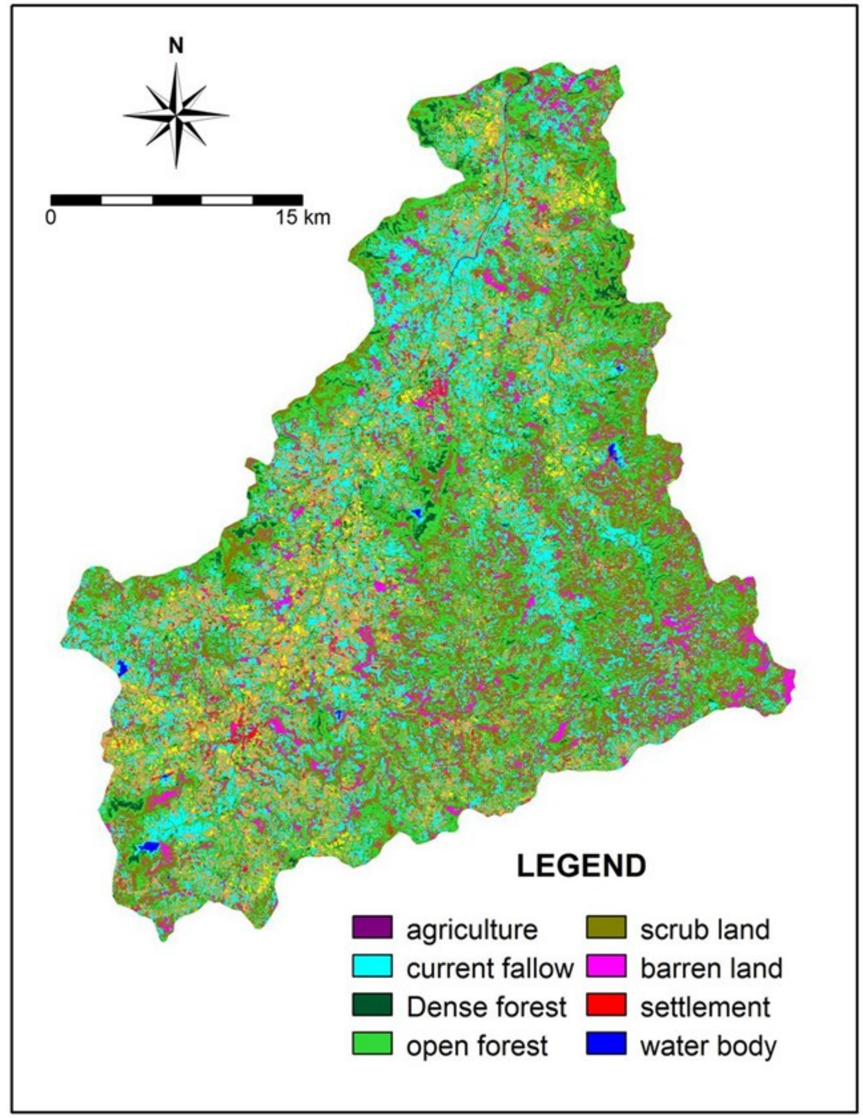

Figure 5.3: Landuse Map of Bina River Watershed

5.4 The SCS-CN Model

5.4.1 Average Curve Number of Bina Watershed

The Curve Number (CN) is an important component in the SCS Method. The weighted average curve number for the Bina watersheds has been computed in GIS platform knowing the landuse and the soil class. For the purpose, the landuse map was imposed on the soil map using ILWIS GIS software to obtain the polygons with identical landuse class and hydrological soil group to assign appropriate curve numbers and to compute area weighted average curve number for each watershed. The curve number represents the soil-cover complex of the watershed and it varies with change in landuse of the watershed. In the present study, the average curve number has been assumed constant though out the entire year, however season-wise average curve numbers may also be computed. The average Curve Numbers for Bina river watershed are given in Table 5.7. The spatial distribution of landuse and soil class in the study area and detailed computations of basin-wise area weighted average CN values for AMC-I, AMC-II and AMC-III are given in tabular form in Annexure-I.

Table 5.7: Area Weighted Average Curve Numbers for Bina Watershed

Sl. No.	Particular	Initial Moisture Condition		
		AMC-I	AMC-II	AMC-III
1.	Average Curve Number (CN)	69.44	83.46	93.99
2.	Potential maximum retention (S)	111.8	50.3	16.2
3.	Initial abstraction (I_a = 0.2 S)	22.36	10.07	3.25

5.4.2 Computation of Surface Runoff by SCS-CN Model

The direct surface runoff have been computed by using SCS-CN method at the outlet of the Bina river watershed at Rahatgarh. The daily average rainfall and appropriate CN values according to the antecedent moisture condition of the watershed based on the 5-days rainfall were used in the model. The MS Excel spread sheet was used for computation of the direct surface runoff. The daily rainfall, AMC and direct surface runoff computed for Bina watershed for the months of June to October for three years, i.e. 2006, 2007 and 2008 have been given at Annexure-II, Annexure-III and Annexure-IV respectively. The month-wise daily values of surface runoff have been accumulated to get the monthly runoff values for comparison with the runoff computed by using Thornthwate & Mather method and also with the observed monthly runoff. The runoff computed by SCS-CN model does not include the base flow component, therefore a lumped volume, 20% of the direct surface runoff was added as base flow in the next month's surface runoff. The monthly runoff values computed by SCS-CN model for the year 2006, 2007 and 2008 are given at Table 5.8.

Table 5.8: Computation of Direct Runoff by SCS-CN Model

Year	Month	June	July	Aug	Sept	Oct	Total
2006	Rainfall (mm)	10.14	272.53	433.08	239.38	2.88	958.01
	Runoff (MCM)	0.00	111.55	303.01	224.09	33.59	672.25
2007	Rainfall (mm)	100.81	378.64	201.54	174.06	0.00	855.05
	Runoff (MCM)	44.55	244.40	125.23	61.41	9.15	484.39
2008	Rainfall (mm)	0.00	308.43	215.18	144.80	19.29	687.70
	Runoff (MCM)	0.00	176.99	139.97	58.13	7.44	382.52

5.5 Thornthwaite and Mather Model of Water Balance

The water balance is an inventory of the water entering and exiting through a hydrologic system. The purpose of water balance for Bina river watershed is to characterize water quantities associated with climate, surface water, soil moisture and net consumptive demand. Precipitation is the main input to the watershed, and evapotranspiration and surface runoff are the outflow from the system. The overall water balance is presented on a monthly basis.

5.5.1 Potential Evapotranspiration (PET)

Land-based evapotranspiration for the Bina watershed, the amount of water returned to the atmosphere from plants and soils through evaporation and vegetation transpiration for various land uses, was calculated using the Thornthawaite's equation. Monthly average values of the temperature, length of day etc. required in the equation 4.1 have been taken from the IMD, Pune. Table 5.9 shows the computation of PET.

5.5.2 Accumulated Potential Water Loss (APWL)

The accumulated values of (P – PET), i.e., the accumulated potential water loss (APWL) for each month, are calculated. This will be zero for months having positive (P – PET) and starting with the first month having a negative value after the monsoon. Calculations of APWL for the year 2006, 2007 and 2008 have been shown in Table 5.10.

Table 5.9: Calculation of Evapotranspiration using the Thornthawaite's Equation

Month	Min. Temp (°C)	Max. Temp (°C)	Avg. Temp (°C)	i (monthly heat index)	a	m (no.of days in month)	d (sun-shine hour)	C (correction factor)	T/I	PET (mm)
Jan	12.1	26.1	19.1	7.61	3.46	31	9.1	0.78	0.13	33.96
Feb	13.7	27.7	20.7	8.59	3.46	28	11.5	0.89	0.14	51.20
Mar	18.4	33.2	25.8	11.99	3.46	31	9	0.78	0.18	95.05
Apr	22.8	37.6	30.2	15.22	3.46	30	10	0.83	0.21	176.24
May	25.8	41.1	33.45	17.77	3.46	31	12.4	1.07	0.23	321.63
Jun	25.0	37.2	31.1	15.91	3.46	30	8.7	0.73	0.22	169.73
Jul	23.1	30.7	26.9	12.78	3.46	31	5.9	0.51	0.19	72.00
Aug	22.5	28.6	25.55	11.82	3.46	31	5.3	0.46	0.18	54.12
Sept	21.8	29.7	25.75	11.96	3.46	30	8	0.67	0.18	81.22
Oct	20.0	32.3	26.15	12.24	3.46	31	8.5	0.73	0.18	94.05
Nov	15.8	28.9	22.35	9.65	3.46	30	8.3	0.69	0.16	51.62
Dec	12.4	26.0	19.2	7.67	3.46	31	7.5	0.65	0.13	28.50
Total				**143.21**						**1229.31**

Table 5.10: Calculation of accumulated potential water loss (APWL) for all the landuse/land cover classes

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	Year 2006												
P	0.00	0.00	0.00	0.00	0.00	10.14	272.53	433.08	239.38	2.88	0.00	0.00	958.01
PET	33.96	51.20	95.05	176.24	321.63	169.73	72.00	54.12	81.22	94.05	51.62	28.50	1229.31
P-PET	-33.96	-51.20	-95.05	-176.24	-321.63	-159.59	200.53	378.96	158.16	-91.17	-51.62	-28.50	-271.30
APWL	-205.2	-256.4	-351.5	-527.7	-849.3	-1008.9	0.00	0.00	0.00	-91.17	-142.8	-171.3	-3604.5
	Year 2007												
P	0.00	1.12	0.00	0.00	0.00	100.81	378.64	201.54	174.06	0.00	0.00	0.00	856.17
PET	33.96	51.20	95.05	176.24	321.63	169.73	72.00	54.12	81.22	94.05	51.62	28.50	1229.31
P-PET	-33.96	-50.08	-95.05	-176.24	-321.63	-68.92	306.64	147.42	92.85	-94.05	-51.62	-28.50	-373.14
APWL	-208.1	-258.2	-353.3	-529.5	-851.1	-920.1	0.00	0.00	0.00	-94.1	-145.7	-174.2	-3534.2
	Year 2008												
P	0.00	0.00	0.00	0.00	0.00	0.00	308.43	215.18	144.80	19.29	0.00	0.00	687.70
PET	33.96	51.20	95.05	176.24	321.63	169.73	72.00	54.12	81.22	94.05	51.62	28.50	1229.31
P-PET	-33.96	-51.20	-95.05	-176.24	-321.63	-169.73	236.44	161.06	63.58	-74.77	-51.62	-28.50	-541.61
APWL	-188.8	-240.0	-335.1	-511.3	-832.9	-1002.7	0.00	0.00	0.00	-74.77	-126.4	-154.9	-3467.0

5.5.3 Available Water Capacity (AWC)

AWC is the moisture storage capacity of the soil. This has been calculated based upon the land use, soil texture and rooting depth as suggested by Thornthwaite & Mather (1955, 1957).

