FINAL
REPORT

WATER AVAILABILITY STUDY AND SUPPLY-DEMAND ANALYSIS IN KHARUN SUB-BASIN OF SEONATH BASIN IN CHHATTISGARH STATE

PURPOSE DRIVEN STUDY (PDS)
UNDER HYDROLOGY PROJECT PHASE-II

APRIL 2014

NATIONAL INSTITUTE OF HYDROLOGY
REGIONAL CENTRE, WALMI CAMPUS
KOLAR ROAD, BHOPAL
MADHYA PRADESH
E-mail: nihrcbhopal@yahoo.com

STATE WATER DATA CENTRE
WATER RESOURCES DEPARTMENT
GOVT. OF CHHATTISGARH, RAIPUR
E-mail: sdc_cg@yahoo.co.in

[TYPE THE COMPANY ADDRESS]

PURPOSE DRIVEN STUDY (PDS) UNDER HYDROLOGY PROJECT PHASE-II

Water Availability Study and Supply-Demand Analysis in Kharun Sub-Basin of Seonath Basin in Chhattisgarh State

Name of the Institutions:

1. Water Resources Department, Govt. of Chhattisgarh, Raipur
2. National Institute of Hydrology, Regional Centre, Bhopal

Study Group

1. National Institute of Hydrology, Regional Centre, Bhopal

Sh. Ravi Galkate, Scientist-D (PI)
Sh. T. Thomas, Scientist-C
Sh. R.K. Jaiswal, Scientist-C
Dr. Surjeet Singh, Scientist-D

2. Water Resources Department, Govt. of Chhattisgarh, Raipur

Sh. S.K. Awadhiya, Superintending Engineer (PI)
Sh. D. K. Sonkusale, Deputy Director
Sh. Akhilesh Verma, Asst. Engineer
Sh. R. K. Sharma, Sub Divisional Officer
Sh. T.L. Chandrakar, Sub Engineer
Sh. J. K. Dass, Sub Engineer

Total Budget (Rs)	**:**	WRD, Chhattisgarh	: 35,17,500
		NIH, RC, Bhopal	: 14,17,500
		Total	**: 49,35,000**

CONTENTS

LIST OF FIGURE

LIST OF TABLE

PREFACE

Chhattisgarh, a newly born state is exploiting its water resources mainly for domestic and industrial water supply and developing irrigation schemes. Though the state is endowed with the network of big rivers like Mahanadi, Godavari, Indravati, Seonath and Narmada, the state is facing the problem of water scarcity in rural as well as in urban areas to meet various water demands during lean period. The huge water demand for irrigation, emerging towns and industries on the banks of rivers in Chhattisgarh, has necessitated the need of long term planning for sustainable water resources development and understanding the complex system of hydrological processes. Reliable assessment of water resources and understanding relationships and interdependencies that exist between supply and demand of the natural resources are vital for water management and its optimal utilization.

The Purpose driven Study (PDS) titled 'Water Availability Study and Supply-Demand Analysis in Kharun Sub-Basin of Seonath Basin in Chhattisgarh State' deals with the problem of water scarcity being faced by Chhattisgarh state. This study has been carried out jointly by National Institute of Hydrology, Regional Centre, Bhopal and Water Resources Department, Govt. of Chhattisgarh, Raipur under World Bank funded Hydrology Project Phase-II. It envisages the rainfall runoff modeling, water availability study and water supply-demand analysis. The study also aims to understand the hydrological behavior of river basins to harness the available water resources optimally using scientific approach. The study also envisages the measures to resolve these issues for optimal and effective utilization of available water resources to meet various demands in Kharun river basin. The research oriented approach adopted in the present PDS using scientific methodologies will be an innovation for tackling the water resources problem highlighted in Seonath basin. The methodologies developed during the course of the study will be helpful in resolving similar type of issues in the other river basins of Chhattisgarh state. It will also help the field engineers to understand and resolve the water resources issues of the region, scientifically. The study will be of great help to the Chhattisgarh state to adopt strategies for management of existing water resources for its effective use and to develop the water resources to meet the future water demands.

This report has been prepared by Sri Ravi Galkate, Scientist-D as a P.I. and Sh. T. Thomas, Scientist-C, Sh. R.K. Jaiswal, Scientist-C, Dr. Surjeet Singh, Scientist-D as Co-PI from National Institute of Hydrology. The study team from Water Resources Department, Chhattisgarh included Sh. S.K. Awadhiya, Superintending Engineer as PI, Sh. D. K. Sonkusale, Deputy Director as key Person, Sh. Akhilesh Verma, Executive Engineer, Sh. R. K. Sharma, Sub Divisional Officer, Sh. R. Chandrakar, Sub Engineer and Sh. J. K. Dass, Sub Engineer. The report is the results of three and half years of collaborative research and field works conducted by both organizations.

(R. D. Singh)
Director, NIH

ABSTRACT

The present Purpose Driven Study (PDS) deals with addressing and resolving various hydrological issues of the Chhattisgarh state to tackle the problem of increasing water demands and water scarcity being faced by state. In present study the hydrometeorological, agricultural and demographic data of the Kharun river basin was analyzed using different technique to carry out the rainfall runoff modeling, water availability study and water supply-demand analysis. In this study, the MIKE BASIN model for Kharun river was developed to study the hydrological behavior of the river. It was observed that the Kharun is originally an intermittent river having no flow during lean season, moreover there has been no water storage structure at the upstream. To tackle the situation, the Kharun river is being supplemented from Ravishankarsagar reservoir through canals to meet various water demands and water supplied for various usages through the series of anicuts. Thus the flow regime in Kharun has been found strongly influenced by regulation operations associated with the river.

The drought study indicated that the Kharun river basin on an average experiences 2 drought years in every 10 years period which were mostly of moderate nature. The low flow analysis indicated that the Kharun river generally experiences 1 or 2 low flow condition every year. The low flow events in this basin usually begin during July to October and terminate during November to December and it can be the matter of concern for water resource planning and allocation in the basin. The Rainfall-Runoff Modeling was carried out using MIKE11 NAM model in the Kharun river using observed discharge at Patherdihi gauge discharge site. The coefficient of determination (R^2) values of model calibration and validation were observed 0.858 and 0.764 respectively. It indicated the good agreement between the simulated and observed catchment runoff in terms of the peak flows with respect to timing, rate and volume. Thus the model can be used for predicting the runoff time series for the extended time period in the Kharun basin and it can also be used for predicting runoff time series of another basin of similar characteristics. The Efficiency of the model was obtained as 81% which shows that the choice of the model parameters was relevant.

The water availability analysis indicated that the Kharun river is originally an intermittent river having flow during monsoon season and 2-3 months thereafter. The average annual rainfall of 1147.57 mm produces 1802.88 MCM of average annual runoff in Kharun. The Ravishankarsagar reservoir and other sources add around average 116.22 MCM water in to the Kharun river and the average annual regulated flow becomes 1919.1 MCM which is supplied to meet various water demands. The water from Kharun river is being utilized mainly to meet domestic and industrial water demand. If the water supply was planned at 90% probability level, the total water demand was observed 65 MCM in 2010-11 and the deficit was 22 MCM. When the demand

would increase to 133 MCM (in 2030-31) and 175 MCM (in 2050-51) the water deficit would becomes 73.56 MCM and 105.33 MCM respectively. In year 2050-51, the additional 105.33 MCM water would be required in Kharun river to fulfill the total demand. The surplus-deficit analysis indicated that, during a water year the period of water deficit prolongs if assured water availability is planned at higher probability level. As the water demand increases, the water deficit period increases and the river starts experiencing the water deficit much earlier.

The study was also carried out for identification of possible storages sites on Kharun river, their submergence area and possible storage capacities. Four best possible dam sites were identified on Kharun river basin for construction of small storage structure using DEM data which would help to meet the future water demand in the basin. The derived Area-Elevation-Capacity curves of the proposed sites would be useful during construction of dam. It was recommended that the water storage in these tanks should be planned to minimize the submergence effect and to create structure of adequate storages.

The infiltration tests were conducted at nine selected sites in Kharun river basin using double ring infiltrometer. The infiltration rate was observed varying from 0.4 to 4.3 cm/hr in Kharun river basin. The regional infiltration models were developed for different soil type and for a Kharun basin as a whole. The regional infiltration model based on the Phillip's two-term model was found best suited for the Kanhar soil. Kostiakov's and Green-Ampt model could be applied for modeling the infiltration rate of Matasi and Sandy-murrum soil. However the regional model based on Green-Ampt model was found best for simulating the infiltration rates for the whole Kharun basin.

On the basis of various hydrological analyses carried out, some of the key recommendations were arisen for the water resources development, management and its optimum utilization in Kharun basin. Though the occurrence of droughts is not a big threat in the region, water crises in rural as well as urban areas during every summer has become common in the state. Hence there is an urgent need to tap the river water which is being drained down causing more dependence on groundwater in the region. The mechanism has to be developed for regular monitoring and assessment of water demands and water availability to meet future challenges. It is recommended that the state WRD should maintain adequate hydro-meteorological data monitoring network which is the key for long term planning of water resources of river basin. To meet the local water demands, state should plan for construction of small dams on Kharun river. The water resources planning should includes issues such as demand management in the river basin, planning of water supply at appropriate level of probability and providing assured water supply to meet demands. WRD should adapt scientific approach like hydrological modeling and use of modern softwares for planning purposes. There is a need to undertake regular awareness programs for field engineers, various water users and stakeholders for judicious use of precious water resources.

1 INTRODUCTION

Water has always been an essential element for survival of livelihood. It is naturally available in space and time, but not necessarily in accordance with man's numerous needs. Since water is limited through renewable resources, the need for its long term planning is increasingly being felt. Chhattisgarh, a newly born state is exploiting its water resources mainly for domestic and industrial water supply and developing irrigation schemes. The surface and ground water resources of the state plays a major role in agriculture, hydropower generation, livestock production, industrial activities, forestry, fisheries, recreational activities, etc. Though the state is endowed with the big river networks like Mahanadi, Godavari, Indravati, Seonath and Narmada, the state is facing the problem of water scarcity in rural as well as in urban areas to meet various water demands. The huge water demand for irrigation, emerging towns and industries on the banks of rivers in Chhattisgarh, has necessitated the need of long term planning for sustainable water resources development, understanding the complex system of hydrological processes, which include rainfall-runoff simulation, water budgeting, land capability analysis, surface water-ground water interaction and soil erosion mechanism. Reliable assessment of water resources and understanding relationships and interdependencies that exist between supply and demand of the natural resources are also vital for water management.

Due to lack of water resources management practices, most of the tributaries in Seonath basin of Chhattisgarh get dried by mid winter season and the rural as well as urban areas under the sub-basin are subjected to severe water crisis during the summer season. Therefore, the need of the hour is to harness the in-situ water resources of the Seonath river sub-basin with scientific inputs so that these developments can be sustained. Monitoring of hydrological data is very important in the study area which is the primary inputs for conducting the various hydrological analyses. Assessment of water demand for various uses and study of supply scenario are the essential elements for planning of water resources management of the region. The rainfall in the sub-basin occurs only within three monsoon months. Tributaries in the study area are ephemeral. Therefore management of water to fulfill the demand throughout the year for various uses as per its availability is essential.

Present study deals with the problem of water scarcity being faced by Chhattisgarh state. It envisages the rainfall runoff modeling, water availability study and study of supply and demand scenario for the water resources development and management plan for the Kharun river basin, a sub-basin of Seonath river. The study also aims to understand the hydrological behavior of river basins to harness the available water resources optimally using scientific approach. The study envisages the measures to resolve these issues for optimal and effective utilization of available water resources to meet various demands of the sub-basin like drinking, industrial and other uses like Nistari and recreation.

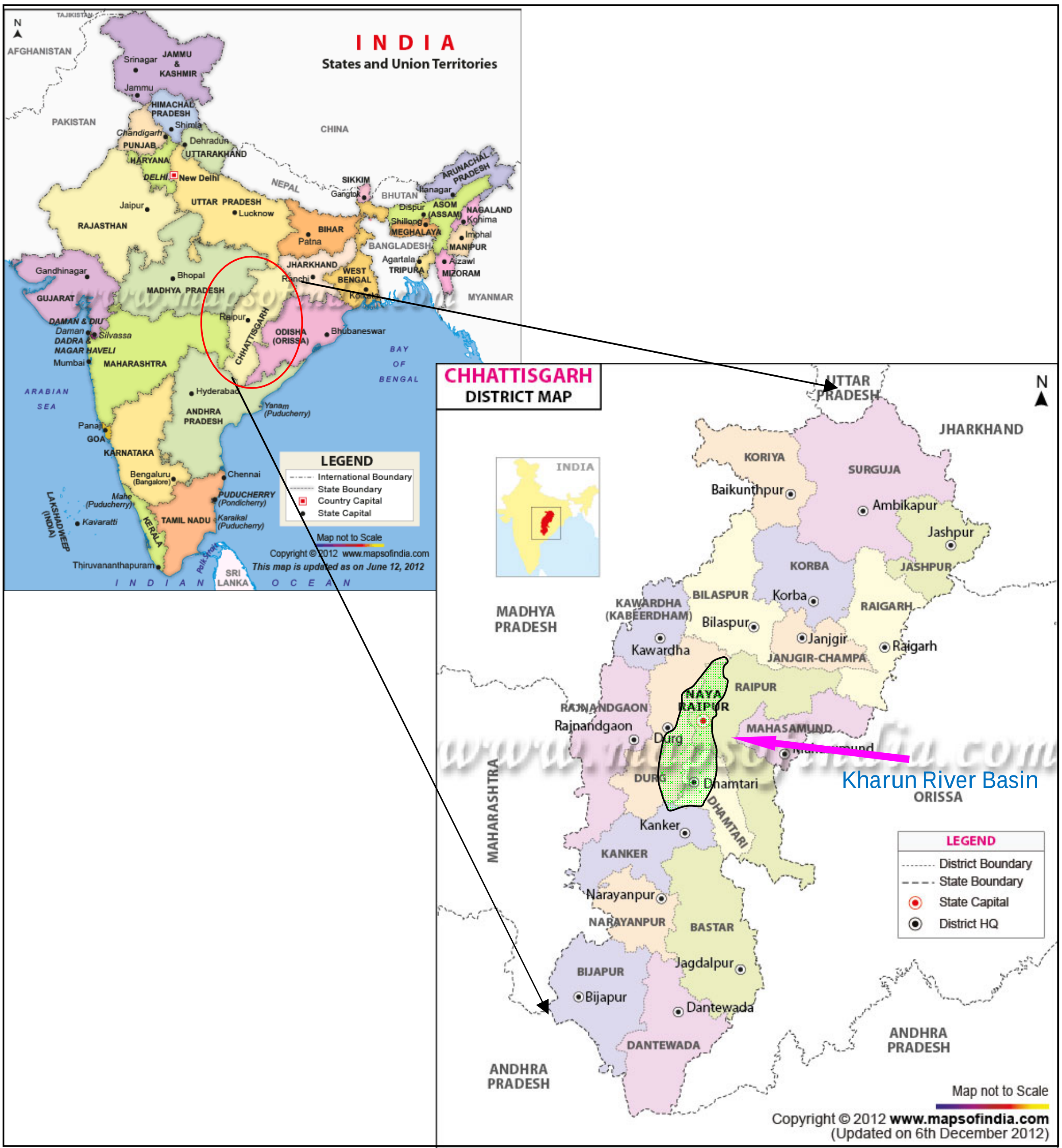
The research oriented approach adopted in the present PDS using the scientific methodologies will be an innovation for tackling the water resources problem highlighted in Seonath basin. The methodologies developed during the course of the study will be helpful in resolving similar type of issues in the other river basins of Chhattisgarh state. It will also help the field engineers to understand and resolve the water resources issues facing the region, scientifically. The study will be of great help to the Chhattisgarh state to adopt strategies for management of existing water resources for its effective use and to develop the resources to meet the additional demand over a long period. The present PDS has been carried out with the following objectives:

- Assessment of drought situation in Kharun basin
- Development of rainfall-runoff model for Kharun river
- Water availability study in Kharun sub-basin
- Assessment of supply-demand scenario
- Optimal utilization of water resources by planning for storage sites (Through Consultancy)
- Evaluation of infiltration characteristics of soil
- Dissemination of knowledge, findings and application of the developed model to field engineers and common people through preparation of manual, leaflets, booklets and by organizing workshops/ seminars every year.

2 STUDY AREA

Chhattisgarh is one of the States which is included in the Hydrology Project Phase-II programme of Ministry of Water Resources funded by World Bank. Chhattisgarh, situated amidst lush green hills and plateaus, is interspersed with several rivers that flow through the state. Due to presence of natural drainage system, Chhattisgarh is blessed abundantly with prolific and fertile plains. This region is characterized by dense forests at some regions, severe soil erosion and increasing water demands. The average annual rainfall in the region is about 1022 mm. Kharun is one of the important tributary of Seonath river. Seonath sub-basin is one of the important sub-basins of Mahanadi river. Kharun river basin falls in Durg, Raipur and Dhamtari districts. The Kharun river basin is situated between 20^o 38' N to 21^o36'N Latitude and 81^o 20' to 81^o55'E Longitude. Kharun river originates from Petechua in the south-east of the Durg district and after flowing 129 km joins Seonath river near Somnath in Raipur district. The index map showing location of Kharun river in Chhattisgarh is shown in Figure 2.1. The map showing location of Kharun river basin in Seonath basin is given in Figure 2.2. The area around Kharun river is very fertile. The area has mainly three different types of soils, i.e. Kanhar, Matasi and Sandy Murrum or sandy soil. This region generally has a dry tropical weather which is moderate but on a warmer side in summer season. The peak temperatures are usually reached in May or June and can be as high as 45^0C. The onset of monsoon is usually from July and the season extends up to September, with monsoon peaking during July and August.

The catchment area of Kharun river basin is 4112 km^2. It flows to the west of Raipur town and supply water to Raipur city through small storage Bhatagaon anicut. It is supplemented from Ravishankarsagar reservoir situated at Dhamtari on Mahanadi river. The major part of Kharun river basin comes under command area of Ravishankarsagar reservoir and small part under Tandula reservoir. The industries like steel plant, cement plant, etc in Urla and Silthara industrial area near Raipur falls in the catchment of Kharun river. The main types of land use and land cover are agriculture, forest, settlements, barren, etc. and main crops are paddy, oilseeds, wheat, gram and vegetable.



(Sources: Maps of India)

Figure 2.1: Index map showing location of Kharun river in Chhattisgarh

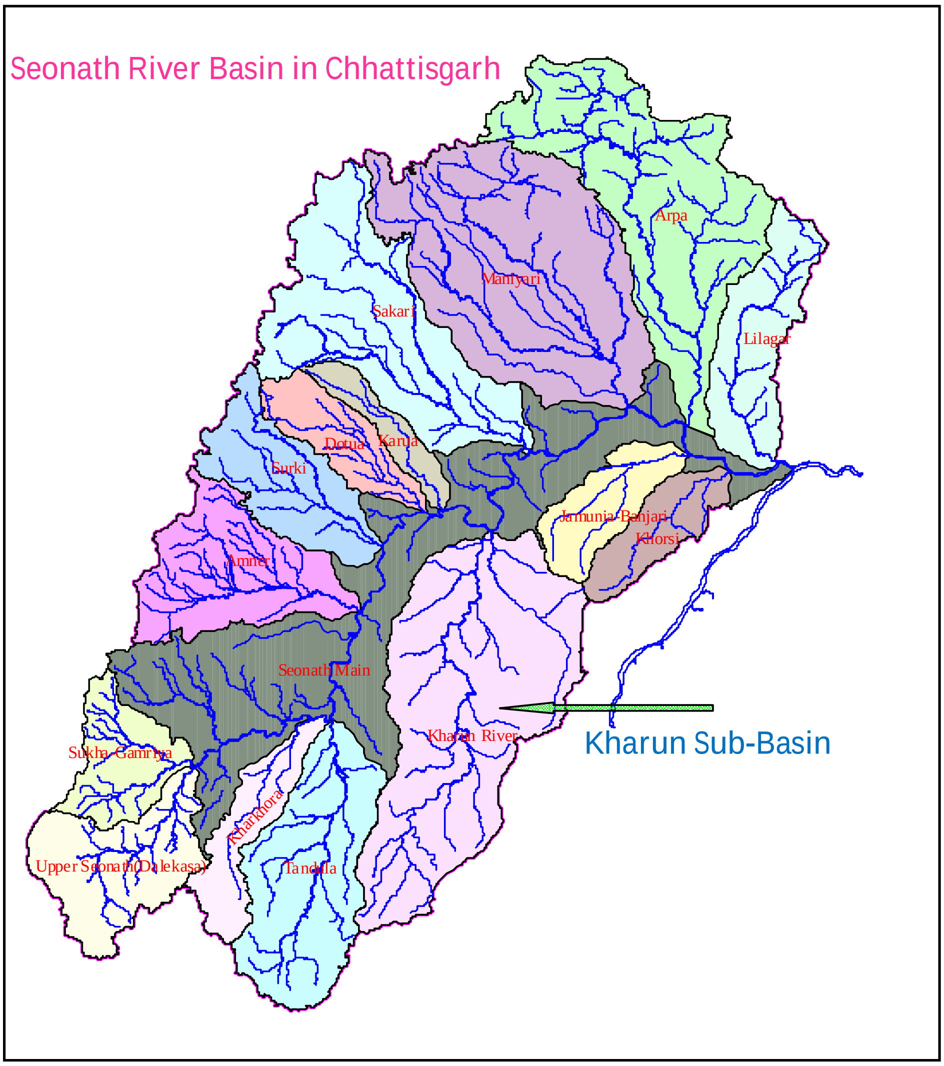


Figure 2.2: Location of Kharun sub-basin in Seonath basin

3 PROBLEM DEFINITION

Mahanadi is one of the important rivers in the Chhattisgarh state. The total catchment area of Mahanadi river Basin is about 75867.63 sq. km. having nine sub-basins. Seonath river is one of the most important river having total fourteen tributaries with total geographical area of 30826 sq. km. As per the estimates made by Water Resources Department, Govt. of Chhattisgarh, the surface water availability in Seonath sub-basin is about 9519.17 MCM and that of groundwater is about 3120.73 MCM. Kharun is one of the important tributary of Seonath river providing domestic water supply to Raipur city, water supply to industrial area and other uses. The major issues characterizing the Kharun river are water scarcity, increasing water demand and under exploitation of the available water resources. The domestic and industrial water demand of Kharun river has been seen increasing speedily due to rapid urbanization and industrialization in Raipur city and its surroundings. However, lack of suitable water management measures leads to most of the precious water being drained down the rivers without being tapped and causing water shortage during lean period to fulfill various water demands. Thus there was an urgent need to carry out systematic research to assess the existing water resources using suitable hydrological modeling technique, preparation of plan for development of water resources to meet various water demands, analysis of supply demand scenario and the optimal utilization of the available water resources in the region. The present study deals with the formulation of the strategies for water resources development and management of Kharun river basin to meet the various water use demands of the basin in future. The scientific study conducted with systematic approach may set up guideline and direction for water resources management and development in the whole Mahanadi Basin.