For estimating the soil-water budget, an estimate of the ability of soil to store water is required. The field capacity is defined as the water content of the soil that has reached equilibrium under gravity after many days of drainage. The field capacity is found to be a function of soil texture and organic content. The permanent wilting point is defined as the water content at which plants can no longer extract a health sustaining quantity of water from the soil and begin to wilt. The water available for evapotranspiration after drainage (or the available water-holding capacity) is defined as the difference between the field capacity and the permanent wilting point. For water balance calculations, the total available water-holding capacity in a soil profile should be known. This value is typically expressed in mm and can be obtained by integrating the available water-holding capacity over the effective depth of the soil layer (www.decagon.com, www.sjrcd.org). A large water-holding capacity implies a small annual runoff and a large annual evapotranspiration relative to a small water-holding capacity under the same climatic conditions. Table 5.11 shows the computation of water holding capacity of the root zone and available water capacities (AWC) for different soil textures and land uses. The available moisture content in root zones varies from 300 mm to 38 mm depending on the land use and soil type.

Table 5.11: Computation of water holding capacity of the root zone

Landuse * soil class	Area	FC	PWP	AWC (% vol.)	Rooting depth(m)	AWC of root zone (mm)
Dense forest * Fine Loam	2088576	31	11	20	1.5	300
Dense forest * Clayey Loam	2375424	36	22	14	1.5	210
Dense forest * Loamy Clay	6716160	27	17	10	1.5	150
Dense forest * Fine Clay	23833728	42	30	12	1.5	180
open forest * Fine Loam	23261184	31	11	20	1	200
open forest * Clayey Loam	14207040	36	22	14	1	140
open forest * Loamy Clay	33409152	27	17	10	1	100
open forest * Fine Clay	224805312	42	30	12	1	120
agriculture1 * Fine Loam	3571776	31	11	20	0.62	124
agriculture1 * Clayey Loam	2909376	36	22	14	0.62	86.8
agriculture1 * Loamy Clay	961920	27	17	10	0.62	62
agriculture1 * Fine Clay	18578880	42	30	12	0.62	74.4

Continue…

Table 5.11: Computation of water holding capacity of the root zone (continue…)

Landuse * soil class	Area	FC	PWP	AWC (% vol.)	Rooting depth(m)	AWC of root zone (mm)
barren land * Fine Loam	3182976	31	11	20	1	200
barren land * Clayey Loam	1596672	36	22	14	1	140
barren land * Loamy Clay	5546880	27	17	10	1	100
barren land * Fine Clay	44902080	42	30	12	1	120
current fallow * Fine Loam	23743872	31	11	20	0.62	124
current fallow * Clayey Loam	9235008	36	22	14	0.62	86.8
current fallow * Loamy Clay	13716864	27	17	10	0.62	62
current fallow * Fine Clay	165116160	42	30	12	0.62	74.4
settlement * Fine Loam	4511232	31	11	20	0.5	100
settlement * Clayey Loam	1680768	36	22	14	0.5	70
settlement * Loamy Clay	2032704	27	17	10	0.5	50
settlement * Fine Clay	25542720	42	30	12	0.5	60
scrub land * Fine Loam	17996544	31	11	20	0.75	150
scrub land * Clayey Loam	13283136	36	22	14	0.75	105
scrub land * Loamy Clay	26985600	27	17	10	0.75	75
scrub land * Fine Clay	259098048	42	30	12	0.75	90
agriculture2 * Fine Loam	22524480	31	11	20	0.38	76
agriculture2 * Clayey Loam	10259136	36	22	14	0.38	53.2
agriculture2 * Loamy Clay	6178752	27	17	10	0.38	38
agriculture2 * Fine Clay	120407616	42	30	12	0.38	45.6

5.5.4 Monthly Water Balance Calculation

The monthly water balance for the Bina river watershed for the year 2006, 2007 and 2008 have been carried out as per the method suggested by Thornthwaite and Mather to compute the monthly AET, Deficit, Surplus and runoff. The detailed computations for water balance of Bina river basin have been shown in Annexure-V. The monthly values of rainfall, PET, AET and Runoff compiled for the study period, i.e. 2006, 2007 and 2008 are given in Table 5.12, Table 5.13 and Table 5.14; and shown in Fig. 5.4, Fig. 5.5 and Fig. 5.6. The runoffs have been computed only for those months in which surplus was observed i.e., July, August, September, except for an additional month October, assuming that some quantity of surplus water computed in September will be available for surface runoff in the month of October.

Table 5.12: Summary of Calculations by Thornthwaite & Mather Model

Month	P	PET	AET	Deficit	Surplus	Runoff
	Year 2006				Values in mm	
Jan	0.00	33.96	4.79	29.17	0.00	0.00
Feb	0.00	51.20	4.91	46.29	0.00	0.00
Mar	0.00	95.05	4.90	90.15	0.00	0.00
Apr	0.00	176.24	3.20	173.04	0.00	0.00
May	0.00	321.63	1.12	320.52	0.00	0.00
Jun	10.14	169.73	10.25	159.48	0.00	0.00
Jul	272.53	72.00	72.00	0.00	104.67	52.33
Aug	433.08	54.12	54.12	0.00	378.96	241.81
Sep	239.38	81.22	81.22	0.00	158.16	268.56
Oct	2.88	94.05	59.67	34.38	0.00	79.08
Nov	0.00	51.62	14.65	36.98	0.00	0.00
Dec	0.00	28.50	5.40	23.09	0.00	0.00
Total	958.01	1229.31	316.22	913.09	641.79	641.79

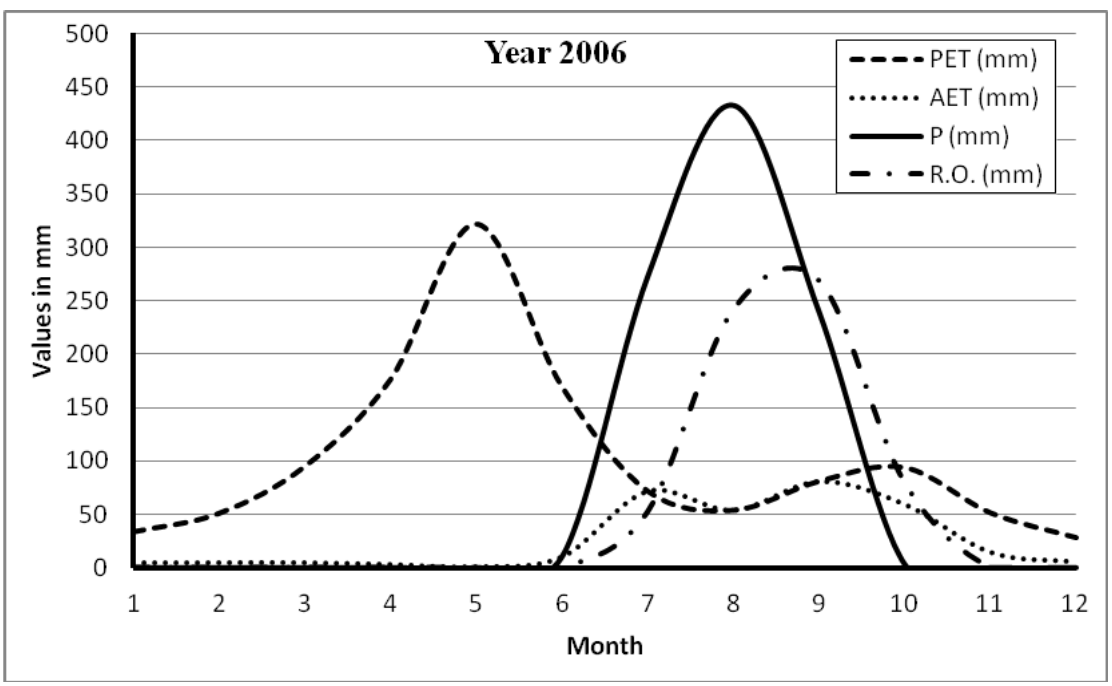

Figure 5.4: Graph showing monthly values of rainfall, PET, AET and Runoff

Table 5.13: Summary of Calculations by Thornthwaite & Mather Model

Month	P	PET	AET	Deficit	Surplus	Runoff
	Year 2007				Values in mm	
Jan	0.00	33.96	4.66	29.29	0.00	0.00
Feb	1.12	51.20	5.82	45.38	0.00	0.00
Mar	0.00	95.05	4.83	90.22	0.00	0.00
Apr	0.00	176.24	3.16	173.08	0.00	0.00
May	0.00	321.63	1.10	320.53	0.00	0.00
Jun	100.81	169.73	100.87	68.86	0.00	0.00
Jul	378.64	72.00	72.00	0.00	210.82	105.41
Aug	201.54	54.12	54.12	0.00	147.42	179.12
Sep	174.06	81.22	81.22	0.00	92.85	120.13
Oct	0.00	94.05	57.83	36.23	0.00	46.42
Nov	0.00	51.62	14.23	37.39	0.00	0.00
Dec	0.00	28.50	5.25	23.24	0.00	0.00
Total	856.17	1229.31	405.08	824.23	451.09	451.09

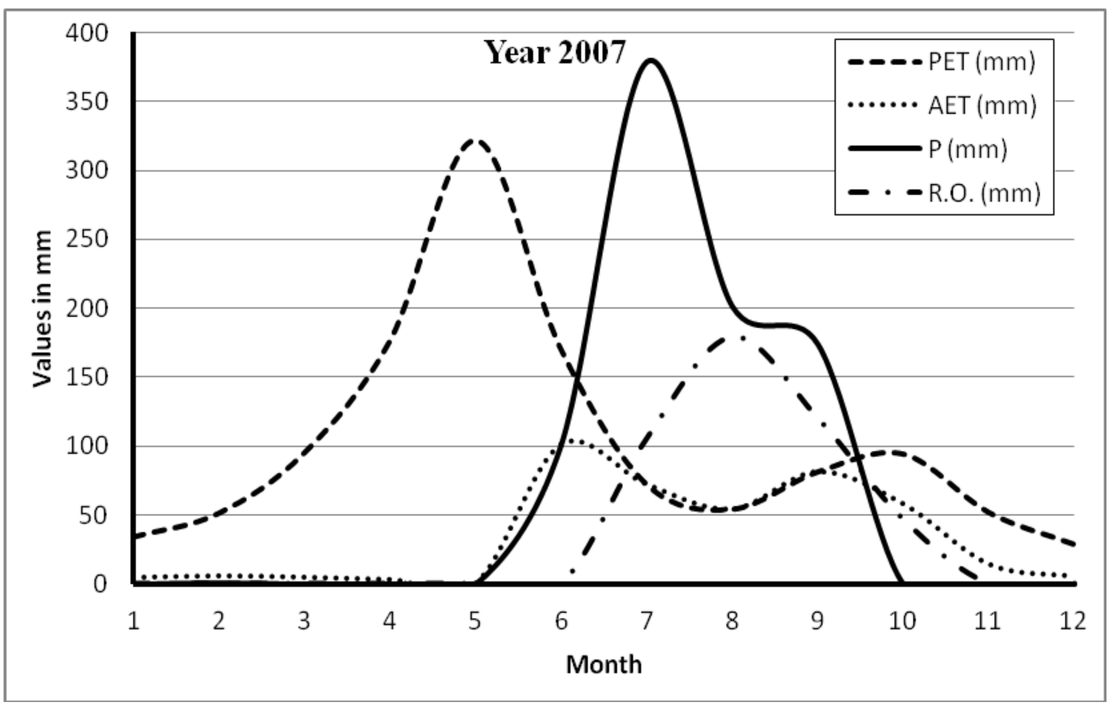

Figure 5.5: Graph showing monthly values of rainfall, PET, AET and Runoff

Table 5.14: **Summary of Calculations by Thornthwaite & Mather Model**

Month	P	PET	AET	Deficit	Surplus	Runoff
	Year 2008				Values in mm	
Jan	0.00	33.96	5.59	28.36	0.00	0.00
Feb	0.00	51.20	5.70	45.50	0.00	0.00
Mar	0.00	95.05	5.65	89.40	0.00	0.00
Apr	0.00	176.24	3.64	172.60	0.00	0.00
May	0.00	321.63	1.25	320.39	0.00	0.00
Jun	0.00	169.73	4.80	164.93	0.00	0.00
Jul	308.43	72.00	72.00	0.00	139.74	69.87
Aug	215.18	54.12	54.12	0.00	161.06	150.40
Sep	144.80	81.22	81.22	0.00	63.57	112.32
Oct	19.29	94.05	69.55	24.51	0.00	31.78
Nov	0.00	51.62	17.31	34.31	0.00	0.00
Dec	0.00	28.50	6.33	22.16	0.00	0.00
Total	687.70	1229.31	327.15	902.16	364.37	364.37

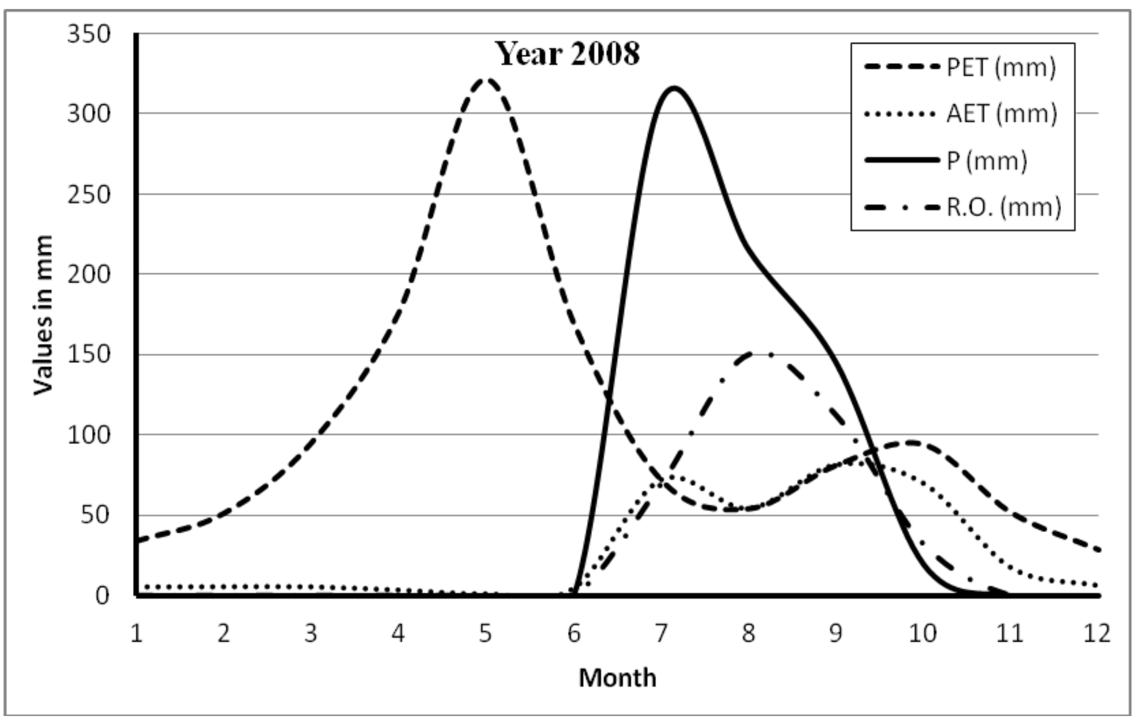

Figure 5.6: Graph showing monthly values of rainfall, PET, AET and Runoff

5.5.5 Comparison between Observed and Calculated Runoff

The comparison of observed flow with computed values of the monthly runoff by SCS-CN model and the Thornthwaite & Mather model are summarised in Table 5.15.

Table 5.15: Monthly Observed and Computed Runoff

Values in MCM

Year	Month	June	July	Aug	Sept	Oct	Total
2006	Observed	27.39	201.46	232.77	152.35	51.90	665.87
	Th.&Mather	0.00	159.36	274.28	204.62	89.70	727.96
	SCS-CN	0.00	111.55	303.01	224.09	33.59	672.25
2007	Observed	9.74	170.92	128.11	111.35	58.87	479.00
	Th.&Mather	0.00	119.56	203.17	136.26	52.66	511.65
	SCS-CN	44.55	244.40	125.23	61.41	9.15	484.39
2008	Observed	13.00	114.51	171.32	55.89	34.69	389.41
	Th.&Mather	0.00	79.25	170.59	127.40	36.06	413.30
	SCS-CN	0.00	176.99	139.97	58.13	7.44	382.52

5.6 Efficiency of Hydrologic Models

Gauging of many streams at desired location for desired length of time is always not possible, however assessment of hydrological behavior of the river basins are essential for designing of any water resource structure and planning of optimum use of the available water resources of the basin. Hydrologic modelling is an efficient tool to assess the inflow and outflow of water from a hydrologic unit, i.e. district or watershed or a river basin. The models can give best estimate of the hydrologic components, viz. evapotranspiration, runoff, groundwater recharge etc., but these are only the estimates and not the actual measurements. Therefore, examination of the model efficiency is necessary for correctness of hydrologic designing and management plan. It also helps in selection of the best model for estimation of hydrologic parameters of a river basin.

5.6.1 Nash–Sutcliffe Coefficient

The Nash–Sutcliffe model efficiency coefficient is used to assess the predictive power of hydrological models. The efficiency is calculated as:

$$E = 1 - \frac{\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{\text{model},i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs,i} - \overline{Q}_{obs}\right)^2} \tag{5.1}$$

Where, $Q_{obs,i}$ is observed values; $Q_{model,i}$ is modelled values at time, i and ($\overline{Q}_{obs}$) is the average observed discharge for whole time period. Nash-Sutcliffe efficiencies can range from - ∞ to 1. An efficiency of 1 (E = 1) corresponds to a perfect match between model and observations. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero (- ∞ < E < 0) occurs when the observed mean is a better predictor than the model. Essentially, the closer the model efficiency is to 1, the more accurate the model is.

5.6.2 Relative Volume Error

The relative volume error (RVE) criterion is defined as:

$$RVE = \left[\frac{\sum_{i=1}^{n}\left(Q_{\text{mod}el,i} - Q_{obs,i}\right)}{\sum_{i=1}^{n}\left(Q_{obs,i}\right)}\right] * 100\% \tag{5.2}$$

Where, Q_{model}: is the modelled flow, Q_{obs}: is the observed low at the time step, i and n: is the total number of model time steps of the calibration period. RVE ranges between ±∞ where with a zero value implies no difference between the simulated and observed discharge. The relative volume error within ±5 % indicates that model performed well while relative volume error between ±5 % to ±10% indicate that model perform reasonably for estimation of flow. However, at the same time the distribution of the discharge throughout the calibration period can be completely wrong. Therefore, this criterion should always be used in combination with another criterion that considers the overall shape agreement.