4 WORK ELEMENTS

- Data collection and preparation of inventory
- Upgradation of Gauge Discharge site and ARG
- Generation of various thematic maps of command and catchments using GIS
- Statistical analysis of rainfall and assessment of meteorological and hydrological drought situation in the study area.
- Development of MIKE BASIN Model of Kharun basin for water resources planning.
- Rainfall runoff modeling using MIKE 11 NAM Model.
- Water availability study for assessment of surface water resources.
- Estimation of various water use demands on Kharun river.
- Analysis of supply-demand scenario in the sub basin and estimation of future water requirement.
- Optimal utilization of water resources by planning for storage sites on river to meet future water requirements (Through Consultancy)
- Evaluation of hydrological properties of soil and development of regional infiltration model.
- Dissemination of outputs by organization of trainings and workshops.

5 PREPARATION OF AN INVENTORY

The main aim of preparation of an inventory and creating data base of the study area was to systematically organize various data like meteorological, hydrological, agricultural, demographic, relevant statistical information and geographical data at one place, which can be further used in various studies and projects for water resources management. The data and information required for the study was collected from various state and central agencies in the region. The database thus prepared will be useful to administrators, policy makers, Water Resources Department, Agriculture Department, Water Users Associations and many state and central agencies responsible for water resources development in the region. This information will be useful for development of water supply schemes, irrigation planning, drought management, flood control, agricultural management, etc. The status of data collection under PDS study is explained in details in this section. The complete data and information of PDS study is available at the both investigation agencies.

5.1. Daily Rainfall Data

The daily rainfall data 13 rain gauge stations of WRD, Raipur and IMD Pune falling in and around Kharun river basin was collected and its status is given in Table 5.1 below:

Table 5.1: Rainfall data availability

S. No.	Station	Daily Rainfall data Availability
1.	Raipur	Jan. 1971 to Dec 2008
2.	Bhatagaon	Jan. 1960 to April 2009
3.	Bhilai	Jan. 1960 to April 2005
4.	Chhati	June 1982 to May 2009
5.	Dhamda	Jan. 1993 to Dec 2007
6.	Dhamtari	Jan. 1960 to April 2009
7.	Durg	Jan. 1970 to June 2008
8.	Gurur	June 1973 to Dec 2008
9.	Kurud	Jan. 1960 to Dec 2008
10.	Patan	Jan. 1993 to Dec 2008
11.	Pindrawan	Jan. 1974 to August 2008
12.	Selud	Jan. 1960 to may 2008
13	Simga	Jan. 1961 to April 2009

5.2. Gauge-Discharge Data

The Gauge-Discharge data was collected as given below:

i. Amdi, WRD, Raipur site having record from year 2000 to 2008

ii. Patherdihi, CWC site having data from year 1989 to 2008

5.3. Ground Water Data

Ground water data was collected from Ground Water Survey, W.R.D., Raipur and its details are given in Table 5.2 below.

Table 5.2: Ground water data availability

S. No.	Station	GW Data Availability
1.	Dhamtari	1973 to 2008
2.	Durg	1974 to 2008
3.	Mahasamund	1973 to 2008
4.	Raipur	1973 to 2008

5.4. Agricultural Data

The agricultural information like crops, area under irrigation, yield, etc. was collected from State Agricultural Department at Raipur.

5.5. Meteorological Data

The meteorological data such as temperature, sunshine hours, evaporation, wind velocity and humidity for the period from 1971 to 2008 was collected from Department of Agricultural Engineering, Indira Gandhi Krishi Vishvavidyalay, Raipur. The additional meteorological data required for the study was procured from IMD Pune.

5.6. Demographic Data

The demographic information (population) of the study area was evaluated from the Census-2001 data which was collected from Bhopal.

5.7. Land Use Information

To extract the land use information of the Kharun basin the Remote Sensing data including four numbers of scenes of LISS-III sensor was procured from NRSA Hyderabad. The details are as given Table 5.3 below.

Table 5.3: Remote sensing data

Scene No.	Path	Row	Date	Sensor	Satellite
1	102	57	24/10/09	LISS-III	IRS-P6
2	102	57	26/02/09	LISS-III	IRS-P6
3	102	58	24/10/09	LISS-III	IRS-P6
4	102	58	26/02/09	LISS-III	IRS-P6

5.8. Generation of Maps

Various layers of information on drainage, soil, geology, etc. were prepared using Arc GIS for the further use in hydrological analysis. These layers were prepared using Survey of India toposheets No. 64G and 64H. The soil and geological layers were prepared using soil and geological maps of study area. The land use map was prepared using remote sensing data of the study area. These maps are shown in Figure 5.1 to 5.4.

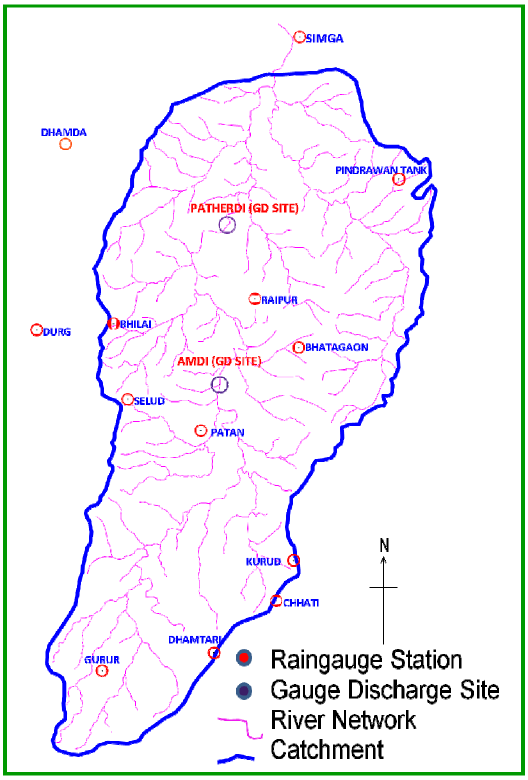


Figure 5.1: Map of Kharun river basin

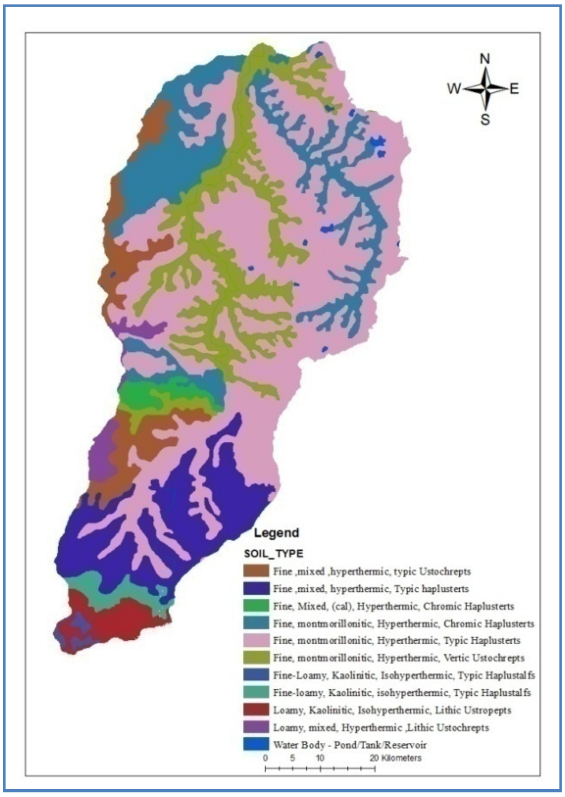


Figure 5.2: Soil map of Kharun river Basin

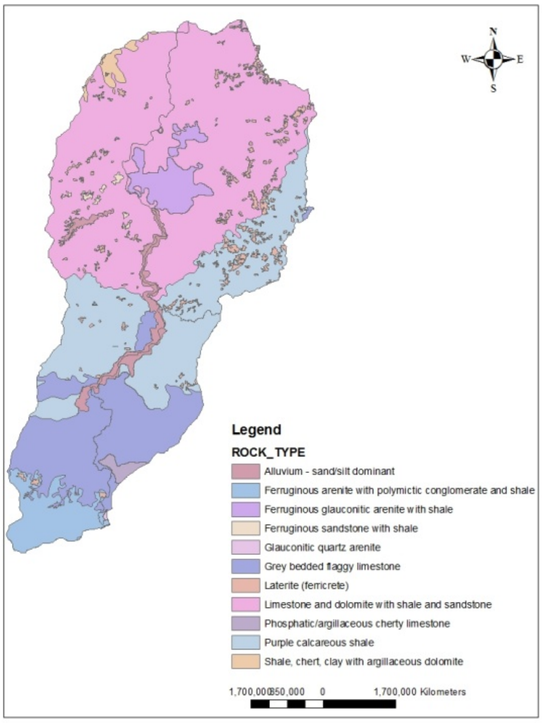


Figure 5.3: Geological map of Kharun river Basin

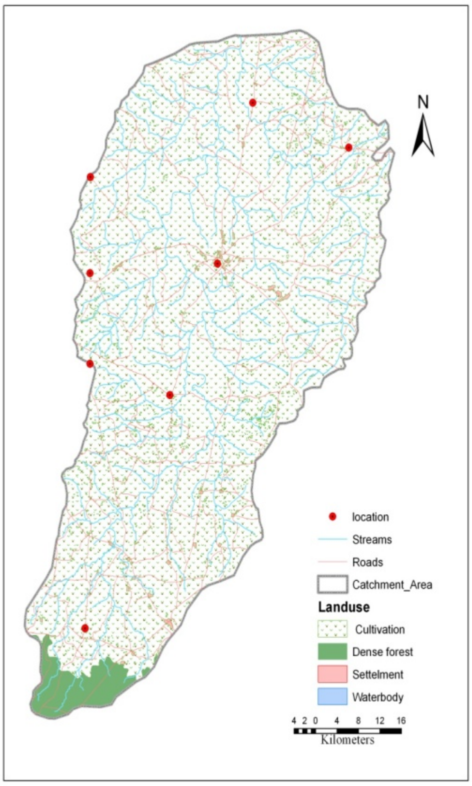


Figure 5.4: Land use map of Kharun river Basin

5.9. Upgradation of Gauge Discharge Site and ARG

The Water Resources Department, State Data Centre, Raipur has been maintaining the Amdi Gauge Discharge site on Kharun river. The condition of gauging site was not satisfactory as the site was established long back, thus to record the reliable and good quality flow data of Kharun river the state had proposed for upgradation of Amdi G/D site. Under the PDS study, the WRD, Raipur has upgraded the G/D site and carried out work for fixing of gauge post and plates, construction of observation and study quest, and replaced ARG (automatic rain gauge) with Tipping Bucket type rain-gauge at Amdi. After the upgradation, the flow measurement is being carried out regularly at this site.

5.10. Collection of Field Information

During the study period, number of field surveys and field visits were conducted in the study area and discussions were held with field officers and local peoples to understand the complex water transfer system of Kharun river. From the information obtained, it was seen that the Kharun is one of the important tributary of Seonath river, falling in Durg, Raipur and Dhamtari districts. The Kharun river basin comes under command area of Ravishankarsagar and Tandula reservoir. Kharun river has been regularly been supplemented from Ravishankarsagar reservoir to meet the various water demands in the basin. The water from Kharun River has been diverted to meet the domestic water demand Raipur city, industrial water demand of Silthara and Urla industrial area, water supply for railways and other water demands through series of anicuts. The photographs of showing panoramic view of Kharun river and various anicuts on it are shown below.

Panoramic view of Kharun river

Bhatagaon anicut providing water supply to Raipur city

Pump house at Murethi anicut providing water supply to Silthara industrial area

Field visit of NIH, Bhopal and WRD, Raipur officers to Kharun river basin

6 ASSESSMENT OF DROUGHT SITUATION

Information on recurrence of drought can provide the important inputs to the planners for water resources development and management in the region. Drought is generally viewed as a sustained and regionally extensive occurrence of appreciably below average natural water availability, either in the form of precipitation, surface water runoff or ground water (Gbeckor-Kove, 1995). Meteorological drought is usually defined by the measure of the departure of precipitation from the normal and the duration of the dry period. According to the National Commission on Agriculture (1976), agricultural drought refers to the inadequate soil moisture during crop growing period and the hydrological drought refers to marked depletion of surface water storage in lakes, reservoirs, rivers and streams etc. in fact the meteorological drought precedes the agricultural and hydrological drought. The agricultural and hydrological drought needs not to occur simultaneously but occur subsequent to a meteorological drought (Sastry, 1986). The present study is aimed to study the meteorological and hydrological aspects of droughts in Kharun river basin of Chhattisgarh for the assessment of threat imposed on water resources of the region. The drought situation in Kharun river basin has been studied by the departure analysis of annual rainfall and low flow analysis of stream flow data. Low stream flows and reduced reservoir storages are indicative of drought situations.

6.1 Assessment of Meteorological Drought

According to WMO (1975) Meteorological drought is characterized by the water shortage induced by the imbalance between precipitation and evaporation, in particular, water shortage based solely on precipitation e.g. rainless situation. Meteorological drought over an area is defined as a situation when seasonal rainfall over the area is less than 75% of its long term normal. It is further classified as “moderate drought” if the rainfall deficit is between 26 and 50% and “severe drought” when it exceeds 50%.

6.1.1 Annual rainfall departure analysis

The Kharun basin has 11 raingauge stations within its catchment. Out of these 11 stations only five stations had a data of sufficient length which is one of the prerequisite to study rainfall distribution and the magnitude and frequency of drought in terms of rainfall deficiency. For meteorological drought assessment in Kharun river basin, five raingauge stations, Raipur, Bhatagaon, Dhamtari, Kurud and Pindrawan having long term rainfall record i.e. from 1972 to 2008 (37 years) were selected for annual rainfall departure analysis and subsequently to identify drought years. Normal annual rainfall was calculated as the arithmetic mean of the rainfall. The annual rainfall departure analysis comprises of the following steps:

(1) Determining the mean (Xm) for a set of annual rainfall data.

$$X_m = \frac{1}{n}\sum_{i=1}^{n} X_i \quad \ldots (6.1)$$

(2) Calculating departure (*Di*) by subtracting the mean (*Xm*) from the individual annual rainfall data (*Xi*).

$$Di = (X_i - X_m) \qquad \text{. . . (6.2)}$$

(3) From resulted departure (Di), the departure percentage ($D_{\%}$) is calculated as follows

$$Di = \frac{D_i}{X_m} \qquad \text{. . . (6.3)}$$

Indian Meteorological Department defined annual drought as the period with the annual rainfall deficiency more than 25% from its normal value. The drought severity has been classified on the basis of percentage deviations from the normal rainfall into two severity classes namely, moderate and severe drought. A moderate drought occurs when the percentage annual rainfall departure lies between 26 to 50% and if the departure percentage is greater than 50% the year is considered to be severe drought year. The annual rainfall departure from its mean at Raipur and Bhatagaon stations are shown in Figure 6.1 and 6.2. From the annual rainfall departure analysis, the drought years were been identified and its average frequency of droughts is presented in Table 6.1.

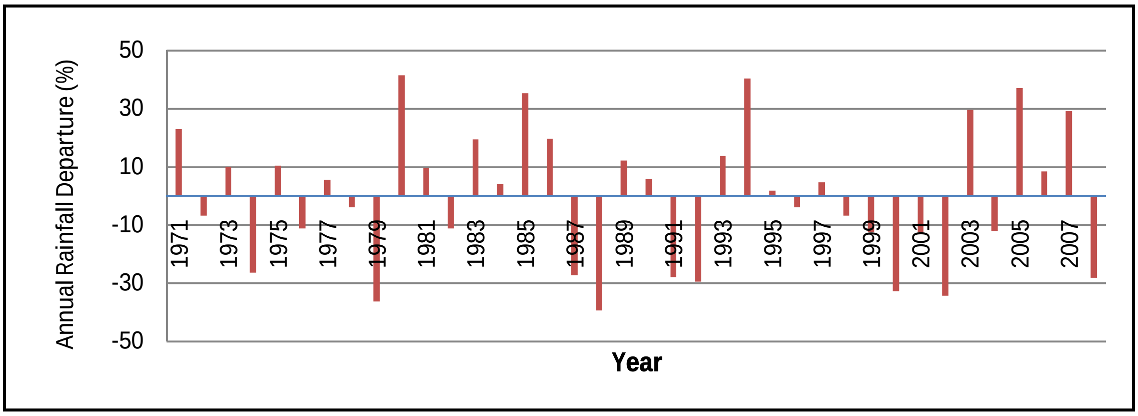


Figure 6.1: Rainfall Departure Analysis to identify rainfall deficit years at Raipur

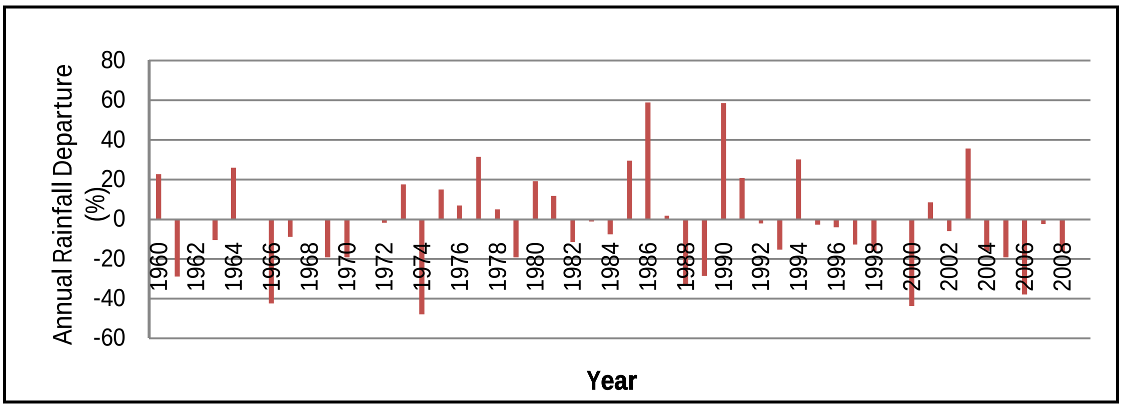


Figure 6.2: Rainfall Departure Analysis to identify rainfall deficit years at Bhatagaon

Table 6.1 : Frequency of drought years in Kharun river basin

SI. No.	Name of Station	Mean annual rainfall (mm)	Average drought frequency in every 10 years	Years with more than 25% deficiency in annual rainfall
1	Raipur	1167	2	1974, 1979, 1987, 1988, 1991,1992, 2000, 2002, 2008
2	Bhatagaon	1267	1	1974, 1988, 1989, 2000, 2006
3	Dhamtari	1073	2	1972, 1979, 1981, 1982, 1987, 1998, 2002, 2008
4	Kurud	1088	2	1979, 1987, 1988, 1996, 2000, 2006
5	Pindrawan	913	2	1979, 1982, 1983, 1988, 1996, 1998

6.1.2 Results

From the frequency analysis of annual rainfall shown in Table 6.1, it was observed that the Kharun river basin experiences on an average two drought years in every 10 years period with 20% frequency. All drought events observed in the basin were the moderate drought events i.e. rainfall deficit was 26 to 50% of normal rainfall. Thus it could be concluded that meteorological droughts do not impose much threat to the water resources in the study area.

6.2 Assessment of Hydrological Droughts

The occurrence of drought leads to reduction in river flow, consequent reduction in reservoir and tank levels and depletion of soil moisture and groundwater. The surface water deficits are reflected through low stream flows and reduced reservoir storages. When the stream flows are not sufficient enough to meet the required demand of water, it is considered that the drought has set in. The drought severity, frequency and duration can be studied by low flow analysis of the local streams. During the rainfall deficient condition the deviation from normal values is greater for stream flows than the rainfall. The low stream flows are indicative of drought situations (Galkate et. al., 2010). In the present study, hydrological aspects of droughts have been studied in Kharun river basin through stream flow analysis using 18 years flow data of Patherdihi Gauge discharge site of CWC on Kharun river located at Latitude $21^0\ 20^{'}\ 28^{''}$ N and Longitude $81^0\ 35^{'}48^{''}$ E near village Kumhari.

6.2.1 Flow duration curve

It is well known that the stream flow varies over a water year. One of the popular methods of studying this stream flow variability is through flow-duration curves. A flow-duration curve of a stream is a plot of discharge against the percent of time the flow was equaled or exceeded. This curve is also known as discharge frequency curve. The stream flow data is arranged in descending order of discharges, using class intervals if the number of individual values is very large. The data used can be daily, weekly, and 10 daily or monthly values. If N numbers of data points are used in this listing, the plotting position of any discharge Q is given by following equation.

$$p_P = {m}/{(N+1)} * 100 \qquad \ldots (6.4)$$

Where, P_p = percentage probability of the flow magnitude being equaled or exceeded
m = the order number of the discharge
N = number of data points

The plot of the discharge Q against P_p is the flow duration curve. Arithmetic scale paper or semi-log or log-log paper is used depending upon the range of data and use of the plot. The flow duration curve represents the cumulative frequency distribution and can be considered to present the stream flow variation of an average year. The ordinate Q_p at any percentage probability Pp represents the flow magnitude in an average year that can be expected to be equaled or exceeded Pp percent of time and is termed as P_p % dependable flow. In a perennial river Q_{100}=100% dependable flow is a finite value. On the other hand in an intermitted and ephemeral river the stream flow is zero for a finite part of a year and as such Q_{100} is equal to zero. Flow-duration curves find considerable use in water-resources planning and development activities such as evaluating various dependable flows in the planning of water-resources engineering projects, evaluating the characteristics of the hydropower potential of a river, design of drainage system, flood-control studies, computing the sediment load and dissolved solids load of a stream and comparing the adjacent catchments with a view to extend the stream flow data

6.2.2 Analysis of flow duration curves

In analyzing the stream flow drought, one of the simplest techniques is to construct a flow duration curve for the given river. The daily flow data of Patherdihi site has been used to prepare monthly flow duration curves for all 12 months of the year and flow duration curves for the August month is shown in Figure 6.3. The flow volumes at 75% probability levels at site are obtained for flow duration curves and results of which are presented in Table 6.2. The flow volumes at 75 % probability are considered as truncation level to obtain deficiency volume and its severity for each event of low flow condition. Severity is the total deficit or cumulative deficient runoff volume below the truncation level during the period of the event of low flow condition. Thus the departure analysis has been carried out and the events of low flow condition persisting for more than ten days period were identified. The low flow events, their severities and durations are presented in Table 6.3.