The modelled values of runoff have been compared with the observed runoff for Bina river basin upto Rahatgarh G&D site. The performance of the SCS-CN model and the Thornthwaite &Mather model applied for the Bina watershed is given in Table 5.16. It is clear from the efficiency that the Thornthwaite and Mather model is better than the SCS-CN model for monthly water balance study in Bina river basin. The rainfall and runoff data used in these models are the daily average values observed at 08.00 AM every day, i.e. the rainfall observed at 08.00 is the cumulative rainfall of the last

24 hours and the flow observed at 08.00 AM is assumed to be constant during the day. Therefore, inherent error in manual measurement of the observed rainfall and runoff data cannot be avoided, which is minimum in case of automatic weather stations due to hourly observations or even the interval of observations can be set to 15 min.

Table 5.16: Calculated Model Efficiency Coefficients for the year 2006-2008

Model	**Year**	**2006**	**2007**	**2008**
SCS-CN	Nash-Sutcliffe Coefficient (E)	0.67	0.60	0.77
	Relative Volume Error (RVE)	1.0 %	1.1 %	-1.8 %
Thornthwaite & Mather	Nash-Sutcliffe Coefficient (E)	0.86	0.69	0.74
	Relative Volume Error (RVE)	9.3 %	6.8 %	6.1 %

The efficiency test carried out for the SCS-CN model show that the Nash-Sutcliffe Coefficient (E) varies between 0.60 to 0.77 and the Relative Volume Error (RVE) ranges from 1.0 % to -1.8%; and the for Thornthwaite-Mather model, the Nash-Sutcliffe Coefficient (E) varies between 0.69 to 0.86 and the Relative Volume Error (RVE) ranges from 6.1 % to 9.3% for the years 2006-2008 for which surface runoff were computed.

6.0 CONCLUSIONS

Based on the observed rainfall, runoff and other hydrogeological data, the water balance of the Bina river watershed was modelled. The water balance components in a monthly time scale utilizing the spatial variability of the catchment characteristics were evaluated using the Thorthwaite and Mather water balance model. The agriculture crops grown in the watershed under consideration is mostly rainfed, therefore the irrigation water supply to the agricultural crops during the Rabi season has not been accounted for, as there is no canal system available for irrigation. The crop water requirements during the Rabi season is met through pumping wells/tube wells from shallow groundwater. Since no additional water inflow into the hydrologic system (watershed), the AET during the post monsoon season is very low and it is high during the monsoon months due to available moisture from the rainfall.

The most widely accepted SCS-CN rainfall-runoff model has also been applied to estimate the runoff volume in the Bina watershed. As stated earlier, the performance of SCS-CN model was affected adversely due to quality and limitations of the available hydrological data. However, the SCS-CN model simulated the total runoff volume accurately, but the N-S efficiency was average.

The result obtained from SCS Method has also been compared with the observed flow on monthly basis. The soil conservation service – curve Number (SCS-CN) Method of rainfall- runoff modelling for an un-gauged catchment gives best estimation of surface runoff. The monthly water balance of Bina river basin has been carried out by using the Thornthwaite and mather model based on the land use, soil texture and climatic condition.

The following conclusions can be drawn from the present study.

i. Both the methods provide best results in the Bina river basin.
ii. The Thornthwaite & Mather method was used for computation of surplus water for surface runoff on monthly basis, where as the SCS-CN model was applied for daily runoff estimation.
iii. Both the models provide results with good correlation, however the RVE of the results of SCS-CN model is found to be better than that of the Thornthwaite & Mather method.

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Annexure-I

Computation of Area Weighted Average SCS Curve Number for Bina River Watershed

Luse use	Soil class	Soil group	Area (sq.m.)	CN_II	Area*CN_II	CN_I	Area*CN_I	CN_III	Area*CN_III
Dense forest	Fine Loam	B	2088576	55	114871680	35.19	73494247.62	74.48	155554328.8
	Clayey Loam	C	2375424	70	166279680	51.26	121761309.65	85.82	203853288.8
	Loamy Clay	D	6716160	77	517144320	60.05	403313205.37	90.12	605249855.5
	Fine Clay	D	23833728	77	1835197056	60.05	1431243037.03	90.12	2147858364
open forest	Fine Loam	B	23261184	60	1395671040	40.15	934042621.98	78.60	1828333149
	Clayey Loam	C	14207040	73	1037113920	54.92	780229820.30	87.73	1246427116
	Loamy Clay	D	33409152	79	2639323008	62.73	2095755079.09	91.24	3048293179
	Fine Clay	D	224805312	79	17759619648	62.73	14102030318.81	91.24	20511520291
agriculture1	Fine Loam	B	3571776	78	278598528	61.38	219239170.78	90.69	323908526.5
	Clayey Loam	C	2909376	85	247296960	71.24	207261512.60	94.34	274477490.1
	Loamy Clay	D	961920	89	85610880	77.33	74381245.84	96.20	92533593.4
	Fine Clay	D	18578880	89	1653520320	77.33	1436626996.74	96.20	1787228177
agriculture2	Fine Loam	B	22524480	81	1824482880	65.49	1475044344.78	92.32	2079434467
	Clayey Loam	C	10259136	88	902803968	75.77	777354820.28	95.75	982298086.5
	Loamy Clay	D	6178752	91	562266432	80.50	497386443.36	97.06	599727381.9
	Fine Clay	D	120407616	91	10957093056	80.50	9692752820.54	97.06	11687108384
barren land	Fine Loam	B	3182976	85	270552960	71.24	226752547.74	94.34	300289568.4
	Clayey Loam	C	1596672	90	143700480	78.90	125979928.11	96.63	154294097.6
	Loamy Clay	D	5546880	93	515859840	83.76	464623110.00	97.89	542981078.6
	Fine Clay	D	44902080	93	4175893440	83.76	3761131312.59	97.89	4395440289

Continue…

Annexure-I

Computation of Area Weighted Average SCS Curve Number for Bina River Watershed

Luse use	Soil class	Soil group	Area (sq.m.)	CN_II	Area*CN_II	CN_I	Area*CN_I	CN_III	Area*CN_III
current fallow	Fine Loam	B	23743872	83	1970741376	68.32	1622229220.04	93.35	2216543892
	Clayey Loam	C	9235008	88	812680704	75.77	699754636.66	95.75	884239246.6
	Loamy Clay	D	13716864	90	1234517760	78.90	1082282109.64	96.63	1325526566
	Fine Clay	D	165116160	90	14860454400	78.90	13027924311.25	96.63	15955968983
settlement	Fine Loam	B	4511232	66	297741312	46.62	210317120.46	83.09	374830679.1
	Clayey Loam	C	1680768	78	131099904	61.38	103167215.02	90.69	152421396.6
	Loamy Clay	D	2032704	83	168714432	68.32	138878436.70	93.35	189757493.5
	Fine Clay	D	25542720	83	2120045760	68.32	1745130143.19	93.35	2384470402
water body	Fine Loam	B	165312	100	16531200	95.92	15857474.47	100.48	16611228.41
	Clayey Loam	C	122112	100	12211200	95.92	11713535.15	100.48	12270315.06
	Loamy Clay	D	177984	100	17798400	95.92	17073030.01	100.48	17884562.99
	Fine Clay	D	1560960	100	156096000	95.92	149734340.82	100.48	156851669
scrub land	Fine Loam	B	17996544	66	1187771904	46.62	839012782.40	83.09	1495302571
	Clayey Loam	C	13283136	77	1022801472	60.05	797667738.34	90.12	1197055482
	Loamy Clay	D	29730240	83	2467609920	68.32	2031229954.69	93.35	2775384819
	Fine Clay	D	259098048	83	21505137984	68.32	17702101170.37	93.35	24187385941
		Sum	**1139030784**	**2993**	**95064853824**	**2507.84**	**79094477112**	**3340.42**	**1.06309E+11**
			Average Curve No.		**83.46**		**69.44**		**93.99**

Annexure - II

Computation of Direct Surface Runoff by SCS-CN Model (2006)