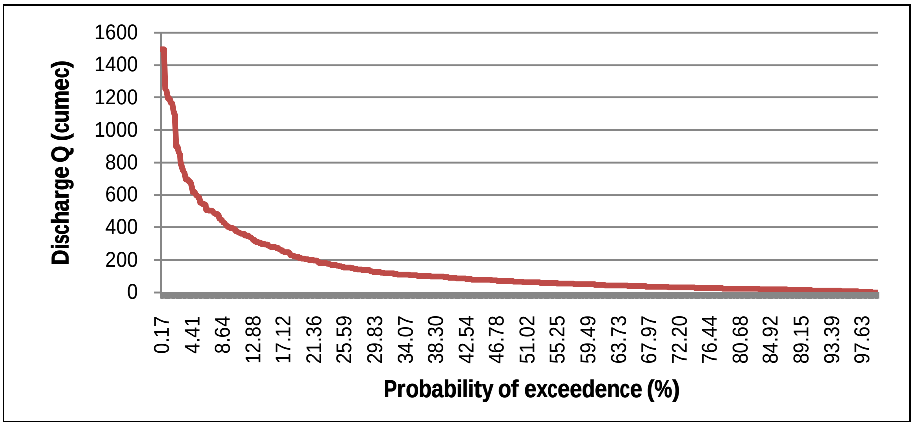


Figure 6.3: Flow duration curves for August month flow at Patherdihi

6.2.3 Estimation of truncation level

The variable truncation approach is efficacious in depicting both the drought and wet events and therefore, in describing drought duration and severity (Pandey et. al., 2008). For determination of the truncation level, it is necessary to derive first the flow duration curve using monthly data. For stream flow data, where the problem of zero flows is encountered, can be resolved as follows:

The number of 'zero flow' and 'non-zero' flow values for each month can be separated from the available flow records to determine the percentage probability of occurrence of zero flow in each months as:

$$P_i = X_i / N \qquad \text{. . . (6.5)}$$

Where Pi = probability of zero flow in the i^{th} month;

i = an integer varying from 1 – 12;

Xi = number of zero flow values in the i^{th} month,

N = total number of flow records for the i^{th} month (i.e. number of years of records).

Then the non-zero flow values for each month are arranged in the descending order to rank the highest as 1 and the lowest as (N-Xi) for computation of the joint probability of exceedance as:

$$P_{nz_{j,i}} = (1 - P_i)\frac{R_{j,i}}{N - X_i} \qquad \text{. . . (6.6)}$$

Where $R_{j,i}$ = rank of the j^{th} flow value of the i^{th} month

$Pnz_{j,i}$ = join probability of the exceedance of the jth value of the non-zero flow in the i^{th} month

i = an integer varying from 1 – 12;

j = an integer varying from 1 – (N-Xi);

Table 6.2: Derived truncation level at 75% Probability at Patherdihi

Sl. NO.	Month	Volume in cumec At 75% dependability
1	June	0.00
2	July	3.17
3	August	28.6
4	September	20.98
5	October	12.17
6	November	2.10
7	December	0.754
8	January	0.55
9	February	0.255
10	March	0.00
11	April	0.00
12	May	0.00

Thus the flow duration curve for each month can be derived by plotting the joint probability of exceedance of non-zero flow values ($Pnz_{j,i}$) against the corresponding discharge value, and a truncation level corresponding to a fixed, for example 75 percentile (Kjeldsen et. al. 2000) can be determined.

Table 6.3: Severity of Low Flow and its duration at Patherdihi
(Flow data of period from July 1989 to Oct 2008)

S.No.	Event	Onset of Event	Termination of Event	Severity MCM	Duration (days)
1	I	06/10/1989	31/10/1989	14.64	26
2	II	08/11/1989	03/12/1989	1.57	26
3	III	11/12/1989	26/12/1989	0.17	16
4	IV	21/01/1990	02/02/1990	0.13	13
5	V	05/09/1991	23/09/1991	20.04	19
6	VI	27/09/1991	09/10/1991	6.59	13
7	VII	01/07/1992	20/07/1992	3.33	20
8	VIII	19/09/1992	12/10/1992	16.33	24
9	IX	01/07/1996	16/07/1996	3.33	16
10	X	01/07/1999	20/07/1999	4.21	20
11	XI	01/08/2000	16/08/2000	24.59	16
12	XII	05/09/2000	28/02/2001	80.26	177
13	XIII	20/10/2001	31/10/2001	4.42	12
14	XIV	01/07/2002	15/08/2002	37.11	46
15	XV	08/09/2002	17/10/2002	42.89	40
16	XVI	15/11/2002	28/02/2003	5.35	106
17	XVII	17/02/2004	29/02/2004	0.26	13
18	XVIII	08/11/2004	12/12/2004	2.11	35
19	XIV	14/12/2004	05/01/2005	0.64	23
20	XX	10/01/2005	28/01/2005	0.46	19
21	XXI	19/02/2005	28/02/2005	0.14	10
22	XXII	18/11/2006	30/11/2006	0.83	13

23	XXIII	18/12/2007	31/12/2007	0.87	14

6.2.4 Results

Low flow analysis was carried out in Kharun river basin using daily stream flow data. The probability of occurrence of particular flow at the particular site can be established with the help of Flow Duration Curves, which is helpful for planning of water resources projects. From Table 6.2, it could be seen that the maximum 75% dependable flow was 28.6 cumec in August whereas the minimum 75% dependable flow was 0.00 cumec in March April May and June.

Analysis had also been carried out to obtain deficit volume and severity of low flow at the Patherdihi site as shown in Table 6.3. From the departure analysis of stream flow from its truncation level, it was observed that the Kharun river had experienced low flow epoch for 23 times over the period of 18 years period (1989-2007) indicating 1 or 2 low flow condition every year. It was observed that low flow events in this basin usually begin during July to October and terminate during November to December. The severity of low flow in the river varied from 0.13 to 80.26 MCM and durations of low flow epochs were ranging from 13 to 177 days. The maximum severity of 80.26 MCM was observed for 177 days during September, 2000 to February, 2001. The years 1989, 2002 and 2004 had experienced three low flow events each, which were highest in any one year. In the year 1989 three low flow events of total 68 days had experienced total severity of 16.38 MCM. In the year 2002 three low flow events of total 172 days had experienced total severity of 85.34 MCM. In the year 2004 three low flow events of total 71 days had experienced total severity of 3.02 MCM. Therefore it could be concluded that year 1989, 2002 and 2004 were the years of deficit runoff volume at Patherdihi and were considered as hydrological drought years. The information on frequency of occurrence of low flow and runoff volume deficit in river is useful in improvement of existing backup practices and to undertake water resources management and development of river basin in systematic manner to meet the various water demands.

7 DEVELOPMENT OF MIKE BASIN MODEL OF KHARUN RIVER

Kharun is one of the important tributary of Seonath river having catchment area 4112 km^2. Kharun river basin falls in Durg, Raipur and Dhamtari districts. The major part of Kharun river basin comes under command area of Ravishankarsagar reservoir and small part under Tandula reservoir. The water from Kharun River has been diverted to meet the domestic water demand Raipur city, industrial water demand of Silthara and Urla industrial area, water supply for railways and other water demands through series of anicuts. As there is no water storage structure (dam) on Kharun river, the river is being supplemented from Ravishankarsagar reservoir to meet the various water demands. Thus the flow regime in Kharun is strongly influenced by regulation operations associated with water transfer from Ravishankarsagar reservoir into the river and its supply for various usages through the series of anicuts.

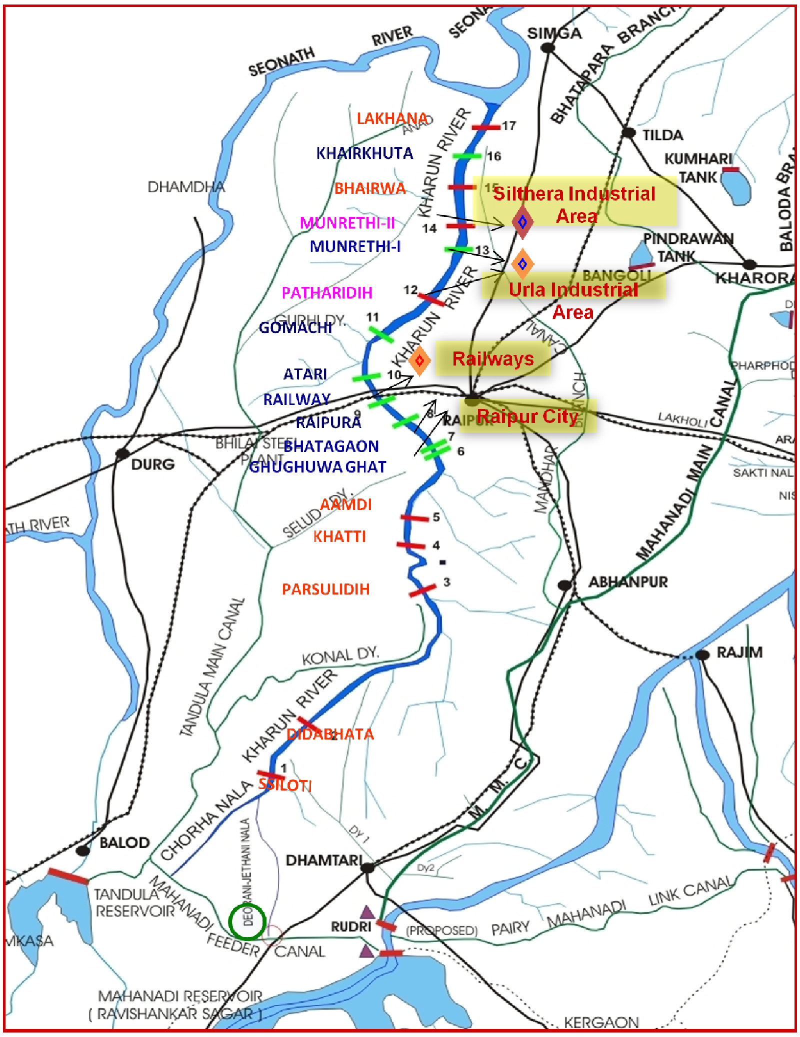


Figure 7.1: Schematic of water transfer system of Kharun river

The discharge data available at Amdi and Patherdihi G/d site is therefore of regulated nature having effect of regulation operation. When there exists such inter basin transfer, storage or diversion works on a stream, the flow in the downstream channel is affected by structures and hence does not represent the true runoff unless corrected for water transfer effects, storage effects and the diversion of flow and return flow. In the present study true runoff time series of the basin was needed for long term planning of water resources of the basin, hence the MIKE BASIN model of Kharun river was developed. The MIKE BASIN model of Kharun thus developed was used for estimation of virgin flow at desired location in Kharun river, water availability study at various location under virgin and regulated condition and deriving information for supply demand anaysis. The water transfer system from Ravishankarsagar reservoir to Kharun river and diversion of water from series of anicuts to meet various demands are demonstrated in detail by schematic shown in Figures 7.1 and 7.2.

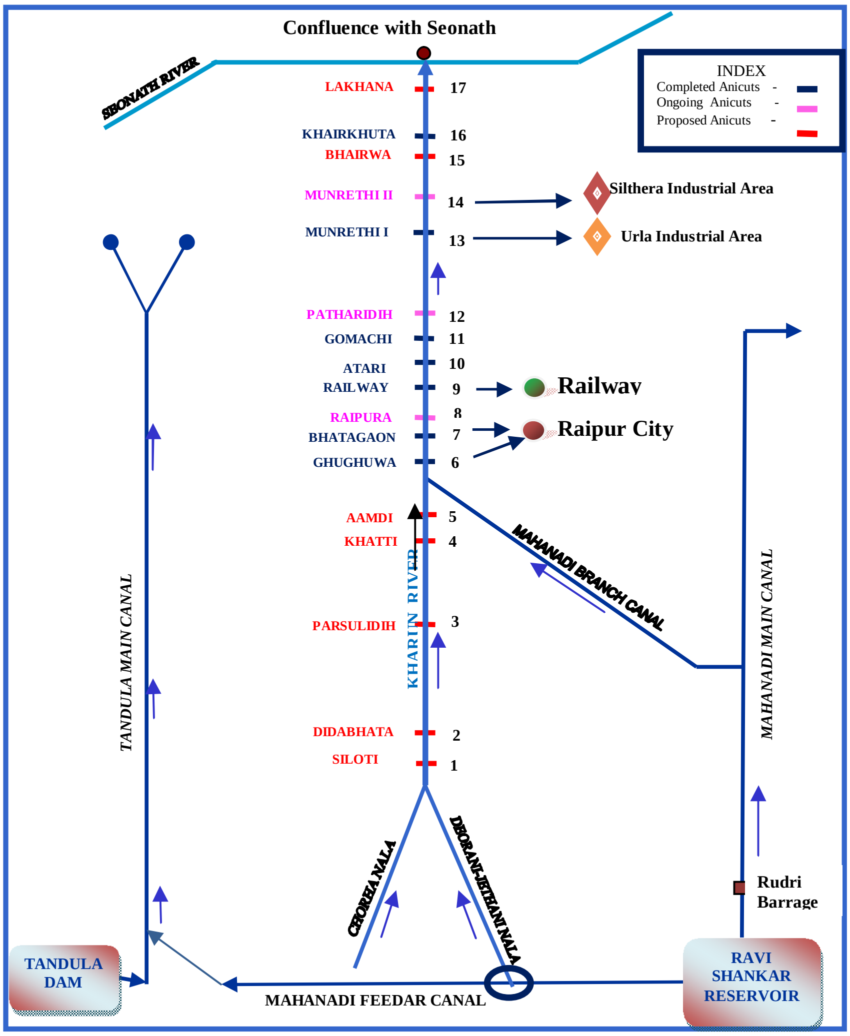


Figure 7.2: Schematic of water transfer system of Kharun rivers

From the Figure 7.1 and 7.2 it is seen that the water from Ravishankarsagar reservoir is being released into Kharun river from Mahanadi Feeder Canal (*MFC*) through Deorani Jethani Nala. The Mandhar Branch Canal (*MBC*) a major distributor of Mahanadi Main Canal (*MMC*) directly releases water into Kharun river. The water transferred into Kharun river is utilized to meet various water demands like domestic water demand of Raipur city, industrial water demand of Urla and Silthara industrial area, water supply for railways and other water demands. The irrigation water supplied through Mahanadi Main Canal (*MMC*) and Tandula Main Canal (*TMC*) in Kharun catchment area also joins the river in the form return flow and has significant contribution to the river. The flow in Kharun river is highly regulated and influenced due to various regulation operations like water transfer, addition and diversions associated with it. Thus the MIKE BASIN model of Kharun river was developed depicting all water transfer operations associated using base map, drainage network and all water addition and diversion time series. MIKE BASIN is a network model in which the river and their tributaries are represented by network of branches and nodes. The river system is represented in model by digitized river network which can be generated directly in Arc Map 9.1 (DHI. 2003). Wubet, et. al. (2009) used MIKE BASIN model to gain an insight in to the potential downstream consequences of the development of physical infrastructure and water abstraction in a number of future development scenario in Abbay river basin in Ethiopia. The existing water transfer setup of Kharun river basin is depicted through MIKE BASIN Model and is shown in Figure 7.3.

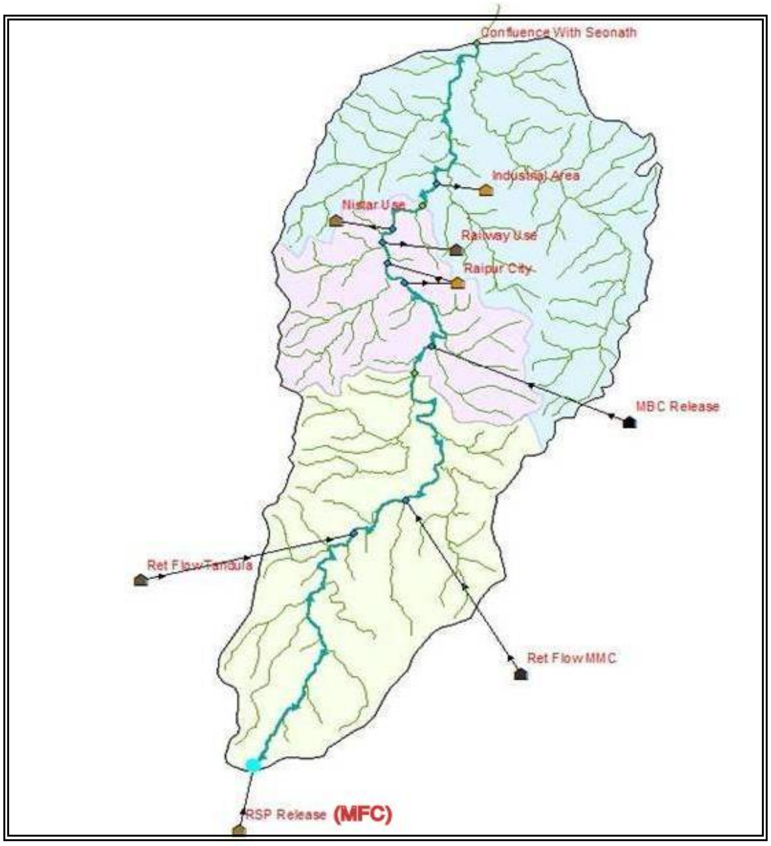


Figure 7.3: Kharun River Basin Model in MIKE BASIN

The various data used to develop the model were actual observed flow at Patherdihi G/D site, flow data from Mahanadi Feeder Canal to river through Deorani Jethani Nala, flow from Mandhar Branch Canal to river, return flow added from command areas of Tandula and Mahanadi Main Canal system, water diverted from river to Raipur city domestic water supply, railway and for the Nistari (public utility) purposes.

8 RAINFALL RUNOFF MODELING USING MIKE 11 NAM MODEL

8.1 Introduction

In water resources planning and development process, it is an essential to measure available water resources in the river system. The water availability in the river basin can be assessed using runoff or discharge data. In India the river gauging network is not adequate and data availability is very poor. In such circumstances the rainfall is transformed to generate the runoff by developing relationship between rainfall and runoff or by using suitable rainfall runoff model. Transformation of rainfall to runoff is rather very significant for the estimation of the available water resources and to explore the new sources of water. Estimation of water flowing down the natural streams is not easy, that too when it is to be estimated on a continuous basis. In order to know the quantity of water flowing in the streams, indirect approaches are adopted for estimating the runoff by knowing the amount of rainfall in the catchment areas. The runoff process is simulated by inputting the rainfall and some other characteristics of the catchment in a suitable mathematical model, thereby transforming the rainfall into runoff. Rainfall runoff modeling thus forms an important component of many hydrological studies and plays an essential character in water resource planning and management of river basins.

The relationship between precipitation and runoff is extremely complex owing to temporal and spatial variability of river basin characteristics, heterogeneity in precipitation, as well as numerous factors involved in generating runoff. Among the components involved in transforming precipitation to runoff, the dominant ones are evaporation, infiltration, soil moisture, overland flow, and channel flow. In addition, soil properties, land use, and geomorphology of catchment also play an important role. Consequently, modeling the rainfall-runoff process is a complex task. That’s why the development and the application of rainfall-runoff models have been a foundation of hydrological research for many decades. In general, the purpose of the development of these models is a two-fold. The first is to advance our understanding and state of knowledge about the hydrological processes involved in the rainfall-runoff transformation. The second is to provide practical solutions to many of the related environmental and water resources management problems. Chiew et. al., (1993) compared six different modeling approaches for the simulation of stream flows. They concluded that simpler models might provide adequate estimates of monthly and annual yields. Mimikov et. al., (1992) and Hughes (1995) have applied some models to different arid and semi-arid regions for prediction of stream flows. In the Indian conditions, Mehrotra et. al., (1996) studied the influence of model parameters in which six rainfall runoff models were analyzed with respect to the efficiency of the model and aridity of the catchment.

This present study deals with the rainfall runoff modeling in Kharun river basin of Chhattisgarh state. The main rivers flowing through the Chhattisgarh state are Mahanadi, Indravati, Godavari and Narmada. These rivers, with many other tributaries, local rivers, and streams drain the state. The northern part of Chhattisgarh shares a part of the Indo-Gangetic plain. The Satpura Range and the Chota Nagpur Plateau divide the Mahanadi River basin from the Indo-Gangetic plain. The Mahanadi river basin, basically, forms the central part of the state. The southern zone of Chhattisgarh includes a part of the Deccan plateau and is served by the Godavari river and its tributaries. Chhattisgarh state has an adequate network of rivers and sufficient water resources potential to meet its water requirements for different uses. But due to the lack of water resources management practices, most of the tributaries in the state gets dried by mid winter season and the rural as well as urban areas under the sub-basin are subjected to severe water crisis during the summer season.

Present study envisages the rainfall-runoff modeling using MIKE 11 NAM Model in Kharun River in Chhattisgarh state. State is experiencing rapid population growth, industrial growth and agricultural development which have increased the water demands. Kharun is one of the important tributary of Seonath river having catchment area 4112 km^2. Kharun river basin falls in Durg, Raipur and Dhamtari districts. The major part of Kharun river basin comes under command area of Ravishankarsagar reservoir and small part under Tandula reservoir. The water from Kharun River has been diverted to meet the domestic water demand, industrial water demand, water supply for railways and other water demands. The flow regime in Kharun is strongly influenced by regulation operations associated with water transfer from Ravishankarsagar reservoir and its supply for various usages through the series of anicuts. Hence it is imperative to estimate the virgin flow (unaltered or neutralized flow), which has to be used as input in rainfall runoff modeling. The rainfall runoff modeling study in Kharun river basin has been conducted with following objectives.

- Estimation of virgin flow from regulated flow using MIKE BASIN software
- Estimation of evapotranspiration using CROPWAT 8.0 software
- Rainfall-Runoff modeling using MIKE-11 NAM Model.

The map showing view of Kharun river basin, location of raingauge station and gauge discharge sites is presented in Figure 8.1.