Month	Date	Ave. Rainfall	5 days rainfall	AMC	P (mm)	P-Ia	$(P-Ia)^2$	(P-Ia+S)	Q (mm)	Q (MCM)
June	1	0		I	0.00	-22.36	0.00	89.43	0.00	0.00
June	2	0.00		I	0.00	-22.36	0.00	89.43	0.00	0.00
June	3	0.00		I	0.00	-22.36	0.00	89.43	0.00	0.00
June	4	1.90		I	1.90	-20.45	0.00	91.33	0.00	0.00
June	5	1.36	3.26	I	1.36	-21.00	0.00	90.79	0.00	0.00
June	6	1.76	5.02	I	1.76	-20.60	0.00	91.19	0.00	0.00
June	7	0.00	5.02	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	8	0.00	5.02	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	9	0.00	3.12	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	10	0.00	1.76	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	11	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	12	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	13	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	14	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	15	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	16	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	17	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	18	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	19	0.44	0.44	I	0.44	-21.92	0.00	89.87	0.00	0.00
June	20	0.71	1.15	I	0.71	-21.64	0.00	90.14	0.00	0.00
June	21	0.00	1.15	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	22	0.62	1.77	I	0.62	-21.74	0.00	90.04	0.00	0.00
June	23	0.00	1.77	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	24	0.00	1.33	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	25	0.00	0.62	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	26	0.00	0.62	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	27	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	28	2.73	2.73	I	2.73	-19.63	0.00	92.15	0.00	0.00
June	29	0.00	2.73	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	30	0.62	3.34	I	0.62	-21.74	0.00	90.04	0.00	0.00
July	1	0.00	3.34	I	0.00	-22.36	0.00	89.43	0.00	0.00
July	2	0.00	3.34	I	0.00	-22.36	0.00	89.43	0.00	0.00
July	3	14.10	14.71	II	14.10	4.03	16.23	54.37	0.30	0.34
July	4	1.94	16.66	II	1.94	-8.12	0.00	42.21	0.00	0.00
July	5	2.31	18.35	II	2.31	-7.76	0.00	42.58	0.00	0.00
July	6	1.30	19.65	II	1.30	-8.77	0.00	41.57	0.00	0.00
July	7	0.00	19.65	II	0.00	-10.07	0.00	40.27	0.00	0.00
July	8	0.00	5.55	I	0.00	-22.36	0.00	89.43	0.00	0.00
July	9	0.00	3.61	I	0.00	-22.36	0.00	89.43	0.00	0.00
July	10	8.68	9.98	I	8.68	-13.68	0.00	98.11	0.00	0.00
July	11	3.60	12.28	II	3.60	-6.47	0.00	43.87	0.00	0.00
July	12	23.26	35.54	III	23.26	20.01	400.31	36.25	11.04	12.58
July	13	8.05	43.58	III	8.05	4.80	23.04	21.04	1.09	1.25
July	14	0.16	43.74	III	0.16	-3.09	0.00	13.15	0.00	0.00
July	15	0.00	35.06	III	0.00	-3.25	0.00	12.99	0.00	0.00
July	16	0.00	31.46	III	0.00	-3.25	0.00	12.99	0.00	0.00
July	17	15.89	24.10	II	15.89	5.82	33.93	56.16	0.60	0.69
July	18	8.04	24.09	II	8.04	-2.03	0.00	48.31	0.00	0.00
July	19	5.70	29.63	III	5.70	2.45	5.99	18.69	0.32	0.37
July	20	5.78	35.40	III	5.78	2.53	6.39	18.77	0.34	0.39
July	21	15.50	50.90	III	15.50	12.25	150.01	28.49	5.27	6.00
July	22	24.23	59.24	III	24.23	20.98	440.32	37.23	11.83	13.47

Annexure - II

Month	Date	Ave. Rainfall	5 days rainfall	AMC	P (mm)	P-Ia	$(P-Ia)^2$	(P-Ia+S)	Q (mm)	Q (MCM)
July	23	19.14	70.34	III	19.14	15.89	252.42	32.13	7.86	8.95
July	24	0.79	65.43	III	0.79	-2.46	0.00	13.79	0.00	0.00
July	25	5.56	65.22	III	5.56	2.31	5.34	18.55	0.29	0.33
July	26	8.01	57.73	III	8.01	4.76	22.65	21.00	1.08	1.23
July	27	8.84	42.34	III	8.84	5.59	31.27	21.83	1.43	1.63
July	28	19.53	42.73	III	19.53	16.28	265.16	32.53	8.15	9.29
July	29	6.90	48.84	III	6.90	3.65	13.31	19.89	0.67	0.76
July	30	1.53	44.80	III	1.53	-1.72	0.00	14.52	0.00	0.00
July	31	63.71	100.51	III	63.71	60.46	3655.8	76.71	47.66	54.29
Aug	1	60.66	152.33	III	60.66	57.41	3296.1	73.65	44.75	50.97
Aug	2	1.61	134.40	III	1.61	-1.64	0.00	14.60	0.00	0.00
Aug	3	13.63	141.14	III	13.63	10.38	107.74	26.62	4.05	4.61
Aug	4	26.59	166.20	III	26.59	23.34	544.93	39.59	13.77	15.68
Aug	5	1.80	104.29	III	1.80	-1.45	0.00	14.79	0.00	0.00
Aug	6	3.00	46.62	II	3.00	-7.07	0.00	43.27	0.00	0.00
Aug	7	11.00	56.02	III	11.00	7.75	60.09	23.99	2.50	2.85
Aug	8	14.60	56.99	III	14.60	11.35	128.86	27.59	4.67	5.32
Aug	9	37.92	68.32	III	37.92	34.67	1202.1	50.91	23.61	26.89
Aug	10	27.01	93.52	III	27.01	23.76	564.52	40.00	14.11	16.07
Aug	11	4.95	95.48	III	4.95	1.70	2.90	17.95	0.16	0.18
Aug	12	0.00	84.48	III	0.00	-3.25	0.00	12.99	0.00	0.00
Aug	13	0.16	70.04	III	0.16	-3.09	0.00	13.15	0.00	0.00
Aug	14	49.85	81.97	III	49.85	46.60	2171.5	62.84	34.56	39.36
Aug	15	22.62	77.58	III	22.62	19.38	375.4	35.62	10.54	12.01
Aug	16	2.61	75.24	III	2.61	-0.64	0.00	15.60	0.00	0.00
Aug	17	4.26	79.50	III	4.26	1.02	1.03	17.26	0.06	0.07
Aug	18	42.62	121.96	III	42.62	39.37	1549.8	55.61	27.87	31.74
Aug	19	2.75	74.86	III	2.75	-0.50	0.00	15.75	0.00	0.00
Aug	20	0.00	52.24	II	0.00	-10.07	0.00	40.27	0.00	0.00
Aug	21	0.00	49.63	II	0.00	-10.07	0.00	40.27	0.00	0.00
Aug	22	3.62	48.98	II	3.62	-6.45	0.00	43.89	0.00	0.00
Aug	23	0.00	6.37	II	0.00	-10.07	0.00	40.27	0.00	0.00
Aug	24	0.83	4.45	II	0.83	-9.24	0.00	41.10	0.00	0.00
Aug	25	20.00	24.45	II	20.00	9.93	98.65	60.27	1.64	1.86
Aug	26	0.00	24.45	II	0.00	-10.07	0.00	40.27	0.00	0.00
Aug	27	0.00	20.83	II	0.00	-10.07	0.00	40.27	0.00	0.00
Aug	28	0.00	20.83	II	0.00	-10.07	0.00	40.27	0.00	0.00
Aug	29	0.00	20.00	II	0.00	-10.07	0.00	40.27	0.00	0.00
Aug	30	0.16	0.16	II	0.16	-9.91	0.00	40.43	0.00	0.00
Aug	31	80.83	80.99	III	80.83	77.58	6019.2	93.83	64.15	73.07
Sept	1	133.86	214.86	III	133.86	130.62	17060.4	146.86	116.17	132.32
Sept	2	11.69	226.54	III	11.69	8.44	71.23	24.68	2.89	3.29
Sept	3	5.45	231.99	III	5.45	2.20	4.84	18.44	0.26	0.30
Sept	4	0.00	231.83	III	0.00	-3.25	0.00	12.99	0.00	0.00
Sept	5	6.69	157.69	III	6.69	3.44	11.83	19.68	0.60	0.68
Sept	6	42.24	66.06	III	42.24	38.99	1520.3	55.23	27.53	31.35
Sept	7	3.60	57.98	III	3.60	0.35	0.12	16.59	0.01	0.01
Sept	8	0.00	52.53	III	0.00	-3.25	0.00	12.99	0.00	0.00
Sept	9	0.00	52.53	III	0.00	-3.25	0.00	12.99	0.00	0.00
Sept	10	1.15	46.99	II	1.15	-8.92	0.00	41.42	0.00	0.00
Sept	11	0.00	4.75	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	12	0.89	2.04	I	0.89	-21.47	0.00	90.31	0.00	0.00
Sept	13	0.00	2.04	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	14	0.00	2.04	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	15	0.48	1.37	I	0.48	-21.88	0.00	89.91	0.00	0.00

Month	Date	Ave. Rainfall	5 days rainfall	AMC	P (mm)	P-Ia	$(P\text{-}Ia)^2$	(P-Ia+S)	Q (mm)	Q (MCM)
Sept	16	6.22	7.59	I	6.22	-16.13	0.00	95.65	0.00	0.00
Sept	17	0.00	6.70	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	18	1.03	7.74	I	1.03	-21.32	0.00	90.46	0.00	0.00
Sept	19	6.76	14.50	I	6.76	-15.60	0.00	96.19	0.00	0.00
Sept	20	0.00	14.02	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	21	12.57	20.36	I	12.57	-9.79	0.00	101.99	0.00	0.00
Sept	22	0.00	20.36	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	23	2.16	21.49	I	2.16	-20.20	0.00	91.59	0.00	0.00
Sept	24	2.64	17.37	I	2.64	-19.72	0.00	92.07	0.00	0.00
Sept	25	0.00	17.37	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	26	1.94	6.74	I	1.94	-20.41	0.00	91.37	0.00	0.00
Sept	27	0.00	6.74	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	28	0.00	4.58	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	29	0.00	1.94	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	30	0.00	1.94	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	1	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	2	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	3	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	4	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	5	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	6	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	7	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	8	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	9	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	10	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	11	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	12	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	13	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	14	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	15	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	16	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	17	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	18	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	19	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	20	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	21	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	22	2.88	2.88	I	2.88	-19.48	0.00	92.31	0.00	0.00
Oct	23	0.00	2.88	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	24	0.00	2.88	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	25	0.00	2.88	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	26	0.00	2.88	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	27	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	28	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	29	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	30	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	31	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00

Annexure-III

Computation of Direct Surface Runoff by SCS-CN Model (2007)