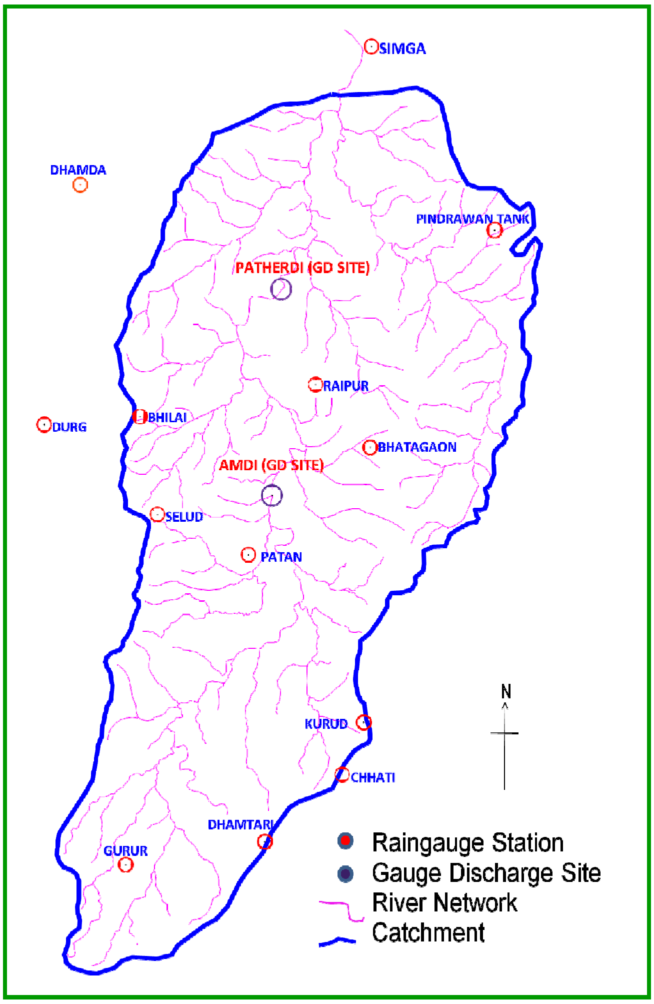


Figure 8.1: Map of Kharun river basin

8.2 Study Area for Rainfall-Runoff (RR) Modeling

The rainfall runoff modeling in Kharun river basin has been carried out using the observed flow data of Patherdihi gauge discharge site. The Kharun river has two gauging sites Amdi and Patherdihi. The flow data at Patherdihi is found more consistent and reliable hence rainfall runoff modeling was carried out at Patherdihi. The catchment area of Kharun river basin is 4112 km^2 and catchment area up to Patherdihi is 2112 km^2. Location of Patherdihi gauge discharge site, location of rain gauges and area covered under Patherdihi site are shown in Figure 8.2.

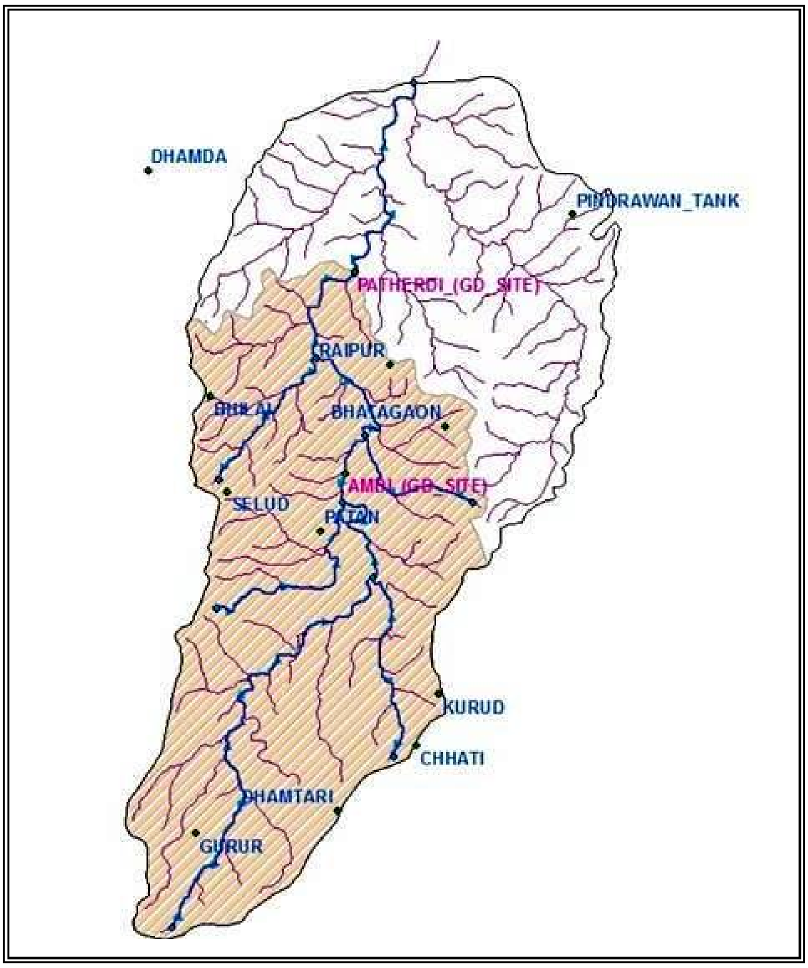


Figure 8.2: Map showing Kharun basin highlighting area up to Patherdihi G/d site

8.3 Input Data

The MIKE11 NAM rainfall runoff model needs long period hydrological and meteorological data like rainfall, runoff, temperature, wind speed, humidity etc as an input to run the model. The model simulates the flow as the response of these parameters in the catchment. The simulations and results are thus depends upon the quality and consistency of data and the proper modeling procedures. Thus all required input data was arranged and processed before using it in the model. The daily rainfall data availability of 8 rain gauge stations falling under catchment area of Patherdihi G/D sites is given in Table 8.1 below. The daily gauge- discharge data from year 1989 to 2008 of Patherdihi site was available for the rainfall runoff modeling. The meteorological data such as temperature, sunshine hours, evaporation, wind velocity and humidity for the period from 1971 to 2008 has been used in the study for estimation of evapotranspiration. After examining the rainfall records it was observed that most of the stations in the study area had the regular and consistent data after the year 1993 for which the other meteorological data and good quality flow data was also available. Thus the RR modeling was carried out by using data for the period from 1993 to 2007. This data was again processed and corrected before using it in the modeling.

Table 8.1: Rainfall data availability

S. No.	Station	Daily Rainfall data Availability
1.	Bhatagaon	January 1960 to April 2009
2.	Bhilai	January 1960 to April 2005
3.	Chhati	June 1982 to May 2009
4.	Durg	January 1970 to June 2008
5.	Gurur	June 1973 to Dec 2008
6.	Kurud	January 1960 to Dec 2008
7.	Patan	January 1993 to Dec 2008
8.	Selud	January 1960 to may 2008

8.4 Data Processing

8.4.1 Rainfall Data Processing

Rainfall and evapotranspiration data are the important inputs used in rainfall-runoff modeling as the runoff volume of a stream is mainly controlled by amount of rainfall and evapotranspiration. The rainfall data is generally being collected by state and central agencies and may have certain discrepancies and some missing values and gaps in the records. Before performing the hydrological modeling it is important to carry out the simple data processing like gap filling so as to bring the data in acceptable form for the modeling.

8.4.1.1 Gap filling

Time-series records often contain gaps that must be filled before the time-series are used for modeling purposes. The gaps in the daily rainfall data were identified and filled up using Temporal Analyst tool in MIKE BASIN software. The purpose of the Gap Fill tool is to make it possible to fill gaps (periods with missing values) in one or more time series with values from other time series. In the present study, the rainfall data of eight rain gauge stations falling in Kharun basin was used for modeling purpose. The daily rainfall data from 1993 to 2007 had some small gaps and missing values. For the rainfall runoff modeling purpose, the rainfall data needs to be validated, corrected and gap filled. Temporal analyst tool of MIKE BASIN enables the storage, management and visualization of time-related data in a spatial context. This is an exceptionally powerful tool especially when it is used for water resource analysis. The tool establishes a linear regression relationship between each pair of time-series. In this typical application, the missing data of one or more climate station were filled by data from nearby stations. Figure 8.3 shows the gaps in the rainfall time series and Figure 8.4 shows the gap filled rainfall time series of all 8 raingauge stations of the study area. From the analysis of these figures, it was observed that Temporal Analyst Tool has systematically filled the missing values and gaps in the data. On critically examining the Bhilai station, the wide gaps in the data have also been filled up using Temporal Analyst tool.

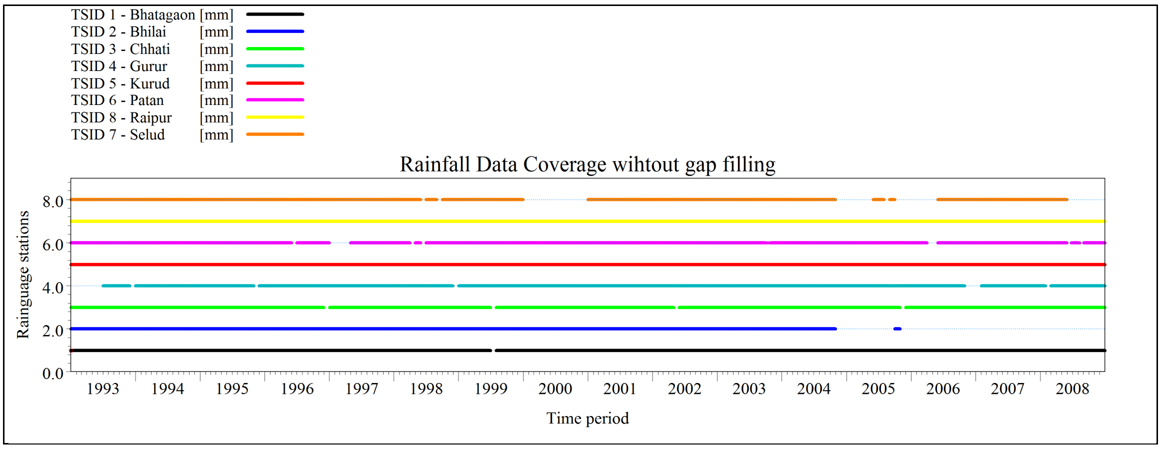


Figure 8.3: Rainfall data coverage without gap filling

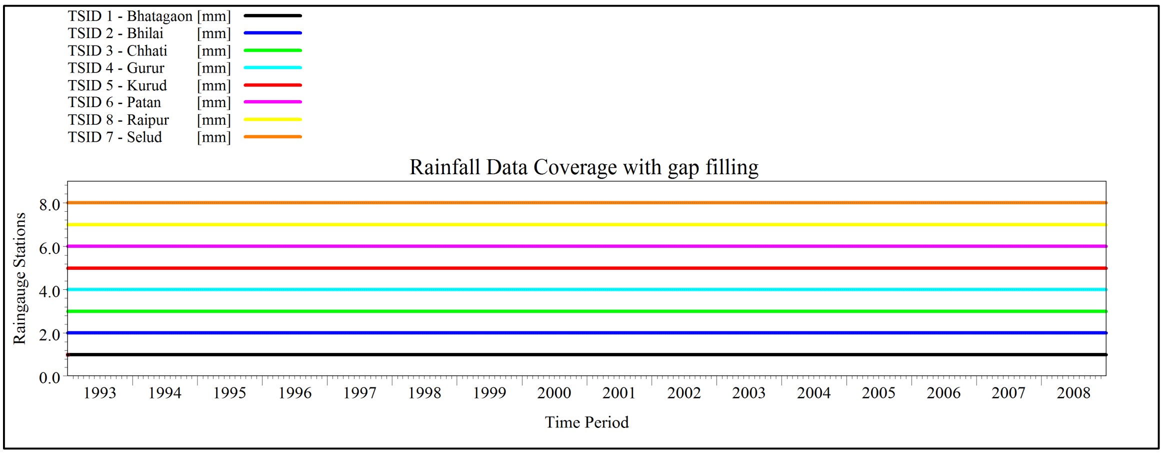


Figure 8.4: Rainfall data coverage with gap filling

8.4.1.2 Identification of Weights for Raingauge Stations

The MIKE11 NAM Model calculates the average rainfall of the study area using weights of the station. In this study the weights of the influencing raingauge station of the study area were identified using Thiessen Polygon application in ILWIS 3.0 software. The Thiessen weights of the stations are given in Table 8.2.

Table 8.2: Thiessen weights for rainfall stations

Station	Rainfall Station	Percentage Weight (%)	Weights
1	Bhatagaon	15	0.15
2	Bhilai	7	0.07
3	Chhati	7	0.07
4	Raipur	20	0.20
5	Gurur	16	0.16
6	Kurud	16	0.10
7	Patan	15	0.15
8	Selud	10	0.10

8.4.2 Estimation of Potential Evapotranspiration

Potential evapotranspiration (ETo) is the amount of water that could be evaporated and transpired if there were sufficient water available. This demand incorporates the energy available for evaporation and the ability of the lower atmosphere to transport evaporated moisture away from the land surface. Estimation of potential evapotranspiration in the RR Model is important due to its high affect on runoff in the form of evaporation from the surface. More evaporation causes the additional loss of water from the basin which was the part of runoff. Evapotranspiration data are frequently needed at short notice for modeling, project planning or irrigation scheduling design. A large number of more or less empirical methods have been developed over the last 50 years by numerous scientists and specialists worldwide to estimate evapotranspiration from different climatic variables. The Modified Penman Method was considered to offer the best results with minimum possible error in relation to a living grass reference crop. In the present study the potential evapotranspiration (ETo) has been estimated using Modified Penman Method (1963). The ETo (mm/day), for 52 standard weeks, has been calculated based on air temperature, wind velocity, relative humidity, sun shine hours and radiation as given in equation 8.1.

$$ET_0 = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,\frac{900}{T + 273}(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \qquad \dots (8.1)$$

Where;

ET_0	=	Reference evapotranspiration [mm/day],
R_n	=	Net radiation at the crop surface [MJ m^2 /day],
G	=	Soil heat flux density [MJ m^2 /day],
T	=	Mean daily air temperature at 2 m height [°C],
u_2	=	Wind speed at 2 m height [m/s],
e_s	=	Saturation vapour pressure [kpa],
e_a	=	Actual vapour pressure [kpa],
$e_s - e_a$	=	Saturation vapour pressure deficit [kpa],
Δ	=	Slope vapour pressure curve [kpa/ °C],
γ	=	Psychrometric constant [kpa /°C].

The climatological data of Raipur station for the period from 1971 to 2008 was used for estimation of potential evapotranspiration (ETo) using CROPWAT software. CROPWAT 8.0 for Windows is a computer programme for the calculation of crop water requirements and irrigation requirements from existing or new climatic and crop data. For calculation of ETo whole data can be monthly, decade and daily input of climatic data. All calculation procedures as used in CROPWAT 8.0 are based on the FAO guidelines as laid down in the publication No. 56 of the Irrigation and Drainage Series of FAO of Doornbos and Pruitt (1977). The estimated monthly ETo for Kharun basin are given in Table 8.3.

Table 8.3: Estimation of monthly *ETo* for Kharun basin and average values of climatic data used in CROWAT 8.0

Month	Min Temp °C	Max Temp °C	Humidity %	Wind Speed km/day	Sunshine hours	Radiation MJ/m^2/day	ETo mm/day	Monthly Total ETo (mm)
JAN	11.2	27.4	63	56	7.7	16	2.67	82.77
FEB	13.9	30.1	58	72	8.7	19.1	3.61	101.08
MAR	17.8	35.0	48	93	8.9	21.4	4.87	150.97
APR	22.5	39.3	37	136	8.8	22.8	6.44	193.20
MAY	26.5	41.8	34	184	8.3	22.5	7.61	235.91
JUNE	26.2	36.9	58	243	4.7	17.0	5.90	177.00
JULY	24.5	31.2	81	223	2.7	13.9	3.68	114.08
AUG	24.3	29.9	85	191	2.8	13.7	3.28	101.68
SEPT	24.1	31.0	82	116	5.3	16.5	3.68	110.4
OCT	20.9	31.1	74	69	7.7	18.2	3.68	114.08
NOV	15.1	29.8	65	56	8.2	16.8	3.00	90.00
DEC	11.1	27.9	62	47	7.8	15.4	2.48	76.88

From the analysis of Table 8.3, it was observed that the potential evapotranspiration of the study area highest in the month of April (193.20 mm) and May (235.91 mm) and lowest during December (76.88 mm) and January (82.77 mm). The rate of Potential evapotranspiration was highest in the month of May i.e. 7.61 mm/day and lowest in the month of December i.e. 2.48 mm/day. From the analysis it was observed that the total annual *ETo* in the study area was 1548 mm and the *ETo* during monsoon and non-monsoon seasons were 503 mm and 1045 mm respectively.

8.4.3 Runoff Data Processing

Before using runoff data for hydrological modeling it needs to be processed carefully to eliminate the errors, to find missing values and check the modification of flow conditions due to human interaction. Human factors that modify hydrologic processes that generate runoff and base flow into streams are considered to have indirect effects on stream flow amounts because these factors do not directly add or subtract flow from the stream. The flow regime in Kharun river has been strongly influenced by regulation operations associated with water transfer from Ravishankarsagar reservoir and its supply for various usages through the series of anicuts. The river flow at the Patherdihi site was thus the regulated flow, hence the virgin flow time series required at Patherdihi was estimated using MIKE BASIN software.

8.4.3.1 Estimation of virgin flow

Runoff representing the response of a catchment to precipitation reflects the integrated effect of a wide range of catchment, climate and precipitation characteristics.

When there exists the storage or diversion works on a stream, the flow in the downstream channel is affected by structures and hence does not represent the true runoff unless corrected for storage effects and the diversion of flow and return flow. True runoff is therefore stream flow in the natural condition that is without human intervention. Such as a stream flow unaffected by works of man, such as structure for storage and diversion works on a stream is called virgin flow.

The flow regime in Kharun has been seen strongly regulated due to water transfer and regulation operations associated with it as discussed in Chapter 7 of this report. Therefore, the virgin flow time series at Patherdihi was estimated from the regulated observed flow data using the equations developed after critically observing the field conditions and existing setup of the Kharun river basin. The following equations were applied in the MIKE BASIN Model of Kharun river (as discussed in Chapter 7). The estimated virgin flow was then used for rainfall runoff model calibration and validation purposes as an observed flow at Patherdihi. Virgin flow was estimated by accounting the water diverted and added into the Kharun river basin and by formulating equation no 8.2, 8.3 and 8.4.

$$Q_{Obs\ virgin} = Q_{Obs\ reguleted} - Q_{Added} + Q_{Diverted} \quad \text{... (8.2)}$$

$$Q_{Added} = Q_{MFC} + Q_{MBC} + RF_{TMC} + RF_{MMC} \quad \text{... (8.3)}$$

$$Q_{Diverted} = Q_{TO\ Raipur+Railway+Nistar} \quad \text{... (8.4)}$$

Where

$Q_{obs\ virgin}$	= Virgin flow at Patherdihi G/D site
$Q_{obs\ regulated}$	= Actual observed flow at Patherdihi G/D site
Q_{MFC}	= Flow from Mahanadi Feeder Canal through Deorani Jethani Nala
Q_{MBC}	= Flow from Mandhar Branch Canal
RF_{TMC}	= Return flow from Tandula Canal System
RF_{MMC}	= Return flow from Mahanadi Main Canal System.
$Q_{Diverted}$	= Water diverted from Raipur city supply, railway and for the purpose of nistari

8.4.4 Comparison of Observed Flow With Rainfall

The virgin flow time series of Kharun basin at Patherdihi Gauge Discharge site thus obtained using MIKE BASIN Model as described above was used as “observed discharge” for the RR Modeling purpose. Before using the processed rainfall runoff records in the model, it is necessary to check whether the rainfall and runoff data are consistent or not. The runoff coefficients in different time period provides useful inferences about the portion of precipitation appeared at the outlet of the catchment during that period. The runoff coefficient is the ratio of runoff and rainfall within the specified period. In order to check the consistency of rainfall-runoff records, the runoff coefficients were computed for the period of 15 years from 1993 to 2007. The annual rainfall, annual runoff and runoff coefficients are given in Table 8.4.

Table No 8.4: Annual rainfall and runoff coefficient

Period	Rainfall (mm)	Q observed Patherdihi(mm)	Runoff coefficient
1993	1182.9	333.4	0.28
1994	1640.8	872.1	0.53
1995	1166.6	554.2	0.48
1996	1129.3	326.5	0.29
1997	1177.1	326.6	0.28
1998	1097.8	220.4	0.20
1999	1074.7	335.3	0.31
2000	698.5	151.4	0.22
2001	1065.7	435.0	0.41
2002	811.9	130.4	0.16
2003	1384.4	482.5	0.35
2004	1023.9	364.9	0.36
2005	1425.1	715.1	0.50
2006	1110.3	490.5	0.44
2007	1224.5	461.5	0.38

From the analysis of the results given in Table 8.4, it was observed that the runoff coefficients were always less than 1 and ranges between 0.16 to 0.53 and showing good match between rainfall and runoff records. It was observed that data used in the study area was consistent and it could be used for rainfall runoff modeling, calibration and validation of model. A linear relation between the annual rainfall and runoff was established and the graph was plotted as given in Figure 8.5 to study its pattern. The correlation coefficient of the linear regression was observed as 0.7745 showing the consistency and linear relation between rainfall and runoff data.

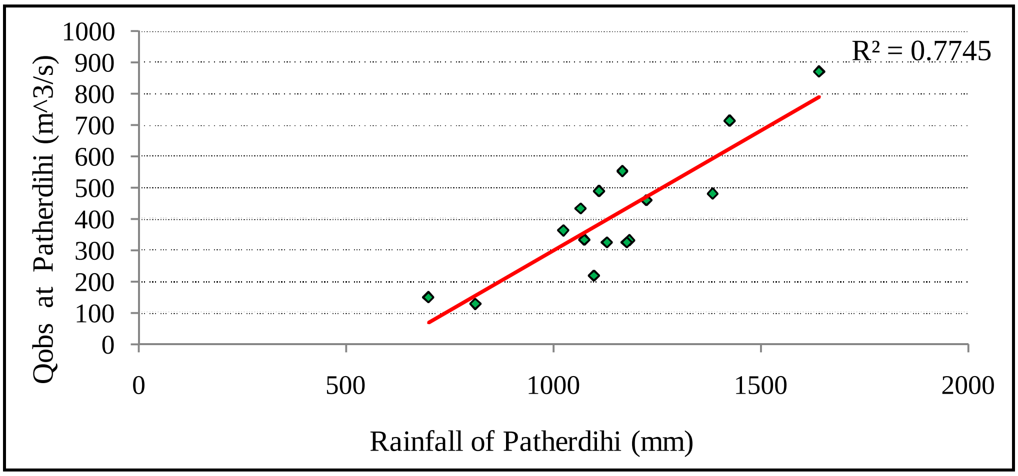


Figure 8.5: Linear relationship between rainfall and runoff

8.5 Rainfall Runoff Modeling: MIKE11 NAM

The NAM model is a deterministic, lumped and conceptual Rainfall-runoff model. It consider river basin as one unit and based on considerations of the physical processes, which is highly relevant with this particular river basin under study and the long term flow simulation desired. In addition, it is complete and effective modeling software which allows flexibility for future investigation. As pointed out by Blackie and Eeles (1985), due to the spatial averaging, the lumped model concept can be considered adequate only for small homogeneous catchments. However, in practice they have been applied to sufficiently big and heterogeneous catchments. MIKE11 NAM is a professional engineering software package developed by Danish Hydraulic Institute (DHI), Denmark. This one-dimensional modeling tool developed since 1972 has been accepted worldwide especially for water resource planning and management applications. Specifically the MIKE11 software is meant for simulation of river flows, irrigation systems, channels and other water bodies. Fleming (1975) concluded that the RMSE values tend to be zero for perfect agreement between observed and simulated value. Root Mean Square Error (RMSE) method used by was another method applied to evaluate the reliability of MIKE11 during this study. This method can be regarded as a measure of absolute error between the computed and observed flows. DHI (2003) studied the case of continuous modeling; the results indicate more accurate outcomes. Nevertheless, it is considered that some of the disagreements are due the lack of more detailed spatial rainfall information. In this instance, the basins size did not constrain the model application since other studies showed its employment in greater catchments.

8.5.1 Description of MIKE11 NAM

DHI's *Nedbør-Afrstrømnings-Model* (NAM) is a lumped conceptual model for simulating stream flows based on precipitation at a catchment scale. Since its creation in 1973, NAM has been used worldwide in a variety of climatic and hydrologic settings to simulate runoff from precipitation events. The model can be used independently, dynamically with MIKE11, or to develop input time series for MIKE BASIN catchment nodes. NAM is a Rainfall-Runoff model that operates by continuously accounting for the moisture content in three different and mutually interrelated storages that represent overland flow, interflow and base-flow (DHI, 2003). As NAM is a lumped model, it treats each sub-catchment as one unit, therefore the parameters and variables considered represent average values for the entire sub-catchments. Precipitation in the form of snow is modeled as a fourth storage unit. Water use associated with irrigation or groundwater pumping can also be accounted for in NAM. The result is a continuous time series of the runoff from the catchment throughout the modeling period. Thus, the NAM model provides both peak and base flow conditions that accounts for antecedent soil moisture conditions over the modeled time period. Calibration of the NAM model involves adjusting the coefficients for the exchange of water between storage units and the storage unit depth so that simulated and observed discharges match as best as possible. A minimum of 3 years including periods of above-average precipitation is recommended for calibration, with longer periods resulting in a more reliable model. Disparity between simulated and observed discharge arise due to quality of time series data or other attributes.

The MIKE11 Rainfall Runoff module includes the NAM model, which is a conceptual representation of the land phase of the hydrological cycle. The structure of the model is shown in Figure 8.6. The hydrological model simulates the rainfall-runoff processes occurring at the catchment scale. This rainfall-runoff module can either be applied independently or used to represent one or more contributing catchments that generate lateral inflows to the river network in a MIKE11 NAM rainfall runoff model. In this manner it is possible to treat a single catchment or a large river basin containing numerous catchments and a complex network of rivers and channels within the same modeling framework.

The basic data input requirements for the MIKE11 NAM model are meteorological data and discharge data for model calibration, definition of the catchment parameters, and definition of initial conditions. The basic meteorological data requirements are precipitation time series, potential evapotranspiration time series and temperature time series. On this basis, the model produces a time series of catchment runoff, a time series of subsurface flow contributions to the channel, and information about other elements of the land phase of the hydrological cycle, such as soil moisture content and groundwater recharge.

8.5.2 MIKE11 NAM Interface

The NAM model is a deterministic, lumped and conceptual Rainfall-Runoff model accounting for the water content up to 4 different storages. NAM can be prepared in a number of different modes depending on the requirement.

8.5.2.1 *Data Requirements*

The basic input requirements for the NAM model consist of:

- Model parameters
- Initial conditions
- Meteorological data
- Stream flow data for model calibration and validation

The basic meteorological data requirements are:

- Rainfall
- Potential evapotranspiration

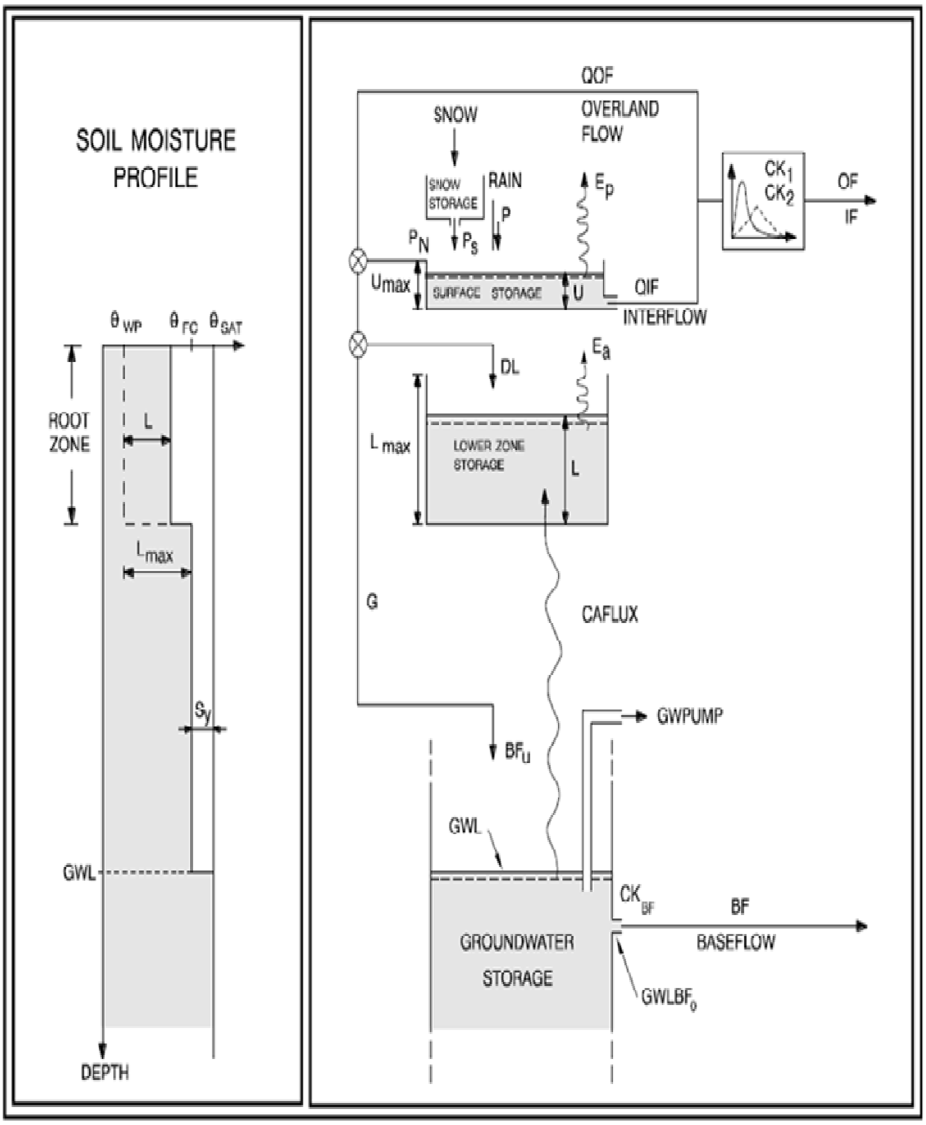


Figure 8.6: Process of NAM model

8.5.3 NAM Model Parameters

As default, NAM is prepared with 9 parameters representing the surface zone, root zone and the ground water storages as shown in Table 8.5. Each NAM parameters are discussed in detail as below.

8.5.3.1 Surface storage

Moisture intercepted on the vegetation as well as water trapped in depressions and in the uppermost, cultivated part of the ground is represented as surface storage. U_{max} denotes the upper limit of the amount of water in the surface storage. The amount of water, *U*, in the surface storage is continuously diminished by evaporative consumption as well as by horizontal (interflow). When there is maximum surface storage, some of the excess water, P_N, will enter the streams as overland flow, whereas the remainder is diverted as infiltration into the lower zone and groundwater storage.

Table 8.5: Different parameters of NAM model

Parameter	Unit	Description	Effects
U_{max}	*mm*	Maximum water content in surface storage	Overland flow, infiltration, evapotranspiration, interflow
L_{max}	*mm*	Maximum water content in lower zone/root storage	Overland flow, infiltration, evapotranspiration, baseflow
C_{QOF}		Overland flow coefficient	Volume of overland flow and infiltration
C_{KIF}	*hrs*	Interflow drainage constant	Drainage of surface storage as interflow
T_{OF}		Overland flow threshold	Soil moisture demand that must be satisfied for overland flow to occur
T_{IF}		Interflow threshold	Soil moisture demand that must be satisfied for interflow to occur
TG		Groundwater recharge threshold	Soil moisture demand that must be satisfied for groundwater recharge to occur
C_{K1}	*hrs*	Timing constant for overland flow	Routing overland flow along catchment slopes and channels
C_{K2}	*hrs*	Timing constant for interflow	Routing interflow along catchment slopes
C_{KBF}	*hrs*	Timing constant for base flow	Routing recharge through linear groundwater recharge

8.5.3.2 Lower zone or root zone storage

The soil moisture in the root zone, a soil layer below the surface from which the vegetation can draw water for transpiration, is represented as lower zone storage. L_{max} denotes the upper limit of the amount of water in this storage. Moisture in the lower zone storage is subject to consumptive loss from transpiration. The moisture content controls the amount of water that enters the groundwater storage as recharge and the interflow and overland flow components.

8.5.3.3 Evapotranspiration

Evapotranspiration demands are first met at the potential rate from the surface storage. If the moisture content U in the surface storage is less than these requirements ($U < Ep$), the remaining fraction is assumed to be withdrawn by root activity from the lower zone storage at an actual rate *Ea*. *Ea* is proportional to the potential evapotranspiration and varies linearly with the relative soil moisture content, L/L_{max}, of the lower zone storage.

$$E_a = (E_p - U)\frac{L}{L_{max}} \quad \text{... (8.5)}$$

8.5.3.4 Overland flow

When the surface storage spills, i.e. when $U > U_{max}$, the excess water P_N give rise to overland flow as well as to infiltration. Q_{OF} denotes the part of P_N that contributes to overland flow. It is assumed to be proportional to P_N and to vary linearly with the relative soil moisture content, L/L_{max}, of the lower zone storage

$$Q_{OF} = \begin{cases} C_{QOF} \dfrac{L/L_{max} - T_{OF}}{1 - T_{OF}} P_N & for\ L/L_{max} > T_{OF} \\ 0 & for\ L/L_{max} \leq T_{OF} \end{cases} \quad \text{... (8.6)}$$

Where;

C_{QOF} is the overland flow runoff coefficient ($0 < C_{QOF} < 1$),
T_{OF} is the threshold value for overland flow ($0 < T_{OF} < 1$).

The proportion of the excess water P_N that does not run off as overland flow infiltrates into the lower zone storage. A portion, DL, of the water available for infiltration, (P_N -Q_{OF}), is assumed to increase the moisture content L in the lower zone storage. The remaining amount of infiltrating moisture, G, is assumed to percolate deeper and recharge the groundwater storage.

8.5.3.5 Interflow

The interflow contribution, Q_{IF}, is assumed to be proportional to U and to vary linearly with the relative moisture content of the lower zone storage.

$$Q_{IF} = \begin{cases} (C_{KIF})^{-1} \dfrac{L/L_{max} - T_{IF}}{1 - T_{IF}} U & for\ L/L_{max} > T_{IF} \\ 0 & for\ L/L_{max} \leq T_{IF} \end{cases} \quad \text{... (8.7)}$$

Where;

C_{KIF} is the time constant for interflow,
TIF is the root zone threshold value for interflow ($0 < T_{IF} < 1$).

8.5.3.6 Interflow and overland flow routing

The interflow is routed through two linear reservoirs in series with the same time constant C_{K1K2}. The overland flow routing is also based on the linear reservoir concept but with a variable time constant.

$$CK = \begin{cases} C_{K_1K_2} & for\ OF < OF_{min} \\ C_{K_1K_2} \left(\dfrac{OF}{OF_{min}}\right)^{-\beta} & for\ OF \geq OF_{min} \end{cases} \quad \text{... (8.8)}$$

Where;

OF is the overland flow (mm/hour),

OF_{min} is the upper limit for linear routing (= 0.4 mm/hour),

The constant b = 0.4 corresponds to using the Manning formula for modelling the overland flow. The Equation above ensures in practice that the routing of real surface flow is kinematic, while subsurface flow being interpreted by NAM as overland flow (in catchments with no real surface flow component) is routed as a linear reservoir.

8.5.3.7 Groundwater recharge

The amount of infiltrating water *G* recharging the groundwater storage depends on the soil moisture content in the root zone

$$G = \begin{cases} (P_N - Q_{OF})\dfrac{L/L_{max} - TG}{1 - TG} & for\ L/L_{max} > TG \\ 0 & for\ L/L_{max} \leq TG \end{cases} \quad \text{... (8.9)}$$

Where;

TG is the root zone threshold value for groundwater recharge ($0 < TG < 1$).

8.5.3.8 Soil moisture content

The lower zone storage represents the water content within the root zone. After apportioning the net rainfall between overland flow and infiltration to groundwater, the remainder of the net rainfall increases the moisture content L within the lower zone storage by the amount DL

$$\Delta L = P_N - Q_{OF} - G \quad \text{... (8.10)}$$

8.5.3.9 Baseflow

The baseflow *BF* from the groundwater storage is calculated as the outflow from a linear reservoir with time constant C_{KBF}.

8.5.4 Model Set Up

While working with "MIKE11 NAM" environment there is the need of special arrangement of the input data in the form of "Time Series". The basic input data requirement of the MIKE11 NAM model are meteorological data and discharge data for model calibration and validation, definition of the catchment parameters, and definition of initial conditions. Before importing input data in the model, it is necessary to create the time series of all three parameter i.e. rainfall, potential evapotranspiration and runoff data in *dfso* format, which has been done using MIKE ZERO software. The rainfall time series of eight rain gauge stations, Bhatagaon, Bhilai, Chhati, Gurur, Kurud, Patan, Raipur and Selud which are falling in the study area, potential evapotranspiration time series and observed runoff in *dfso* format were given as input information in the NAM RR model. The default NAM parameters were applied as model parameters and then runoff was simulated using auto calibration application of the model. Then the model was run for several times by increasing and decreasing the model parameters gradually one by one. The model was then calibrated and validated as described below. The procedures and steps of the calibration and validation of the model are same except the simulation period of the model. The model was calibrated for the period 1993 to 2000 and validated for the period 2001-2007.

8.5.5 Model Calibration

The main purpose of the model calibration is to obtain a parameter set for a catchment which gives the best possible fit between the simulated and observed runoff for the calibration period. Calibration is the process of modifying model parameters to reduce the error between the simulated stream flow and some portion of the observed flow record. Calibration is a development of standardizing predicted values, using deviations from observed values for a particular area to derive correction factors that can be applied to generate predicted values that are consistent with the observed values. Such empirical corrections are common in modeling, and it is understood that every hydrologic model should be tested against observed data, preferably from the river basin under study, to understand the level of reliability of the model (Linsley 1982, Melching 1995).

The MIKE11 NAM Model was calibrated by applying daily rainfall time series of eight raingauge stations, their weights, daily potential evaporation time series, and daily observed discharge time series (virgin) for the periods of 15 years from 1993 to 2007. The catchment information like name and area of the catchment were also specified in the RR Input Model. After importing the various time series, the default model parameters of surface root zone and groundwater were selected and the model was run using autocalibration application of the model and time step of one day. It simulated the runoff with the best combination of all the parameter. Then the model was run for several times by increasing and decreasing the model parameters gradually one by one. In this process of calibration, model parameters were modified to reduce the error between the simulated stream flow and observed flow record. The steps in setting up of MIKE11 NAM Model during model calibration for the period of initial 8 years from 1993 to 2000 are shown in Figures 8.7 to 8.11.