Month	Date	Ave. Rainfall	5 days rainfall	AMC	P (mm)	P-Ia	$(P\text{-}Ia)^2$	(P-Ia+S)	Q (mm)	Q (MCM)
June	1	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	2	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	3	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	4	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	5	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	6	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	7	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	8	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	9	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	10	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	11	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	12	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	13	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	14	0.42	0.42	I	0.42	-21.94	0.00	89.85	0.00	0.00
June	15	1.41	1.83	I	1.41	-20.95	0.00	90.83	0.00	0.00
June	16	3.54	5.37	I	3.54	-18.82	0.00	92.97	0.00	0.00
June	17	0.00	5.37	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	18	2.55	7.92	I	2.55	-19.80	0.00	91.98	0.00	0.00
June	19	48.62	56.12	III	48.62	45.37	2058.2	61.61	33.41	38.05
June	20	10.32	65.03	III	10.32	7.07	50.01	23.31	2.15	2.44
June	21	2.64	64.13	III	2.64	-0.61	0.00	15.63	0.00	0.00
June	22	0.00	64.13	III	0.00	-3.25	0.00	12.99	0.00	0.00
June	23	0.00	61.58	III	0.00	-3.25	0.00	12.99	0.00	0.00
June	24	1.24	14.20	II	1.24	-8.83	0.00	41.51	0.00	0.00
June	25	0.80	4.68	I	0.80	-21.56	0.00	90.23	0.00	0.00
June	26	0.00	2.04	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	27	0.00	2.04	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	28	25.35	27.39	II	25.35	15.28	233.62	65.62	3.56	4.05
June	29	1.38	27.53	II	1.38	-8.69	0.00	41.65	0.00	0.00
June	30	2.54	29.28	III	2.54	-0.70	0.00	15.54	0.00	0.00
July	1	6.69	35.97	III	6.69	3.44	11.86	19.69	0.60	0.69
July	2	5.16	41.13	III	5.16	1.91	3.65	18.15	0.20	0.23
July	3	0.00	15.78	II	0.00	-10.07	0.00	40.27	0.00	0.00
July	4	3.75	18.15	II	3.75	-6.32	0.00	44.02	0.00	0.00
July	5	2.60	18.21	II	2.60	-7.46	0.00	42.87	0.00	0.00
July	6	7.92	19.43	II	7.92	-2.15	0.00	48.19	0.00	0.00
July	7	37.14	51.41	III	37.14	33.89	1148.3	50.13	22.91	26.09
July	8	164.74	216.15	III	164.74	161.50	26080.8	177.74	146.74	167.14
July	9	36.11	248.51	III	36.11	32.86	1080.0	49.11	21.99	25.05
July	10	5.84	251.74	III	5.84	2.59	6.70	18.83	0.36	0.41
July	11	0.48	244.31	III	0.48	-2.76	0.00	13.48	0.00	0.00
July	12	1.29	208.46	III	1.29	-1.96	0.00	14.28	0.00	0.00
July	13	0.00	43.72	III	0.00	-3.25	0.00	12.99	0.00	0.00
July	14	8.33	15.94	I	8.33	-14.03	0.00	97.75	0.00	0.00
July	15	7.86	17.96	I	7.86	-14.50	0.00	97.28	0.00	0.00
July	16	26.48	43.95	II	26.48	16.41	269.37	66.75	4.04	4.60
July	17	6.13	48.79	II	6.13	-3.94	0.00	46.40	0.00	0.00
July	18	9.17	57.96	II	9.17	-0.90	0.00	49.44	0.00	0.00
July	19	0.00	49.63	II	0.00	-10.07	0.00	40.27	0.00	0.00
July	20	0.00	41.78	II	0.00	-10.07	0.00	40.27	0.00	0.00
July	21	0.00	15.30	II	0.00	-10.07	0.00	40.27	0.00	0.00
July	22	0.00	9.17	I	0.00	-22.36	0.00	89.43	0.00	0.00

Month	Date	Ave. Rainfall	5 days rainfall	AMC	P (mm)	P-Ia	$(P\text{-}Ia)^2$	(P-Ia+S)	Q (mm)	Q (MCM)
July	23	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
July	24	2.26	2.26	I	2.26	-20.09	0.00	91.69	0.00	0.00
July	25	2.04	4.30	I	2.04	-20.32	0.00	91.47	0.00	0.00
July	26	16.88	21.18	II	16.88	6.81	46.41	57.15	0.81	0.92
July	27	20.21	41.39	III	20.21	16.96	287.63	33.20	8.66	9.87
July	28	1.87	43.26	III	1.87	-1.38	0.00	14.87	0.00	0.00
July	29	1.01	42.01	III	1.01	-2.24	0.00	14.00	0.00	0.00
July	30	4.68	44.65	III	4.68	1.43	2.05	17.67	0.12	0.13
July	31	0.00	27.77	II	0.00	-10.07	0.00	40.27	0.00	0.00
Aug	1	0.29	7.85	I	0.29	-22.07	0.00	89.71	0.00	0.00
Aug	2	8.85	14.82	I	8.85	-13.51	0.00	98.27	0.00	0.00
Aug	3	48.55	62.37	III	48.55	38.48	1481.06	54.73	27.06	30.83
Aug	4	25.20	82.89	III	25.20	21.95	481.88	38.19	12.62	14.37
Aug	5	19.49	102.38	III	19.49	16.24	263.73	32.48	8.12	9.25
Aug	6	1.20	103.29	III	1.20	-2.05	0.00	14.19	0.00	0.00
Aug	7	5.14	99.58	III	5.14	1.89	3.56	18.13	0.20	0.22
Aug	8	19.77	70.79	III	19.77	16.52	272.90	32.76	8.33	9.49
Aug	9	0.29	45.88	II	0.29	-9.78	0.00	40.56	0.00	0.00
Aug	10	0.00	26.39	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	11	6.93	32.12	I	6.93	-15.42	0.00	96.36	0.00	0.00
Aug	12	0.00	26.99	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	13	0.00	7.22	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	14	0.53	7.46	I	0.53	-21.83	0.00	89.95	0.00	0.00
Aug	15	2.44	9.90	I	2.44	-19.92	0.00	91.87	0.00	0.00
Aug	16	0.92	3.89	I	0.92	-21.44	0.00	90.35	0.00	0.00
Aug	17	0.00	3.89	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	18	0.00	3.89	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	19	0.00	3.36	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	20	0.24	1.16	I	0.24	-22.12	0.00	89.67	0.00	0.00
Aug	21	41.90	42.14	II	41.90	31.84	1013.5	82.17	12.33	14.05
Aug	22	2.51	44.66	II	2.51	-7.56	0.00	42.78	0.00	0.00
Aug	23	0.00	44.66	II	0.00	-10.07	0.00	40.27	0.00	0.00
Aug	24	0.00	44.66	II	0.00	-10.07	0.00	40.27	0.00	0.00
Aug	25	0.00	44.42	II	0.00	-10.07	0.00	40.27	0.00	0.00
Aug	26	0.00	2.51	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	27	2.19	2.19	I	2.19	-20.16	0.00	91.62	0.00	0.00
Aug	28	14.01	16.20	I	14.01	-8.35	0.00	103.43	0.00	0.00
Aug	29	0.94	17.14	I	0.94	-21.42	0.00	90.36	0.00	0.00
Aug	30	0.00	17.14	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	31	0.16	17.30	I	0.16	-22.20	0.00	89.59	0.00	0.00
Sept	1	29.43	44.53	III	29.43	26.18	685.38	42.42	16.16	18.40
Sept	2	17.30	47.83	III	17.30	14.06	197.56	30.30	6.52	7.43
Sept	3	13.83	60.72	III	13.83	10.58	111.93	26.82	4.17	4.75
Sept	4	17.56	78.28	III	17.56	14.31	204.82	30.55	6.70	7.64
Sept	5	1.14	79.26	III	1.14	-2.10	0.00	14.14	0.00	0.00
Sept	6	8.48	58.31	III	8.48	5.23	27.33	21.47	1.27	1.45
Sept	7	10.34	51.35	III	10.34	7.09	50.29	23.33	2.16	2.46
Sept	8	8.41	45.93	III	8.41	5.16	26.62	21.40	1.24	1.42
Sept	9	3.03	31.40	II	3.03	-7.04	0.00	43.30	0.00	0.00
Sept	10	0.00	30.26	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	11	0.00	21.78	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	12	0.00	11.44	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	13	0.35	3.38	I	0.35	-22.00	0.00	89.78	0.00	0.00
Sept	14	0.00	0.35	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	15	0.00	0.35	I	0.00	-22.36	0.00	89.43	0.00	0.00

Month	Date	Ave. Rainfall	5 days rainfall	AMC	P (mm)	P-Ia	$(P\text{-}Ia)^2$	(P-Ia+S)	Q (mm)	Q (MCM)
Sept	16	0.00	0.35	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	17	0.12	0.47	I	0.12	-22.24	0.00	89.55	0.00	0.00
Sept	18	0.00	0.12	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	19	2.92	3.04	I	2.92	-19.44	0.00	92.35	0.00	0.00
Sept	20	0.00	3.04	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	21	11.23	14.27	I	11.23	-11.12	0.00	100.66	0.00	0.00
Sept	22	2.20	16.35	I	2.20	-20.16	0.00	91.63	0.00	0.00
Sept	23	0.00	16.35	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	24	0.05	13.48	I	0.05	-22.31	0.00	89.47	0.00	0.00
Sept	25	0.00	13.48	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	26	0.04	2.28	I	0.04	-22.32	0.00	89.46	0.00	0.00
Sept	27	27.33	27.42	I	27.33	4.98	24.75	116.76	0.21	0.24
Sept	28	10.46	37.87	II	10.46	0.39	0.15	50.73	0.00	0.00
Sept	29	9.51	47.34	III	9.51	6.26	39.23	22.51	1.74	1.99
Sept	30	0.34	47.67	III	0.34	-2.91	0.00	13.33	0.00	0.00
Oct	1	0.00	47.64	III	0.00	-3.25	0.00	12.99	0.00	0.00
Oct	2	0.00	20.30	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	3	0.00	9.85	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	4	0.00	0.34	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	5	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	6	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	7	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	8	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	9	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	10	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	11	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	12	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	13	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	14	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	15	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	16	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	17	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	18	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	19	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	20	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	21	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	22	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	23	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	24	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	25	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	26	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	27	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	28	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	29	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	30	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	31	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00

Annexure-IV

Computation of Direct Surface Runoff by SCS-CN Model (2008)