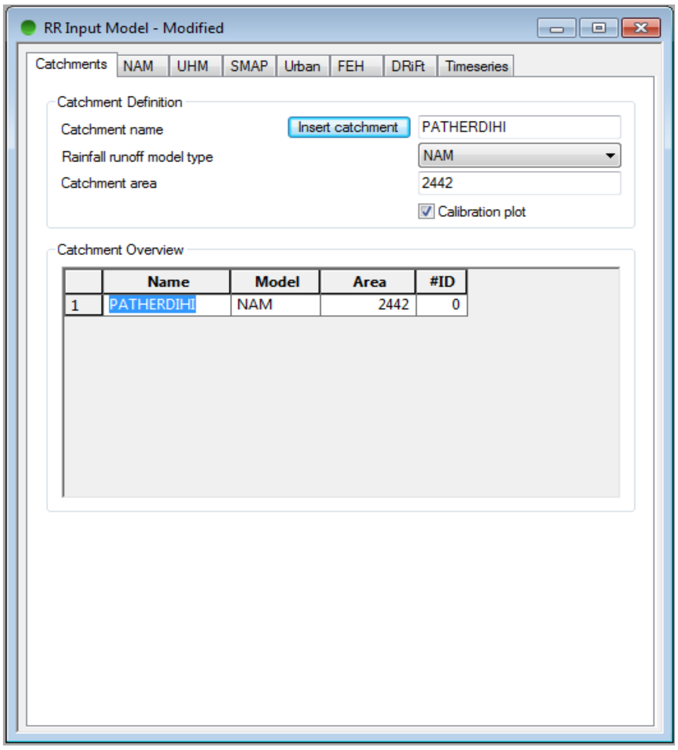


Figure 8.7: MIKE11 NAM model interface

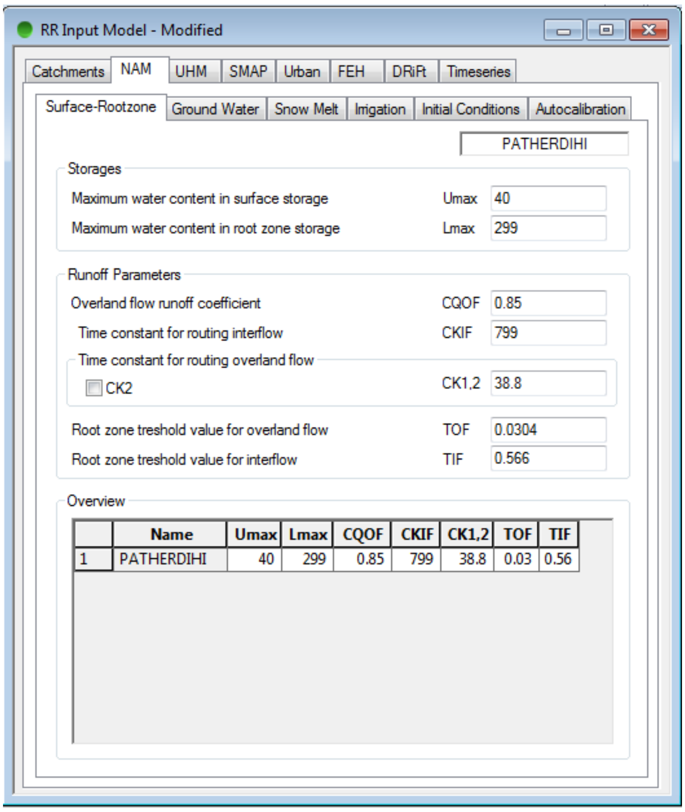


Figure 8.8: MIKE11 NAM model input default model parameters

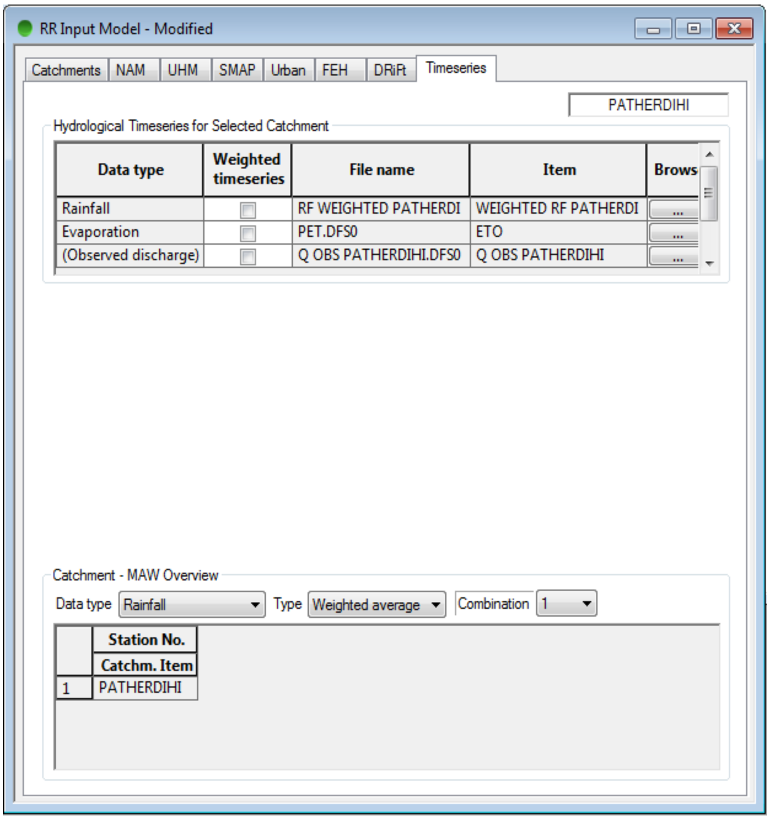


Figure 8.9: MIKE11 NAM model input data time series

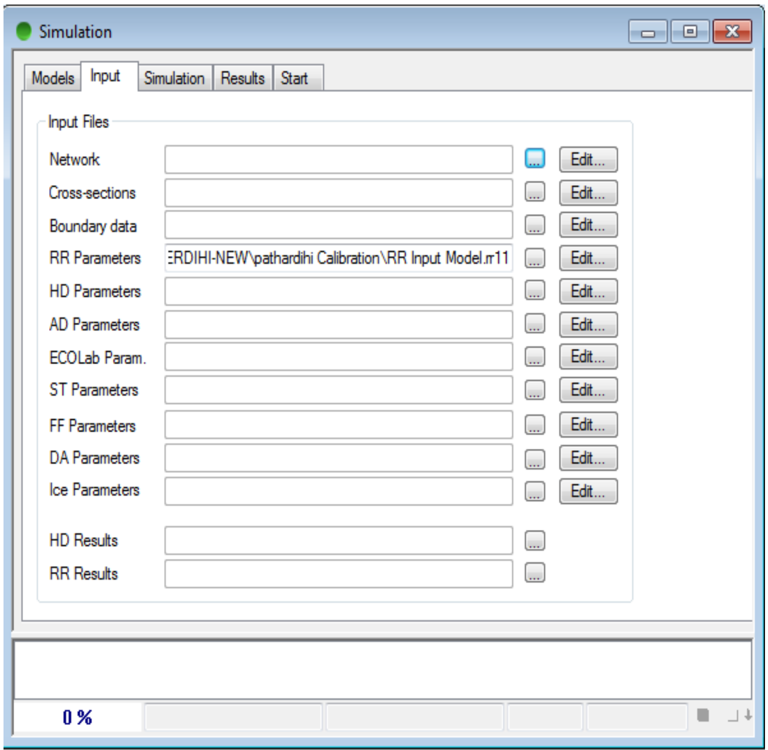


Figure 8.10: MIKE11 NAM model input for model simulation

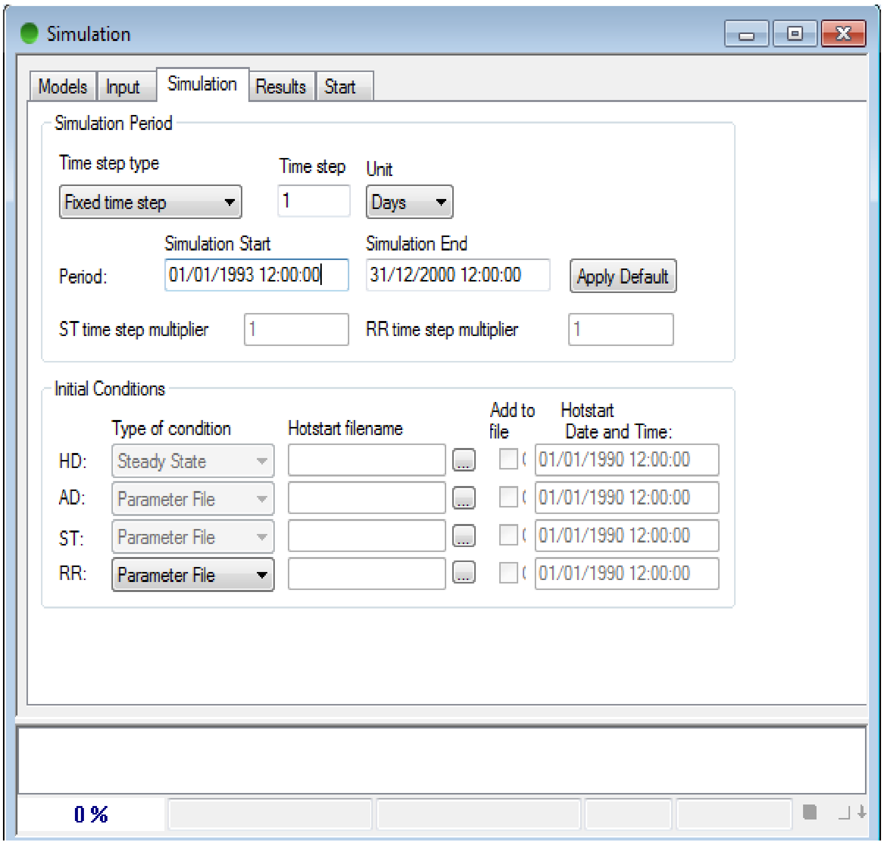


Figure 8.11: MIKE11 NAM model simulation period for calibration

After carrying out number of trials for the calibration of the model, the trial giving best results was selected as final best fit model and its model parameters were selected as final resulting parameters of the model calibration. Table 8.6 shows the values of parameter obtained during calibration and the range of each parameter of the rainfall runoff model. The statistics of the Model calibration result is shown in Table 8.7. From the analysis it was observed that the value of U_{max} was 40mm, which was the upper limit of that parameter and value of C_{KBF} was 300 hrs, which was the lower limit of that parameter. The model parameter values obtained during the model calibration was finest combination of model parameters.

Table 8.6: Final calibrated model parameters value and range of the NAM Model

Parameter	Values of the Parameter	Parameter Range
U_{max}	40.00	10 – 40
L_{max}	299.00	100 – 480
C_{QOF}	0.85	0.1 – 1
C_{KIF}	799.00	200 – 1000
C_{K1K2}	38.80	10 – 50
T_{OF}	0.0304	0 – 0.99
T_{IF}	0.566	0 – 0.99
TG	0.926	0 – 0.99
C_{KBF}	300.00	300 – 4000

Table 8.7: Statistics of model calibration result (values in mm)

Period	Q-Obs	Q-sim	% Diff	Rainfall	Overland	Interflow	Baseflow
1993	333.40	332.20	0.36	1113.10	272.30	38.10	21.80
1994	872.00	917.90	-5.26	1634.90	757.30	84.30	76.30
1995	554.20	442.50	20.16	1165.70	361.40	48.20	32.80
1996	326.50	386.70	-18.44	1104.00	301.70	54.50	30.40
1997	326.60	338.10	-3.52	1093.70	276.30	39.60	22.20
1998	218.20	212.50	2.61	1070.40	152.20	42.30	18.00
1999	335.30	347.50	-3.64	1130.60	277.10	48.70	21.70
2000	151.40	151.60	-0.13	630.30	117.00	18.30	16.30
Total	**3117.60**	**3129.00**	**-0.37**	**8942.70**	**2515.30**	**374.00**	**239.50**
R^2 = 0.858							

Table 8.6 and 8.7 shows the model parameters obtained during rainfall runoff modeling and statistic of the model calibration results at Patherdihi. The coefficient of determination (R^2) value of model calibration, which provides a measure of how well future outcomes are likely to be predicted by the model, was observed as 0.858, which indicated the good agreement between the average simulated and observed catchment runoff in terms of the peak flows with respect to timing, rate and volume. The statistical analysis given in Table 8.6 shows that, the difference in Q-observed and Q-simulated was reasonable i.e. -0.37 %, which shows good match between the observed and simulated runoff values.

8.5.6 Comparison of Observed and Simulated Runoff during Model Calibration

The resultant graphs presenting comparison between observed and simulated discharge are shown in Figures 8.12 below which gives the idea and view of best match obtained during the model Calibration. Figure 8.13 shows the Double Mass Curve for the calibration period showing cumulative graph of between observed and simulated discharge. The typical example of graphical results for the years 1993 and 1994 are shown in Figure 8.14 and 8.15. To spot out the results minutely the monsoon season graphs of the years 1994 and 1997 are presented in Figure 8.16 and 8.17. The graph showing comparison of the observed and simulated annual runoff depth during calibration is shown in Figure 8.18

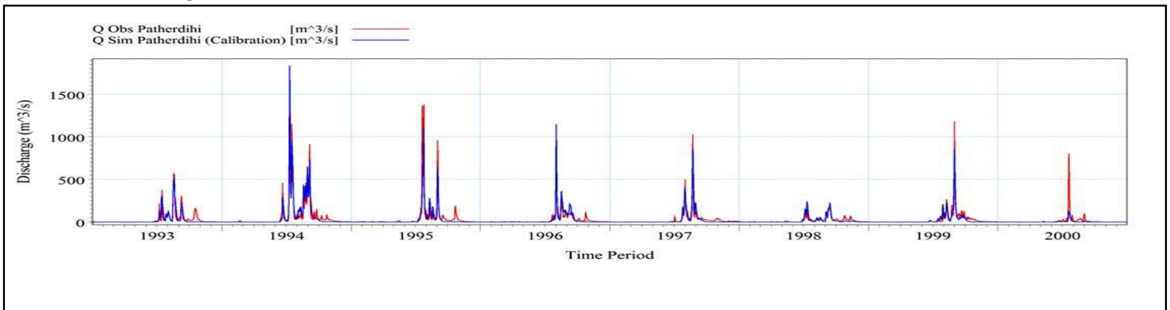


Figure 8.12: Comparison between observed and simulated discharge for calibration

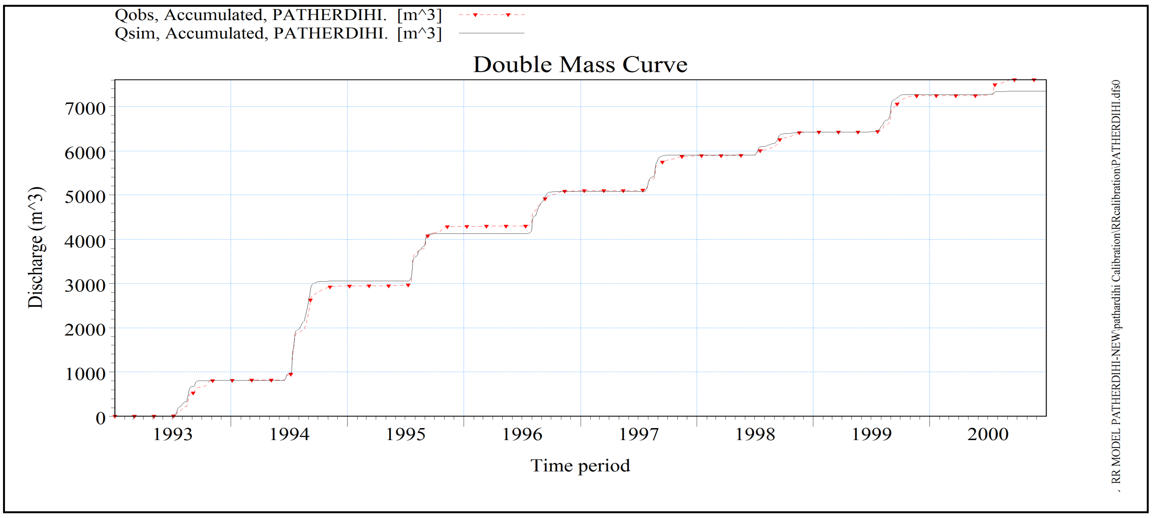


Figure 8.13: Double Mass Curve for the calibration period

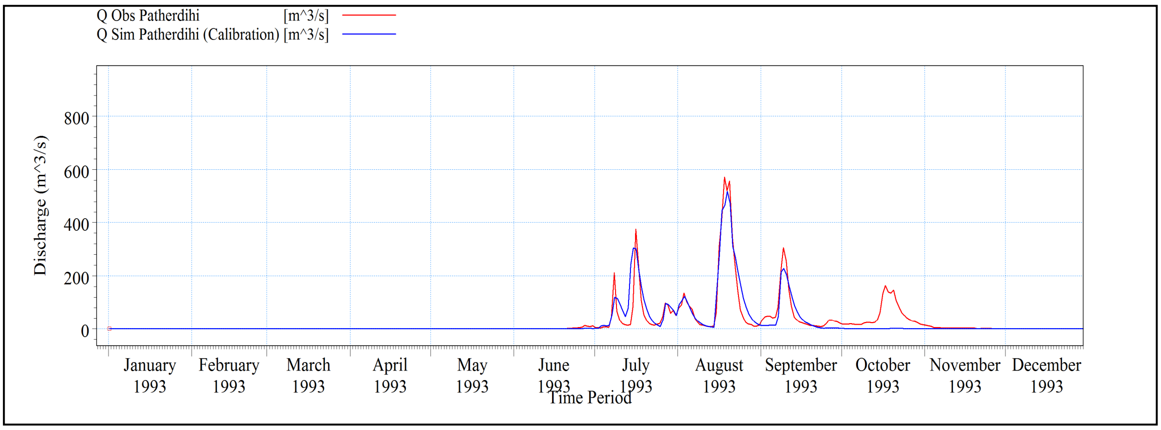


Figure 8.14: Model calibration results for year 1993

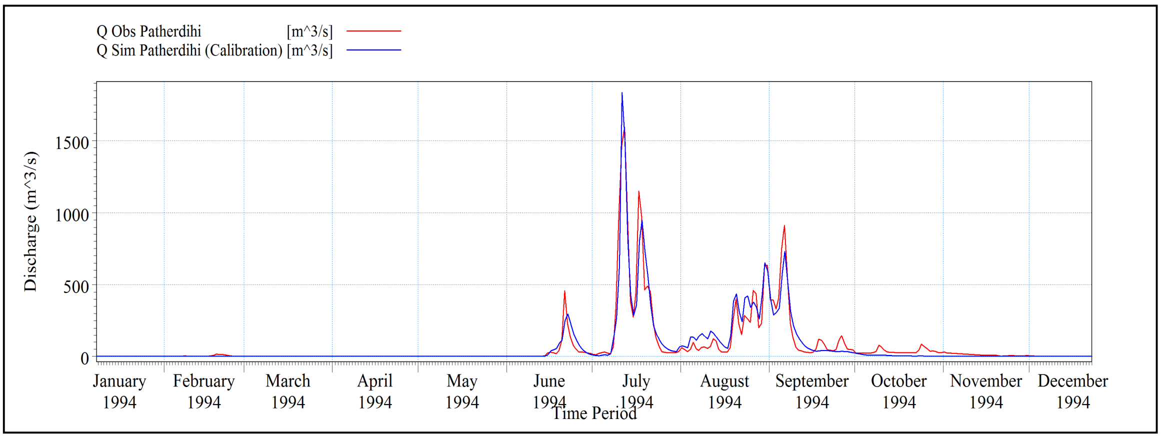


Figure 8.15: Model calibration result for year 1994

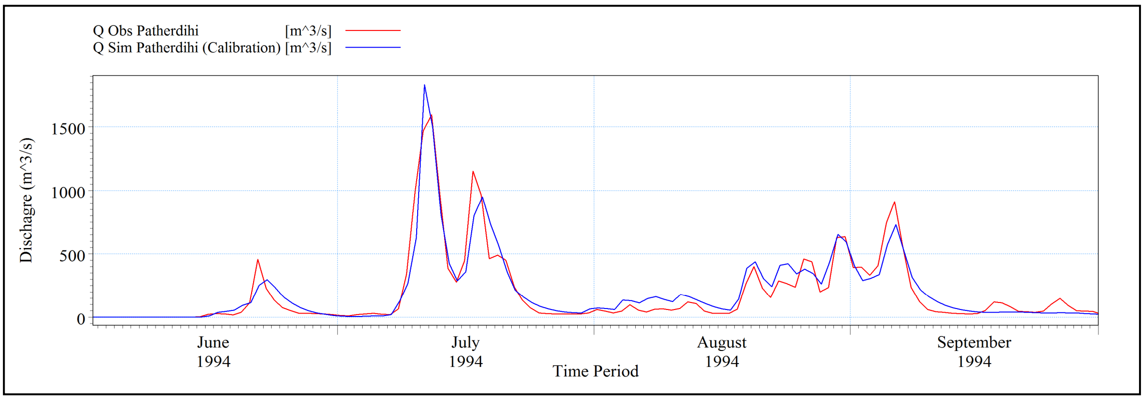


Figure 8.16: Calibration result for year 1994

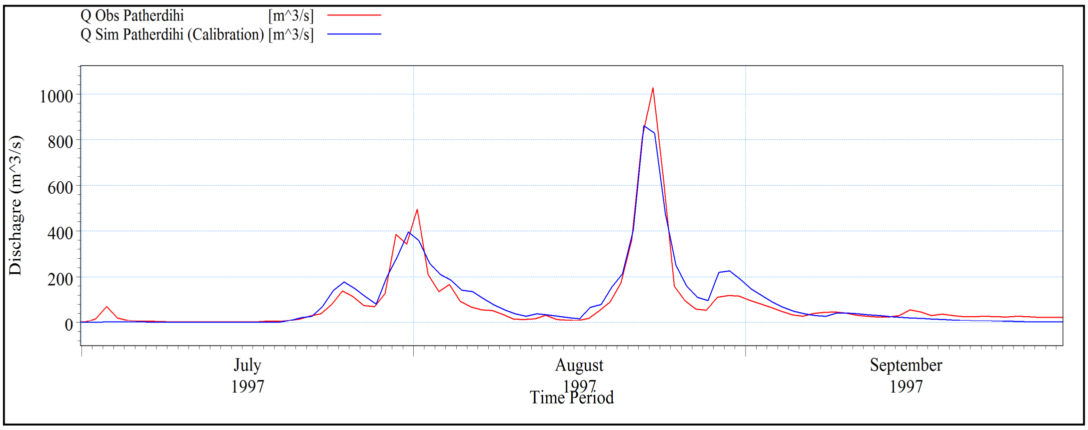


Figure 8.17: Calibration result for year 1997

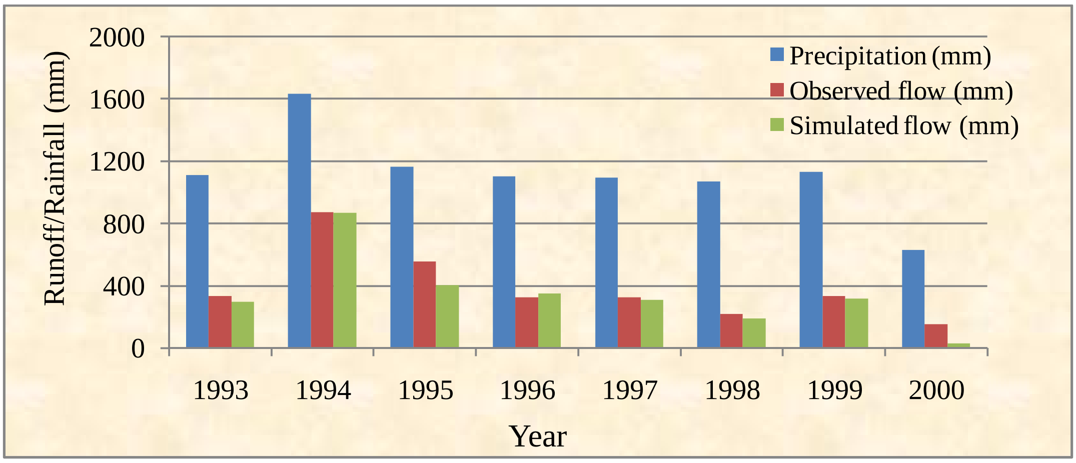


Figure 8.18: Observed and simulated annual runoff depth during calibration

From the analysis of above graphs showing comparison between observed and simulated discharge of model calibration, it was observed that the observed and simulated discharge were matching very well. Double Mass Curve gives the idea of good match between observed and simulated accumulated flow volume and accuracy of the model. From the graph comparing observed and simulated discharge of monsoon season it can be seen that the beginning and termination of observed and simulated flow events were matching well. In case of amplification of the flows i.e. peaks, it was observed that model could predict the peak flow with moderate accuracy. The overall comparison showed the MIKE11 NAM Model as a suitable model for Kharun basin and predicting runoff with high degree of accuracy and can be applied for other similar basins in semi arid region of Chhattisgarh.

8.5.7 Model Validation

Model validation tests the ability of the model to estimate runoff for periods outside that used to calibrate the model. Once the calibration of a model is completed, it becomes necessary to check that the calibrated parameter values which can be used satisfactorily to simulate events, for the period other than those used for the calibration (Sorooshian et. al., 1983). In the process of validation, the model parameters were kept as the parameters obtained during model calibration and runoff was simulated for the remaining period of 7 years for the data from year 2001 to 2007 and statistics of the output were compared with the calibration results. This process is supportive for the prediction of runoff for the remote river basin similar to the modeled basin or the data of different period for the same basin. Table 8.8 shows the model validation results at Patherdihi. The coefficient of determination for the validation process of the model was observed as 0.764, indicating good agreement between the simulated and observed catchment runoff in terms of the peak flows with respect to timing, rate and volume. The statistical analysis given in Table 8.8 shows difference in Q-observed and Q-simulated was reasonable i.e. 7.8 % indicating good match between the observed and simulated runoff. Figure 8.19 shows the comparison of observed and simulated runoff with respect to the precipitation during validation of model and it was seen that in year 2007, the difference between observed and simulated runoff was minimum. Figure 8.20 shows the graphical representation of the results obtained during model validation. From the analysis of results of model validation, it can also be concluded that, the model parameters obtained during model calibration can be used for predicting the runoff time series for the extended time period in the Kharun basin and it can be used for predicting runoff time series of another basin of similar characteristics using the rainfall data.

Table 8.8: Model validation result (values in mm)

Period	Q-obs	Q-sim	% diff	Rainfall	OF	IF	BF
2001	435.00	352.20	19.00	1037.60	275.00	55.20	22.00
2002	130.40	178.90	-37.20	840.70	149.30	17.60	12.00
2003	482.50	627.50	-30.10	1414.90	502.60	81.00	43.90
2004	365.40	271.50	25.70	988.70	208.40	44.20	19.00
2005	715.10	549.40	23.20	1301.30	458.40	53.70	37.30
2006	490.50	343.30	30.00	1084.70	276.70	45.50	21.20
2007	461.50	517.40	-12.10	1246.40	394.60	91.80	31.00
Total	**3080.40**	**2840.20**	**7.8**	**7914.30**	**2265.00**	**389.00**	**186.40**
R^2 = 0.764							

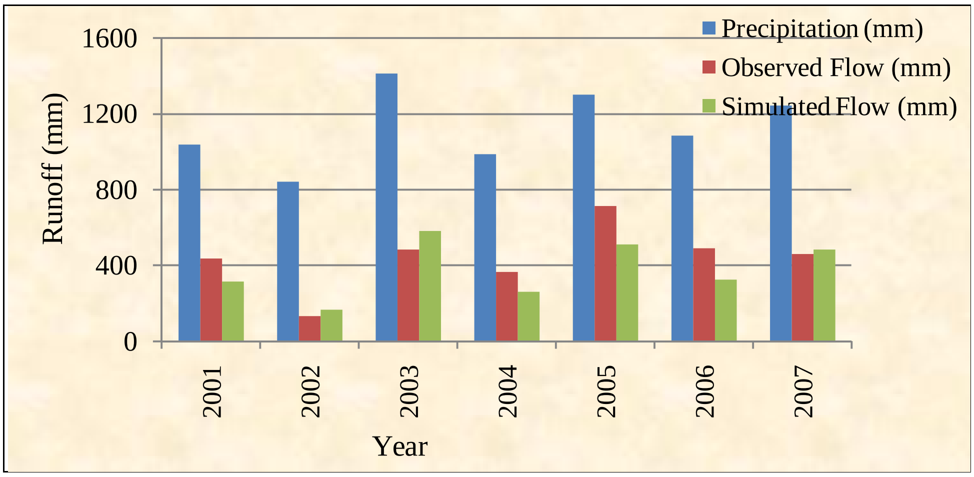


Figure 8.19: Comparison of the observed and simulated annual runoff during Validation

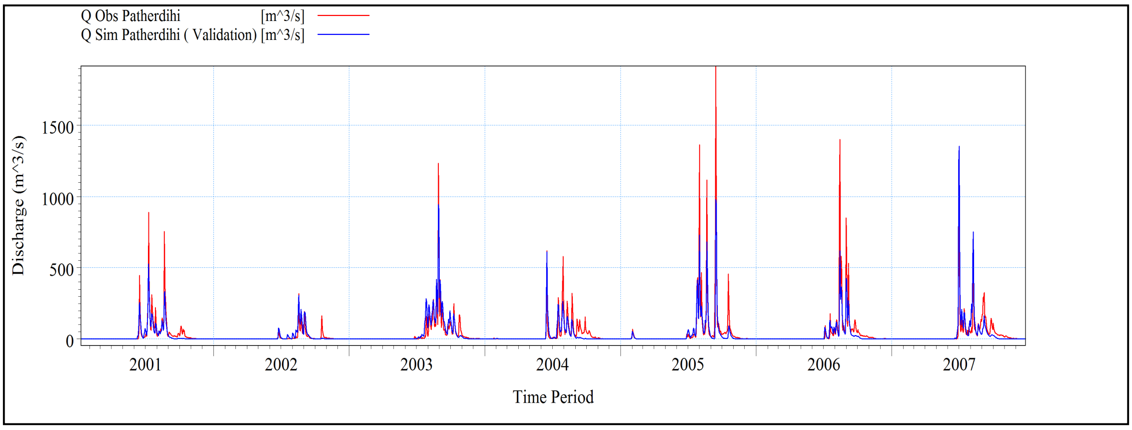


Figure 8.20: Observed and simulated annual runoff during Validation

8.5.8 Application of model for extended period

Once the MIKE11 NAM rainfall runoff model was developed, calibrated, validated, the next step was to check the application of model for predicting runoff for extended period using long period rainfall data. The Model was run for the extended period of time from year 1993 to 2007 using the same parameters obtained during model calibration. Table 8.9 shows statistics of the results. The difference in Q-observed and Q-simulated was reasonable i.e. 3.58 % indicating good match between the observed and simulated runoff. The coefficient of determination during model application was observed as 0.814, which indicated the good match between observed and simulated runoff. It can also be concluded that, the MIKE11 NAM Model was applicable and capable of predicting the runoff time series with high degree of accuracy in Kharun river basin. Figure 8.21 shows the graphical representation of the results obtained during model application for extended period.

Table 8.9: Complete model run result (1993-2007)

Period	Q-obs	Q-sim	% diff	Rainfall	OF	IF	BF
1993	333.40	332.20	0.30	1113.10	272.30	38.10	21.80
1994	872.00	917.90	-5.30	1634.90	757.30	84.30	76.30
1995	554.20	442.50	20.20	1165.70	361.40	48.20	32.80
1996	326.50	386.70	-18.40	1104.00	301.70	54.50	30.40
1997	326.60	338.10	-3.50	1093.70	276.30	39.60	22.20
1998	218.20	212.50	2.60	1070.40	152.20	42.30	18.00
1999	335.30	347.50	-3.60	1130.60	277.10	48.70	21.70
2000	151.40	151.60	-0.13	630.30	117.00	18.30	16.30
2001	435.00	359.40	17.40	1038.00	275.00	55.20	22.00
2002	130.40	178.90	-37.30	840.70	149.30	17.60	12.00
2003	482.50	627.50	-30.10	1414.90	502.60	81.00	43.90
2004	365.40	271.50	25.70	988.70	208.40	44.20	19.00
2005	715.10	549.40	23.20	1301.30	458.40	53.70	37.30
2006	490.50	343.30	30.00	1084.70	276.70	45.50	21.20
2007	461.50	517.40	-12.10	1246.40	394.60	91.80	31.00
Total	**6198.00**	**5855.50**	**3.58**	**16857.40**	**4686.00**	**744.70**	**417.60**
R^2 = 0.814							

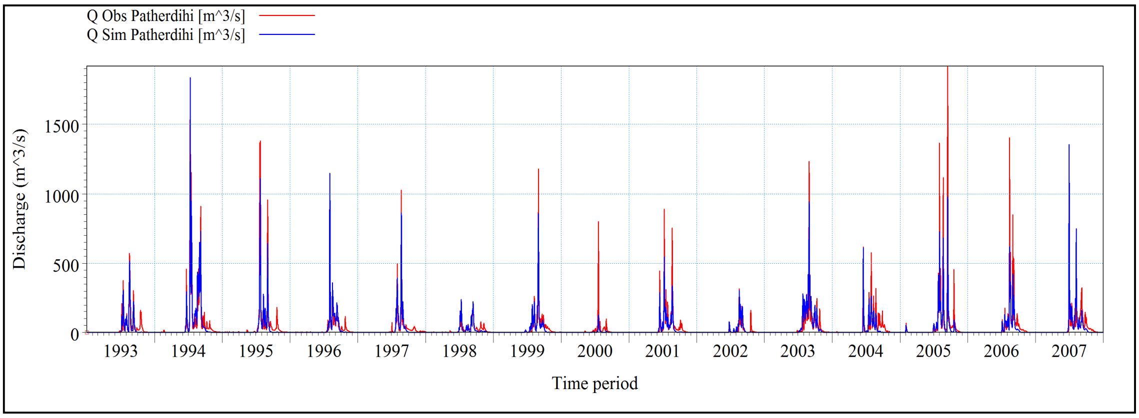


Figure 8.21: Comparison between observed and simulated flow for complete data set

8.5.9 Efficiency of Rainfall Runoff Model

Efficiency of the rainfall runoff model is directly dependent on the error present in the model by any means like missing data and or unavailability of data. Error present in the rainfall data, runoff data and potential evapotranspiration data, reduces the efficiency of the rainfall runoff model. The efficiency of the NAM Model developed in the study was checked using Equation 8.11 as given below.

$$E = \frac{(F_0^2 - F^2)}{F_0^2} \quad \text{... (8.11)}$$

Where;

F_o^2 = Sum of square of error between observed and simulated runoff

F^2 = Initial variance of runoff

The efficiency of the NAM Model developed in the study was checked using Equation 8.11. Efficiency of the model calibration was 81% showing the suitability of model for the selected basin.

8.5.10 Sum of Square of Error (*SSE*)

The constrained Rosenbrook's optimization algorithm has been used for parameter estimation. Even though it is rather very difficult to find the global optimum values of the parameters, many runs with different initial values of parameters can increase the likelihood of finding parameters close to the global optimum. The objective function was to minimize the Sum of Square of Errors (*SSE*) between the observed and computed surface runoff, which is given by Equation 8.12.

$$SSE = F^2 = \sum_{i=0}^{n} (Q_{obs} - Q_{sim})^2 \quad \text{... (8.12)}$$

Where;

Q_{obs} = Observed discharge

Q_{sim} = Simulated discharge

Many runs with different initial values of parameters were considered to find the parameter values for the minimum *SSE*. At each time the graphical comparison of the historical and simulated runoff was also performed. The initial variance of the runoff is given by Equation 8.13.

$$F_0^2 = \sum_{i=0}^{n} (Q_{obs} - \overline{Q_{obs}})^2 \quad \text{... (8.13)}$$

Where;

Q_{obs} = Observed discharge

$\overline{Q}_{obs}$ = Average observed discharge

The sum of square of error (*SSE*) is a quantity used in describing how well a model, often a NAM model, represents the data being modeled. In particular, the sum of square of error measures how much variation there is in the modeled values, observed data, and variation in the modeling errors. Sum of square of error has been calculated for the model calibration, validation and for the complete data were 5266670, 43393934 and 319241 respectively. Result shows that the SSE was in the range during the modeling.

8.5.11 Coefficient of Determination (R^2)

Another measure of the quality of calibration is the correlation coefficient "R^2" between the simulated and observed runoff data given in equation 8.14.

$$R^2 = \frac{\sum_{i=0}^{n}\{(Q_{obs_i} - \overline{Q_{obs}})(Q_{sim_i} - \overline{Q_{sim}})\}}{\sqrt{\sum_{i=0}^{n}(Q_{obs_i} - \overline{Q_{obs}})^2 \left(\sum_{i=0}^{n} Q_{sim_i} - \overline{Q_{sim}}\right)^2}} \quad \ldots(8.14)$$

Where;

Q_{obs} = Observed discharge,

$\bar{Q}_{obs}$ = Average observed discharge

Coefficients of determination observed during model calibration, model validation and for the extended data were 0.864, 0.762 and 0.816 respectively indicating good agreement between the simulated and observed catchment runoff.

8.6 Sensitivity Analysis

Sensitivity analysis is a measure of the effect of change in one factor on another factor. It is used as a tool in all the phases of the modeling processes i.e. the calibration and the validation of the model. Thus, sensitivity analysis explains how output variations depend on input ones. Sensitivity analysis is a crucial part of the development of any kind of model. Essentially it is the process of varying model input parameters over a reasonable range and observing the relative change in model response.

Once the model was set, its model parameters were identified for the basin. Then for carrying out sensitivity analysis, the same model was run by selecting one parameter as a variable and keeping other parameters constant. In the study, for the sensitivity analysis, five important parameters were selected one by one, which were L_{max}, C_{QOF}, C_{K1K2}, T_{OF} and C_{KBF}. These all parameter were increased and decreased by 20% to both side from their values obtained during calibration of the model.

These processes were then applied for all five parameter. A number of optimization runs were made with different initial values of the parameters. The response surface in the vicinity of optimum parameter values was then examined in detail by manually varying the parameter in small steps with 20% change in its value. As the sensitivity of the each parameter is dependent on the sum of square of error (*SSE*) and efficiency of the model, its *SSE* and efficiency were estimated for each run as per the equation given above. The output results were analyzed by plotting selected parameter values against the *SSE* and efficiency and the most influencing and sensitive parameters of the model were identified.

8.6.1 Maximum water content in lower zone/root storage (*Lmax*)

From the analysis of Figure 8.23 showing the relation between L_{max} and *SSE*, it was observed that the value of *SSE* was lowest for the L_{max} value of 300. From Table 8.10, Figure 8.22 and 8.23, it was observed that, as the L_{max} was increased or decreased from this value the value of *SSE* increasing significantly and efficiency of the model was increased significantly due to increase of L_{max}. Hence it can be concluded that Maximum water content in lower zone/root storage (L_{max}) was the sensitive parameter which affects the output of the NAM model.

Table 8.10: *SSE* and Efficiency of model with respect to *Lmax*

L_{max}	*SSE*	Efficiency
120.00	12823202.00	0.5337
180.00	8885704.00	0.6169
240.00	6345835.00	0.7692
300.00	5257898.00	0.8088
360.00	5117686.00	0.8139
420.00	5393051.00	0.8039
480.00	5286316.00	0.7881
540.00	6337247.00	0.7695

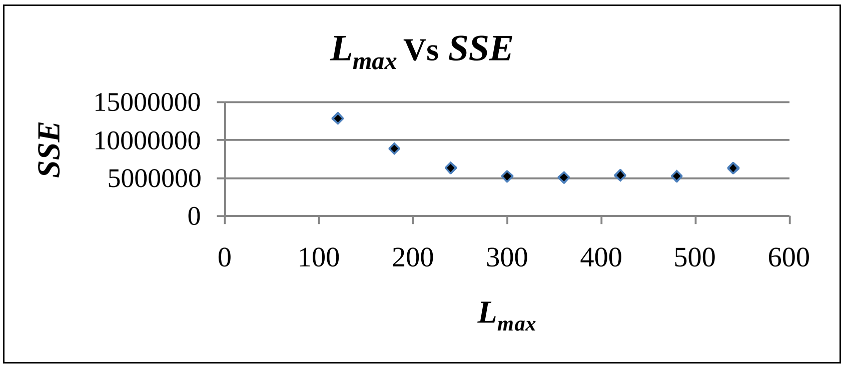


Figure 8.22: Relation between L_{max} and *SSE*

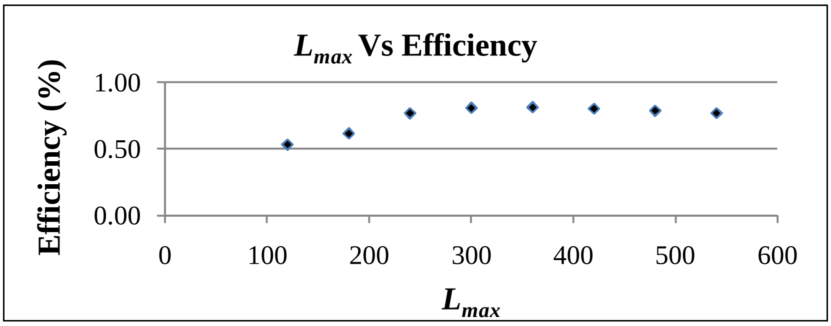


Figure 8.23: Relation between L_{max} and Efficiency

8.6.2 Overland flow coefficient (C_{QOF})

From the analysis of Figure 8.24, 8.25 and Table 8.11 showing the relation of C_{QOF} with *SSE* and efficiency, it was observed that the value of *SSE* was decreasing significantly with increase of C_{QOF} and value of efficiency increasing significantly with increase of C_{QOF}. Hence it can be concluded that Overland flow coefficient (C_{QOF}) was the sensitive parameter which affects the output of the NAM model. It was observed that C_{QOF} has significant role in the model and it is the most important sensitive parameter of the model which influences the rainfall runoff modeling results.

Table 8.11: *SSE* And Efficiency of model with respect to C_{qof}

C_{QOF}	*SSE*	Efficiency
0.34	12151414.00	0.5582
0.51	8423909.00	0.6937
0.68	6024104.00	0.7810
0.85	5117686.00	0.8139
1.00	5203490.00	0.8108

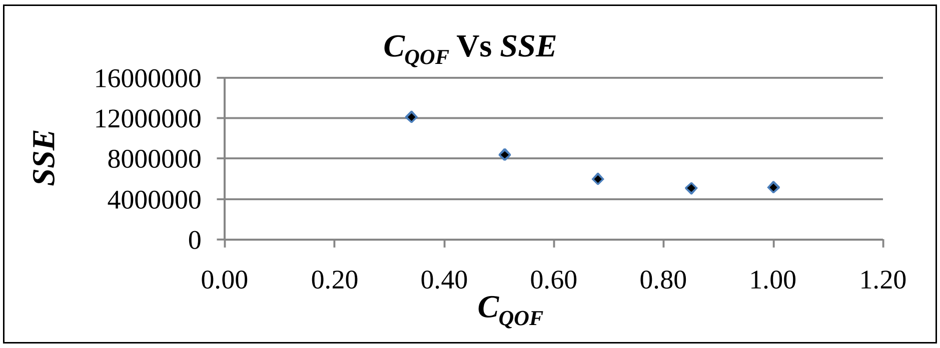


Figure 8.24: Relation between C_{QOF} and *SSE*

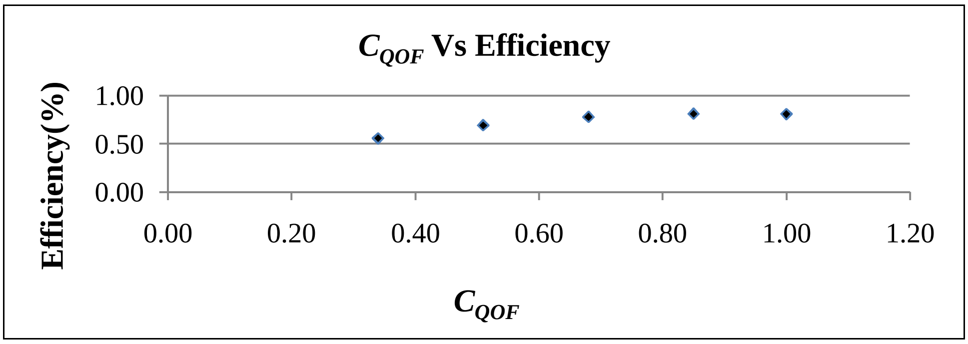


Figure 8.25: Relation between C_{QOF} and Efficiency

8.6.3 Overland flow threshold (T_{OF})

From the analysis of Figure 8.26, 8.27 and Table 8.12 showing the relation of T_{OF} with *SSE* and efficiency, it was observed that the value of *SSE* and efficiency was observed unaffected with increase or decrease of T_{OF}. Hence it can be concluded that Overland flow threshold (T_{OF}) was not the sensitive parameter in the NAM model.

Table 8.12: *SSE* And Efficiency of model with respect to T_{of}

T_{OF}	*SSE*	Efficiency
0.0122	5105289.00	0.8144
0.0182	5109023.00	0.8142
0.0243	5113196.00	0.8141
0.0304	5117686.00	0.8139
0.0365	5122549.00	0.8137
0.0426	5127753.00	0.8135
0.0486	5133292.00	0.8130

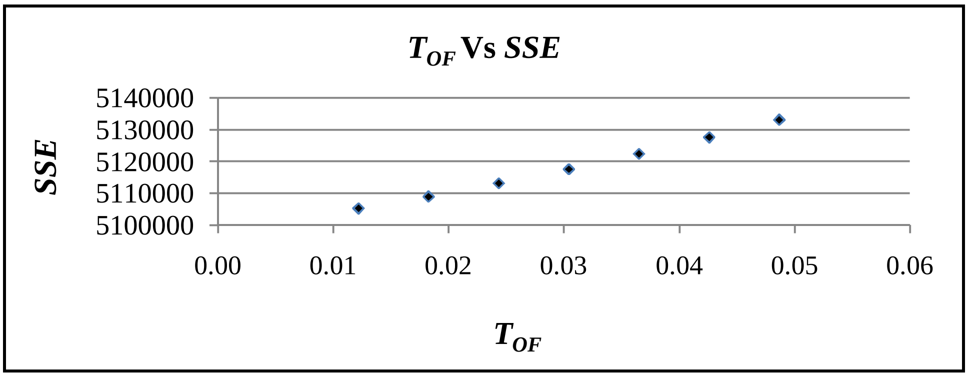


Figure 8.26: Relation between T_{OF} and *SSE*

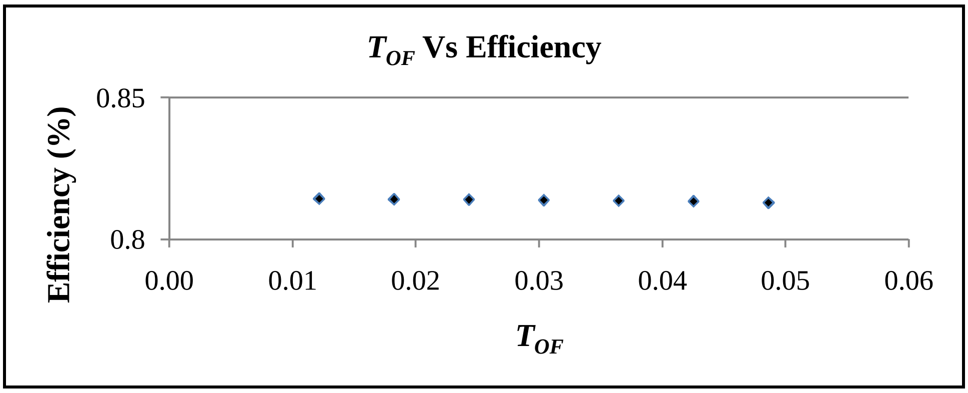


Figure 8.27: Relation between T_{OF} and Efficiency

8.6.4 Time constant for overland flow and interflow (C_{K1K2})

From the analysis of Figure 8.28 showing the relation between C_{K1K2} and *SSE*, it was observed that the value of *SSE* was lowest for the C_{K1K2} value of 38.80. As the C_{K1K2} was increased or decreased from this value the value of *SSE* increasing significantly. From Figure 8.29 it was observed that the efficiency of the model was increased significantly due to increase of C_{K1K2}. Hence it can be concluded that Timing constant for overland flow and interflow (C_{K1K2}) was the sensitive parameter which affects the output of the NAM model. The results are also shown in Table 8.13.