Month	Date	Ave. Rainfall	5 days rainfall	AMC	P (mm)	P-Ia	$(P\text{-}Ia)^2$	(P-Ia+S)	Q (mm)	Q (MCM)
June	1	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	2	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	3	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	4	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	5	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	6	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	7	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	8	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	9	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	10	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	11	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	12	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	13	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	14	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	15	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	16	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	17	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	18	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	19	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	20	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	21	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	22	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	23	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	24	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	25	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	26	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	27	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	28	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	29	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
June	30	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
July	1	15.23	15.23	II	15.23	5.16	26.67	55.50	0.48	0.55
July	2	11.59	26.82	II	11.59	1.52	2.32	51.86	0.04	0.05
July	3	5.37	32.19	III	5.37	2.12	4.49	18.36	0.24	0.28
July	4	0.00	32.19	III	0.00	-3.25	0.00	12.99	0.00	0.00
July	5	17.65	49.84	III	17.65	14.40	207.35	30.64	6.77	7.71
July	6	0.40	35.01	III	0.40	-2.85	0.00	13.39	0.00	0.00
July	7	0.00	23.42	II	0.00	-10.07	0.00	40.27	0.00	0.00
July	8	11.00	29.05	III	11.00	7.75	60.09	23.99	2.50	2.85
July	9	9.73	38.78	III	9.73	6.48	41.99	22.72	1.85	2.10
July	10	36.64	57.76	III	36.64	33.39	1114.7	49.63	22.46	25.58
July	11	57.28	114.64	III	57.28	54.03	2919.4	70.27	41.54	47.32
July	12	1.11	115.75	III	1.11	-2.14	0.00	14.10	0.00	0.00
July	13	0.00	104.75	III	0.00	-3.25	0.00	12.99	0.00	0.00
July	14	7.54	102.56	III	7.54	4.29	18.38	20.53	0.90	1.02
July	15	0.54	66.46	III	0.54	-2.71	0.00	13.53	0.00	0.00
July	16	0.00	9.18	II	0.00	-10.07	0.00	40.27	0.00	0.00
July	17	0.00	8.08	II	0.00	-10.07	0.00	40.27	0.00	0.00
July	18	0.25	8.33	II	0.25	-9.82	0.00	40.52	0.00	0.00
July	19	0.00	0.79	I	0.00	-22.36	0.00	89.43	0.00	0.00
July	20	0.00	0.25	I	0.00	-22.36	0.00	89.43	0.00	0.00
July	21	0.00	0.25	I	0.00	-22.36	0.00	89.43	0.00	0.00
July	22	0.00	0.25	I	0.00	-22.36	0.00	89.43	0.00	0.00

Month	Date	Ave. Rainfall	5 days rainfall	AMC	P (mm)	P-Ia	$(P\text{-}Ia)^2$	(P-Ia+S)	Q (mm)	Q (MCM)
July	23	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
July	24	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
July	25	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
July	26	4.92	4.92	I	4.92	-17.44	0.00	94.34	0.00	0.00
July	27	77.17	82.08	III	77.17	73.92	5464.1	90.16	60.60	69.03
July	28	2.80	84.88	III	2.80	-0.45	0.00	15.79	0.00	0.00
July	29	15.07	99.95	III	15.07	11.82	139.71	28.06	4.98	5.67
July	30	13.24	113.20	III	13.24	10.00	99.91	26.24	3.81	4.34
July	31	20.92	129.20	III	20.92	17.67	312.15	33.91	9.21	10.49
Aug	1	26.00	78.02	III	26.00	22.75	517.46	38.99	13.27	15.12
Aug	2	41.04	116.26	III	41.04	37.79	1427.9	54.03	26.43	30.10
Aug	3	7.50	108.69	III	7.50	4.25	18.04	20.49	0.88	1.00
Aug	4	8.72	104.16	III	8.72	5.47	29.94	21.71	1.38	1.57
Aug	5	1.71	84.96	III	1.71	-1.54	0.00	14.71	0.00	0.00
Aug	6	31.20	90.16	III	31.20	27.95	781.30	44.19	17.68	20.14
Aug	7	17.44	66.57	III	17.44	14.20	201.52	30.44	6.62	7.54
Aug	8	0.44	59.52	III	0.44	-2.80	0.00	13.44	0.00	0.00
Aug	9	7.44	58.24	III	7.44	4.20	17.60	20.44	0.86	0.98
Aug	10	29.91	86.44	III	29.91	26.66	710.95	42.91	16.57	18.87
Aug	11	19.48	74.72	III	19.48	16.23	263.47	32.47	8.11	9.24
Aug	12	1.36	58.64	III	1.36	-1.88	0.00	14.36	0.00	0.00
Aug	13	1.37	59.57	III	1.37	-1.88	0.00	14.36	0.00	0.00
Aug	14	0.00	52.12	II	0.00	-10.07	0.00	40.27	0.00	0.00
Aug	15	0.00	22.21	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	16	1.23	3.96	I	1.23	-21.12	0.00	90.66	0.00	0.00
Aug	17	0.40	3.00	I	0.40	-21.96	0.00	89.83	0.00	0.00
Aug	18	0.00	1.63	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	19	0.00	1.63	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	20	0.00	1.63	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	21	0.00	0.40	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	22	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	23	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	24	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	25	8.13	8.13	I	8.13	-14.23	0.00	97.55	0.00	0.00
Aug	26	9.76	17.89	I	9.76	-12.59	0.00	99.19	0.00	0.00
Aug	27	0.00	17.89	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	28	0.00	17.89	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	29	2.04	19.93	I	2.04	-20.32	0.00	91.47	0.00	0.00
Aug	30	0.00	11.80	I	0.00	-22.36	0.00	89.43	0.00	0.00
Aug	31	0.00	2.04	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	1	0.00	2.04	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	2	0.00	2.04	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	3	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	4	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	5	1.52	1.52	I	1.52	-20.84	0.00	90.95	0.00	0.00
Sept	6	0.00	1.52	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	7	29.55	31.07	I	29.55	7.20	51.77	118.98	0.44	0.50
Sept	8	0.00	31.07	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	9	13.25	44.32	II	13.25	3.18	10.12	53.52	0.19	0.22
Sept	10	0.80	43.60	II	0.80	-9.27	0.00	41.07	0.00	0.00
Sept	11	20.92	64.52	III	20.92	17.68	312.43	33.92	9.21	10.49
Sept	12	1.18	36.15	II	1.18	-21.18	0.00	90.61	0.00	0.00
Sept	13	0.00	36.15	II	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	14	3.31	26.22	I	3.31	-19.04	0.00	92.74	0.00	0.00
Sept	15	0.00	25.42	I	0.00	-22.36	0.00	89.43	0.00	0.00

Month	Date	Ave. Rainfall	5 days rainfall	AMC	P (mm)	P-Ia	$(P\text{-}Ia)^2$	(P-Ia+S)	Q (mm)	Q (MCM)
Sept	16	0.00	4.49	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	17	0.00	3.31	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	18	2.64	5.95	I	2.64	-19.72	0.00	92.07	0.00	0.00
Sept	19	39.02	41.66	II	39.02	28.95	838.02	79.29	10.57	12.04
Sept	20	10.91	52.57	III	10.91	7.66	58.73	23.91	2.46	2.80
Sept	21	21.69	74.26	III	21.69	18.44	340.17	34.69	9.81	11.17
Sept	22	0.00	74.26	III	0.00	-3.25	0.00	12.99	0.00	0.00
Sept	23	0.00	71.62	III	0.00	-3.25	0.00	12.99	0.00	0.00
Sept	24	0.00	32.60	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	25	0.00	21.69	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	26	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	27	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	28	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	29	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Sept	30	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	1	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	2	10.08	10.08	I	10.08	-12.28	0.00	99.51	0.00	0.00
Oct	3	0.00	10.08	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	4	5.28	15.36	I	5.28	-17.08	0.00	94.71	0.00	0.00
Oct	5	0.00	15.36	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	6	0.00	15.36	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	7	0.00	5.28	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	8	3.93	9.21	I	3.93	-18.43	0.00	93.35	0.00	0.00
Oct	9	0.00	3.93	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	10	0.00	3.93	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	11	0.00	3.93	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	12	0.00	3.93	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	13	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	14	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	15	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	16	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	17	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	18	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	19	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	20	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	21	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	22	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	23	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	24	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	25	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	26	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	27	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	28	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	29	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	30	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00
Oct	31	0.00	0.00	I	0.00	-22.36	0.00	89.43	0.00	0.00

Calculation of Monthlu Runoff using the Thornthawaite's Equation for the year 2006

AWC (mm)	area (sq.km)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (mm)
300	2.09	0.00	0.00	0.00	0.00	0.00	0.00	-44.54	144.94	268.56	79.08	0.00	0.00	448.04
210	2.38	0.00	0.00	0.00	0.00	0.00	0.00	-3.87	185.61	268.56	79.08	0.00	0.00	529.38
200	26.44	0.00	0.00	0.00	0.00	0.00	0.00	0.91	190.39	268.56	79.08	0.00	0.00	538.95
180	23.83	0.00	0.00	0.00	0.00	0.00	0.00	10.60	200.08	268.56	79.08	0.00	0.00	558.32
150	24.71	0.00	0.00	0.00	0.00	0.00	0.00	25.36	214.84	268.56	79.08	0.00	0.00	587.84
140	15.80	0.00	0.00	0.00	0.00	0.00	0.00	30.32	219.80	268.56	79.08	0.00	0.00	597.76
124	27.32	0.00	0.00	0.00	0.00	0.00	0.00	38.29	227.77	268.56	79.08	0.00	0.00	613.69
120	269.71	0.00	0.00	0.00	0.00	0.00	0.00	40.28	229.76	268.56	79.08	0.00	0.00	617.68
105	13.28	0.00	0.00	0.00	0.00	0.00	0.00	47.77	237.25	268.56	79.08	0.00	0.00	632.66
100	43.47	0.00	0.00	0.00	0.00	0.00	0.00	50.27	239.75	268.56	79.08	0.00	0.00	637.66
90	259.10	0.00	0.00	0.00	0.00	0.00	0.00	55.27	244.75	268.56	79.08	0.00	0.00	647.66
86.8	12.14	0.00	0.00	0.00	0.00	0.00	0.00	56.87	246.35	268.56	79.08	0.00	0.00	650.86
76	22.52	0.00	0.00	0.00	0.00	0.00	0.00	62.27	251.75	268.56	79.08	0.00	0.00	661.66
75	26.99	0.00	0.00	0.00	0.00	0.00	0.00	62.77	252.25	268.56	79.08	0.00	0.00	662.66
74.4	183.70	0.00	0.00	0.00	0.00	0.00	0.00	63.07	252.55	268.56	79.08	0.00	0.00	663.26
70	1.68	0.00	0.00	0.00	0.00	0.00	0.00	65.27	254.75	268.56	79.08	0.00	0.00	667.66
62	14.68	0.00	0.00	0.00	0.00	0.00	0.00	69.27	258.75	268.56	79.08	0.00	0.00	675.66
60	25.54	0.00	0.00	0.00	0.00	0.00	0.00	70.27	259.75	268.56	79.08	0.00	0.00	677.66
53.2	10.26	0.00	0.00	0.00	0.00	0.00	0.00	73.67	263.15	268.56	79.08	0.00	0.00	684.46
50	2.03	0.00	0.00	0.00	0.00	0.00	0.00	75.27	264.75	268.56	79.08	0.00	0.00	687.66
45.6	120.41	0.00	0.00	0.00	0.00	0.00	0.00	77.47	266.95	268.56	79.08	0.00	0.00	692.06
38	6.18	0.00	0.00	0.00	0.00	0.00	0.00	81.27	270.75	268.56	79.08	0.00	0.00	699.66
Total area	1134.26	0.00	0.00	0.00	0.00	0.00	0.00	59361.16	274280.72	304618.35	89698.80	0.00	0.00	
Weighted Average Runoff	mm	0.00	0.00	0.00	0.00	0.00	0.00	52.33	241.81	268.56	79.08	0.00	0.00	641.79
	(MCM)	0.00	0.00	0.00	0.00	0.00	0.00	**59.36**	**274.28**	**304.62**	**89.70**	0.00	0.00	**727.96**

Annexure-V

Calculation of Monthlu Runoff using the Thornthawaite's Equation for the year 2007

AWC (mm)	area (sq.km)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (mm)
300	2.09	0.00	0.00	0.00	0.00	0.00	0.00	10.31	84.02	120.13	46.42	0.00	0.00	260.88
210	2.38	0.00	0.00	0.00	0.00	0.00	0.00	49.63	123.34	120.13	46.42	0.00	0.00	339.53
200	26.44	0.00	0.00	0.00	0.00	0.00	0.00	54.33	128.04	120.13	46.42	0.00	0.00	348.92
180	23.83	0.00	0.00	0.00	0.00	0.00	0.00	63.86	137.57	120.13	46.42	0.00	0.00	367.99
150	24.71	0.00	0.00	0.00	0.00	0.00	0.00	78.48	152.19	120.13	46.42	0.00	0.00	397.23
140	15.80	0.00	0.00	0.00	0.00	0.00	0.00	83.42	157.13	120.13	46.42	0.00	0.00	407.10
124	27.32	0.00	0.00	0.00	0.00	0.00	0.00	91.36	165.07	120.13	46.42	0.00	0.00	422.98
120	269.71	0.00	0.00	0.00	0.00	0.00	0.00	93.35	167.06	120.13	46.42	0.00	0.00	426.96
105	13.28	0.00	0.00	0.00	0.00	0.00	0.00	100.83	174.54	120.13	46.42	0.00	0.00	441.92
100	43.47	0.00	0.00	0.00	0.00	0.00	0.00	103.33	177.04	120.13	46.42	0.00	0.00	446.92
90	259.10	0.00	0.00	0.00	0.00	0.00	0.00	108.32	182.03	120.13	46.42	0.00	0.00	456.91
86.8	12.14	0.00	0.00	0.00	0.00	0.00	0.00	109.92	183.63	120.13	46.42	0.00	0.00	460.11
76	22.52	0.00	0.00	0.00	0.00	0.00	0.00	115.32	189.03	120.13	46.42	0.00	0.00	470.91
75	26.99	0.00	0.00	0.00	0.00	0.00	0.00	115.82	189.53	120.13	46.42	0.00	0.00	471.91
74.4	183.70	0.00	0.00	0.00	0.00	0.00	0.00	116.12	189.83	120.13	46.42	0.00	0.00	472.51
70	1.68	0.00	0.00	0.00	0.00	0.00	0.00	118.32	192.03	120.13	46.42	0.00	0.00	476.91
62	14.68	0.00	0.00	0.00	0.00	0.00	0.00	122.32	196.03	120.13	46.42	0.00	0.00	484.91
60	25.54	0.00	0.00	0.00	0.00	0.00	0.00	123.32	197.03	120.13	46.42	0.00	0.00	486.91
53.2	10.26	0.00	0.00	0.00	0.00	0.00	0.00	126.72	200.43	120.13	46.42	0.00	0.00	493.71
50	2.03	0.00	0.00	0.00	0.00	0.00	0.00	128.32	202.03	120.13	46.42	0.00	0.00	496.91
45.6	120.41	0.00	0.00	0.00	0.00	0.00	0.00	130.52	204.23	120.13	46.42	0.00	0.00	501.31
38	6.18	0.00	0.00	0.00	0.00	0.00	0.00	134.32	208.03	120.13	46.42	0.00	0.00	508.91
Total area	1134.26	0.00	0.00	0.00	0.00	0.00	0.00	119563.95	203170.25	136262.45	52656.14	0.00	0.00	
Weighted Average Runoff	mm	0.00	0.00	0.00	0.00	0.00	0.00	105.41	179.12	120.13	46.42	0.00	0.00	451.09
	(MCM)	0.00	0.00	0.00	0.00	0.00	0.00	**119.56**	**203.17**	**136.26**	**52.66**	0.00	0.00	**511.65**

Annexure-V

Calculation of Monthlu Runoff using the Thornthawaite's Equation for the year 2008

AWC (mm)	area (sq.km)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (mm)
300	2.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	80.53	112.32	31.79	0.00	0.00	224.64
210	2.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	80.53	112.32	31.79	0.00	0.00	224.64
200	26.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	80.53	112.32	31.79	0.00	0.00	224.64
180	23.83	0.00	0.00	0.00	0.00	0.00	0.00	28.56	109.09	112.32	31.79	0.00	0.00	281.76
150	24.71	0.00	0.00	0.00	0.00	0.00	0.00	43.31	123.84	112.32	31.79	0.00	0.00	311.26
140	15.80	0.00	0.00	0.00	0.00	0.00	0.00	48.27	128.80	112.32	31.79	0.00	0.00	321.18
124	27.32	0.00	0.00	0.00	0.00	0.00	0.00	56.24	136.77	112.32	31.79	0.00	0.00	337.11
120	269.71	0.00	0.00	0.00	0.00	0.00	0.00	58.23	138.76	112.32	31.79	0.00	0.00	341.10
105	13.28	0.00	0.00	0.00	0.00	0.00	0.00	65.72	146.25	112.32	31.79	0.00	0.00	356.08
100	43.47	0.00	0.00	0.00	0.00	0.00	0.00	68.22	148.75	112.32	31.79	0.00	0.00	361.08
90	259.10	0.00	0.00	0.00	0.00	0.00	0.00	73.22	153.75	112.32	31.79	0.00	0.00	371.08
86.8	12.14	0.00	0.00	0.00	0.00	0.00	0.00	74.82	155.35	112.32	31.79	0.00	0.00	374.28
76	22.52	0.00	0.00	0.00	0.00	0.00	0.00	80.22	160.75	112.32	31.79	0.00	0.00	385.07
75	26.99	0.00	0.00	0.00	0.00	0.00	0.00	80.72	161.25	112.32	31.79	0.00	0.00	386.07
74.4	183.70	0.00	0.00	0.00	0.00	0.00	0.00	81.02	161.55	112.32	31.79	0.00	0.00	386.67
70	1.68	0.00	0.00	0.00	0.00	0.00	0.00	83.22	163.75	112.32	31.79	0.00	0.00	391.07
62	14.68	0.00	0.00	0.00	0.00	0.00	0.00	87.22	167.75	112.32	31.79	0.00	0.00	399.07
60	25.54	0.00	0.00	0.00	0.00	0.00	0.00	88.22	168.75	112.32	31.79	0.00	0.00	401.07
53.2	10.26	0.00	0.00	0.00	0.00	0.00	0.00	91.62	172.15	112.32	31.79	0.00	0.00	407.87
50	2.03	0.00	0.00	0.00	0.00	0.00	0.00	93.22	173.75	112.32	31.79	0.00	0.00	411.07
45.6	120.41	0.00	0.00	0.00	0.00	0.00	0.00	95.42	175.95	112.32	31.79	0.00	0.00	415.47
38	6.18	0.00	0.00	0.00	0.00	0.00	0.00	99.22	179.75	112.32	31.79	0.00	0.00	423.07
Total area	1134.26	0.00	0.00	0.00	0.00	0.00	0.00	79246.21	170588.16	127399.34	36057.38	0.00	0.00	
Weighted Average Runoff	mm	0.00	0.00	0.00	0.00	0.00	0.00	69.87	150.40	112.32	31.79	0.00	0.00	364.37
	(MCM)	0.00	0.00	0.00	0.00	0.00	0.00	**79.25**	**170.59**	**127.40**	**36.06**	0.00	0.00	**413.30**