Table 8.13: *SSE* And Efficiency of Model With Respect to C_{k1k2}

C_{K1K2}	*SSE*	Efficiency
15.52	18226258.00	0.3373
23.28	10091738.00	0.6331
31.04	6225194.00	0.7736
38.80	5117686.00	0.8139
46.56	5654851.00	0.7944
54.32	6977289.00	0.7463
62.08	8635198.00	0.6860

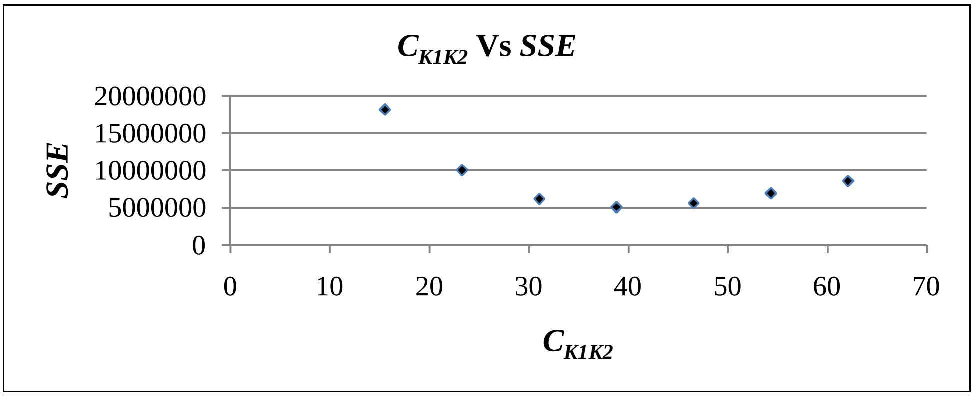


Figure 8.28: Graph between C_{K1K2} and *SSE*

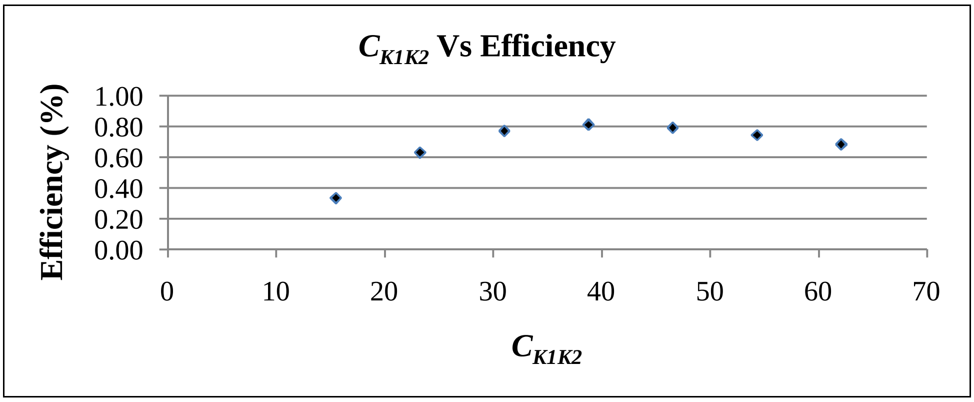


Figure 8.29: Graph between C_{K1K2} and Efficiency

8.6.5 Time constant for base flow (C_{KBF})

From the analysis of Table 8.13, Figure 8.30 and 8.31 showing the relation of C_{KBF} with *SSE* and efficiency, it was observed that the value of *SSE* and efficiency was observed unaffected with increase or decrease of C_{KBF}. Hence it can be concluded that Timing constant for base flow (C_{KBF}) was not the sensitive parameter in the NAM model.

Table 8.14: *SSE* And Efficiency of Model With Respect to C_{kbf}

C_{KBF}	*SSE*	Efficiency
120.00	5140934.00	0.8131
180.00	5132687.00	0.8134
240.00	5124779.00	0.8137
300.00	5117686.00	0.8139
360.00	5111546.00	0.8141
420.00	5106361.00	0.8143
480.00	5102067.00	0.8145
540.00	5098564.00	0.81

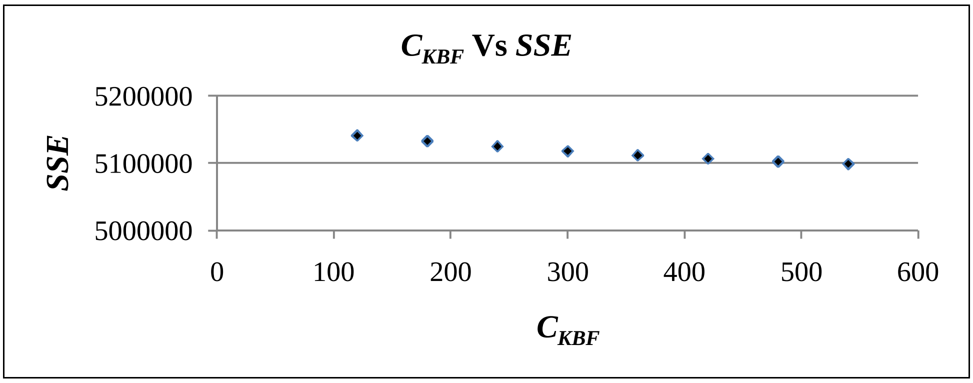


Figure 8.30: Graph between C_{KBF} and *SSE*

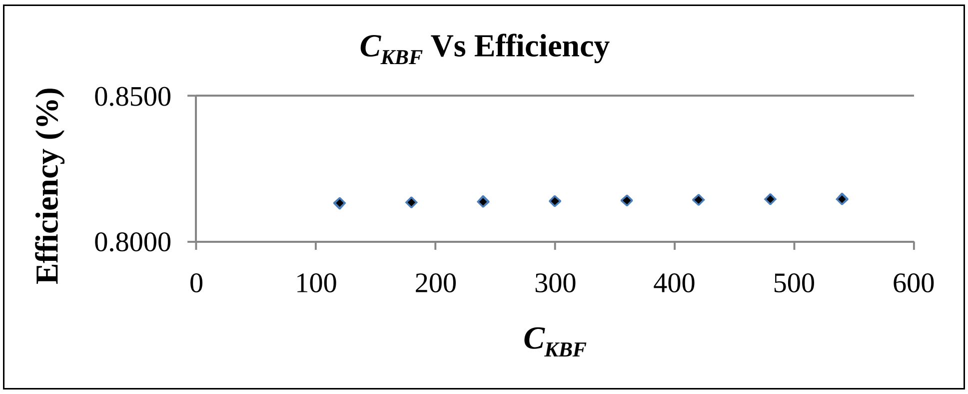


Figure 8.31: Graph between C_{KBF} and Efficiency

From the sensitivity analysis of the model parameters it was observed that L_{max} , C_{QOF}, & C_{K1K2} were the important influencing parameter which influences simulated runoff. NAM model was found sensitive to these three model parameters which influence the runoff response of the catchment.

9 WATER AVAILABILITY STUDY

9.1 Introduction

Chhattisgarh state is facing the problem of water scarcity in rural as well as in urban areas to meet various water demands. Understanding the complex system of hydrological processes and the water availability in the Kharun river basins are important for the sustainable water resources development of an area. Present study deals with the water availability study in Kharun river basin. The area under Kharun river basin is characterized by water shortage, increasing water demand and over exploitation of available water resources. Lack of suitable water resources management measures in Kharun river causing most of the precious water being drained down the rivers without being tapped imposing more dependence on groundwater resources (Galkate et al., 2010). Thus, water availability study of a Kharun river is an important component of hydrological planning, on the basis of which development of water resources of a river for various beneficial uses is thought of (Galkate et al., 2012). The flow regime in Kharun river has been seen strongly influenced by regulation operations associated with water transfer from Ravishankarsagar reservoir to Kharun and its supply for various usages through the series of anicuts. Therefore water availability study in Kharun basin has been carried out to analyze the flow regime under regulated flow condition and virgin flow condition both to understand the river characteristics.

9.2 Estimation of Catchment Yield

The virgin flow time series at Patherdihi was already estimated from the regulated observed flow at Patherdihi using the equations developed after critically observing the field conditions and existing water transfer system in the Kharun river basin. The process of estimation of virgin flow at Patherdihi has been discussed in detail in section 8.4.3.1 in this report. The regulated and virgin flows of Kharun basin were simulated for the period of 15 years from year 1993 to 2007 using the same MIKE BASIN model of Kharun river as discussed in Chapter 7 of this report. To simulate the runoff at the river outlet, the virgin flow time series (in m^3/sec) thus generated at Patherdihi was converted in the form of specific runoff time series (in l/sec/km^2). This specific runoff time series was then applied in MIKE BASIN model to catchment properties of the model and model was run to simulate the runoff at outlet of the Kharun river. The runoff time series thus obtained was the virgin flow time series at Kharun river outlet. The observed regulated flow data at Patherdihi was then routed in same MIKE BASIN model in a similar way to obtain regulated flow time series of Kharun river at its outlet point. The virgin and regulated flow time series of Kharun basin thus obtained using MIKE BASIN Model as described above were used for the water availability analysis using flow duration curve technique.

The runoff time series of virgin and regulated flow thus generated were converted in the form of annual yield of the Kharun catchment. Average annual rainfall, virgin flow, water added to Kharun river and regulated flow in river were estimated and are given in Table 9.1. From the analysis of the results given in Table 1, it was observed that the average annual rainfall in Kharun basin was 1147.57 mm which had produced 1802.88 MCM average annual runoff. The river had sufficient annual water yield but due to lack of big storage structures on river because of prevailing flat topographic conditions, the water demands in the basin could not fulfilled by the river. The Ravishankarsagar reservoir and other sources had been observed adding around average 116.22 MCM water in the river which was supplied to Raipur city, railways and industrial area through the series of anicuts and the average annual regulated flow in Kharun river was 1919.1 MCM.

Table 9.1: Annual rainfall, virgin flow, water added and regulated flow in Kharun

Year	Rainfall (mm)	Virgin Flow (MCM)	Water Added to river (MCM)	Regulated Flow (MCM)
1993	1182.9	1620.12	112.85	1732.97
1994	1640.8	3688.99	99.60	3788.60
1995	1166.6	2084.71	117.56	2202.27
1996	1129.3	1648.02	93.85	1741.88
1997	1177.1	1564.40	109.91	1674.31
1998	1097.8	1163.47	80.82	1244.29
1999	1074.7	1544.13	110.79	1654.91
2000	698.5	484.38	114.62	599.00
2001	1065.7	1529.47	134.48	1663.95
2002	811.9	993.54	127.20	1120.73
2003	1384.4	2642.12	125.31	2767.44
2004	1023.9	1452.38	139.54	1591.91
2005	1425.1	2794.48	118.08	2912.55
2006	1110.3	1681.78	138.34	1820.12
2007	1224.5	2151.22	120.33	2271.54
Average	**1147.57**	**1802.88**	**116.22**	**1919.10**

9.3 Estimation of Dependable Flow

Water availability analysis in Kharun basin has also been carried out by estimation of dependable flow volumes at various probability levels using Flow Duration Curve technique. The method of deriving Flow Duration Curves from the discharge data has been discussed in section 6.2.1 of this report. Assessment of dependable flows along with their distribution in time is essential for planning and development of water supply schemes. Especially the study of the lean season flow characteristics is important to determine the probability of the river system to provide adequate and assured water supply for meeting the expected demands (Pandey and Ramasastry, 2003). It is generally observed that the flow characteristics of the streams are highly dependent upon watershed topography, climate and land use. The flow duration depends on natural conditions as well as man-made effects and may reflect some specific water use practices (Chang and Boyer, 1977 and Clausen and Pearson, 1995). The time periods usually considered in flow duration analyses are 1 day, 7 days, 10 days or 30 days. The present study aims to assess the availability of dependable flows volumes in the Kharun river on monthly basis within a year at 60, 70, 80 and 90% probability of exceedance. The virgin and regulated daily flow data of 15 years from 1993 to 2007 was grouped under twelve months periods. The monthly Flow Duration Curves (FDC) for the month of December under virgin and regulated flow condition are shown in Figure 9.1. The dependable flow available in Kharun river under virgin condition (m^3/s) at various probability levels is given in Table 9.2. The dependable flow available in Kharun river under regulated condition (m^3/s) at various probability levels is given in Table 9.3. The graph showing water availability in Kharun river under virgin and regulated flow condition at 90% probability is given in Figure 9.2.

Table 9.2: Dependable flow available in Kharun river under virgin condition (m^3/s) at various probability levels

Prob. (%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
60	0.00	0.00	0.00	0.00	0.00	3.500	36.715	102.867	33.332	0.624	0.127	0.069
70	0.00	0.00	0.00	0.00	0.00	2.230	17.819	72.327	17.380	0.279	0.067	0.042
80	0.00	0.00	0.00	0.00	0.00	1.830	12.296	47.180	7.898	0.052	0.040	0.035
90	0.00	0.00	0.00	0.00	0.00	1.032	8.107	19.035	1.540	0.030	0.022	0.000

Table 9.3: Dependable flow available in Kharun river under regulated condition (m^3/s) at various probability levels

Prob. (%)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
60	3.960	3.960	4.250	4.955	5.100	5.100	36.393	111.842	38.907	4.866	3.204	2.833
70	2.955	3.850	3.400	4.608	4.540	4.250	17.891	77.743	22.030	4.443	3.013	2.831
80	2.916	2.955	2.830	3.648	3.018	2.915	12.910	48.446	11.598	4.255	2.953	2.830
90	2.830	2.830	2.830	3.262	3.013	2.830	8.189	19.399	5.450	3.943	2.851	2.830

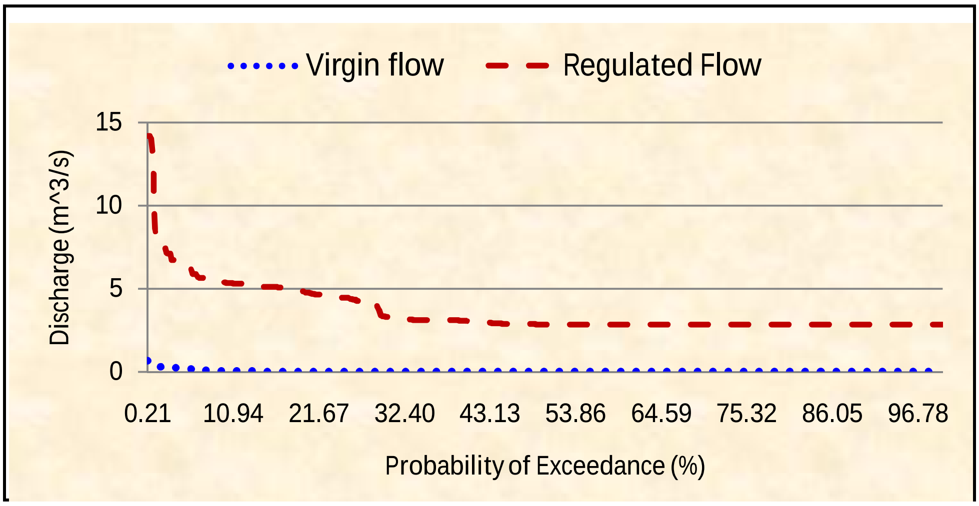


Figure 9.1: Flow Duration Curve for December under virgin and regulated flow condition

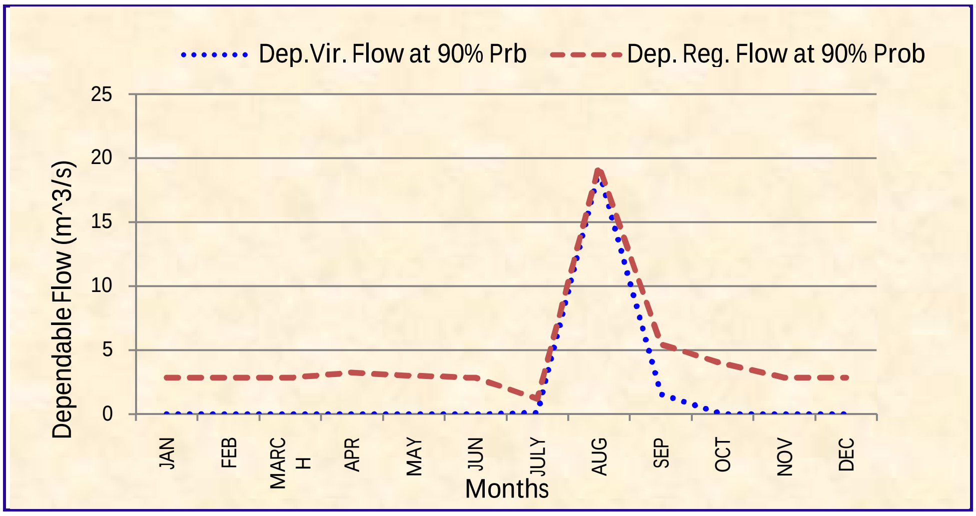


Figure 9.2: Dependable flow in Kharun river under virgin and regulated flow condition

9.4 Results and Discussion

From the analysis of Table 9.2, dependable flow available in Kharun river under virgin condition, it was observed that the Kharun river is originally a intermittent river having flow during monsoon season and 2 or 3 months thereafter. Under the natural virgin condition, the river has no flow during January to May at even at 60% probability. The river has high dependable flow at during July to September and highest in the month of August. The highest dependable flow 102.8 m^3/s at 60% probability and 19.03 m^3/s at 90% probability levels were observed in the month of August. The river flow has significant temporal variation in monsoon and non-monsoon season, contributing large yield during July to Septembers and low flow thereafter prevailing up to December. Thus the demands of the river cannot be fulfilled with the water availability under the virgin condition.

To tackle this situation the water from Ravishankarsagar reservoir is being released into Kahrun river from Mahanadi Feeder Cannal (MFC) through Deorani Jethani Nala and Mandhar Branch Cannal (MBC) to meet the various demands in Kharun basin and river experiences flow throughout the year under regulated flow condition. From the analysis of Table 9.3, dependable flow available in Kharun river under regulated condition, it was observed that the Kharun river has now considerable flow during January to May even at 90% probability. At 90% probability the dependable flow in river was observed 2.83 m^3/s in January whereas 3.01 m^3/s in May which is due to addition of more water during summer months to fulfill the demand. The highest dependable flow 111.84 m^3/sec at 60% probability and 19.39 m^3/s at 90% probability levels were observed in the month of August which is almost same as the virgin flow condition indicating no need of additional water release in to the river during monsoon season.

From the analysis of Flow Duration Curve for the month of December shown in Figure 9.1, it was observed that the dependable flow volume has been considerably increased under regulated flow as compared to virgin flow condition in the month of December. Similarly, Figure 9.2 illustrate the increase of monthly dependable flow volume or water availability in Kharun river at 90% probability when water is added to river from the external sources like Ravishankarsagar reservoir and Mandhar Branch canal to meet the various on-stream water demands in the river basin. The water has also been added to Kharun river in the form of return flows from the agricultural area under the command of Mahanadi Main Canal and Tandula Main Canal.

10 DEMAND SUPPLY ANALYSIS

Supply and demand is perhaps one of the most fundamental concepts of economics, which is equally important in water sector also, especially in semi-arid region like Chhattisgarh. Water has sources and supplies; it has economic, social, and political characteristics which make it a unique and challenging natural resource to manage. Water resources are used in various ways including direct consumption, agricultural irrigation, fisheries, hydropower, industrial production, recreation, navigation, environmental protection, the disposal and treatment of sewage and industrial effluents. Hendricks et. al. (2007) carried out case study for the application of a water balance model in finding "solutions" to the supply-demand problem in the South Platte River basin and solutions were ascertained using both "average" and "stress" and supply- demand scenarios were developed to meet future demands.

Chhattisgarh, a newly formed state developing its water resources to meet the domestic, agricultural, industrial and other important demands. State is experiencing rapid population growth, industrial growth and agricultural development which have increased the water demands. Therefore, in this context, basin-wise water demand projections need to be assessed in the state. Water demand estimates over long period are essential in river basin planning process as it gives important directions for policy formulation and system planning. In the present study, the supply-demand analysis has been carried out for Kharun river basin with an aim to assess the supply and demand scenario in the basin at present and in future. Kharun is one of the important tributary of Seonath river having catchment area 4112 km^2. Kharun river basin falls in Durg, Raipur and Dhamtari districts. The major part of Kharun river basin comes under command area of Ravishankarsagar reservoir and small part under Tandula reservoir. The water from Kharun river has been diverted to meet the domestic water demand, industrial water demand, water supply for railways and other water demands. At present the around 50% of total water demand of Raipur city and Industrial area is being fulfilled from Kharun river and remaining demand is being fulfilled from groundwater and other sources. In the analysis, the amount of water available in the Kharun was considered as the “supply”. The “demand” includes the amount of water needs to be supplied from Kharun river through various anicuts to meet various water uses in the basin. The Kharun river is regularly supplemented from Ravishankarsagar reservoir situated at Dhamtari on Mahanadi river to meet these water demands. Thus the study has been carried out to assess demand supply scenario of Kharun river basin. Present analysis carried out with the observed data at Patherdihi G/D site on Kharun river which is a regulated flow.

10.1 Water Demands

At present the available water in Kharun river during lean season is inadequate to meet the various water use demands in the basin. Situation will become critical in future if the developments in the Kharun river basin take place with the same rate. In water resources planning process, domestic water demand is important as its aim is to determine the allocation of available scare resources to achieve a ‘social minimum’ of adequate water supply. Other important demands are industrial and agricultural water demand. The most important water demands in the Kharun river basin, which are to be met from Kharun river are given below.

1. Domestic water demand
2. Industrial water demand
3. Railway water demand.
4. Other demands (Nistari purpose, recreational purpose etc.)

These four important water demands are discussed in detail and are considered for demand supply analysis of Kharun river. The water from Kharun is being not used for irrigation purpose, the irrigation demand in the basin is being fulfilled by the separate Mahanadi Main Cannal (MMC) system from Ravishankarsagar reservoir on Mahanadi river and Tandual Main Canal (TMC) system from Tandula reservoir on Tandula river. Hence irrigation demand is not accounted for supply-demand analysis.

10.1.1 Domestic water Demands

The Kharun river is one of the important sources of domestic water supply to Raipur city. The water is being supplied from Bhatagaon and Ghugwa anicuts to the Raipur city. The existing water supply arrangements are designed to meet water demand of 10.28 lakhs population at rate of 110 lpcd, which is lower than the water supply norms of National Building Code (NBC) and Indian Standards suggesting 135 lpcd and Urban Development Plan Formulation and Implementation (UDPFI) Guidelines suggesting 170 lpcd. Due to increase in population and growth of the city, existing water system is becoming more and more inadequate day by day. Apart from this, extended municipal limits of the city that included some newly developed areas are not having their own protected water supply. As per the report published under City Development Plan, Raipur City Municipal Infrastructure, the urban population of the Raipur city is increasing at the rate of 3.5% per year. The projected population and domestic water demands during next decades in the Raipur city have been estimated considering the population growth rate of 3.5% and various water supply norms. Around 50% water demand of the Raipur city is fulfilled from Kharun and remaining demand is fulfilled from groundwater and other sources. The water demand of Raipur city to be fulfilled Kharun river for domestic supply in Raipur city is estimated and is shown in Table 10.1.

Table 10.1: Domestic water demand in Raipur City and demand to be fulfilled from Kharun

Sl. No	Year	Estimated Population	Water Demand (MCM) of Raipur City			Water Demand (MCM) to be full filled from Kharun River		
			Existing Arrangement	NBC Guide line	UDPFI Guide line	Existing Arrangement	NBC Guide line	UDPFI Guideline
1	2006-07	896711	36.00	44.19	55.64	18.00	22.09	27.82
2	2007-08	927927	37.26	45.72	57.58	18.63	22.86	28.79
3	2008-09	960230	38.55	47.32	59.58	19.28	23.66	29.79
4	2009-10	993658	39.90	48.96	61.66	19.95	24.48	30.83
5	2010-11	102824	41.28	50.67	63.80	20.64	25.33	31.90
6	2011-12	106404	42.72	52.43	66.02	21.36	26.22	33.01
7	2020-21	133647	53.66	65.85	82.93	26.83	32.93	41.46
8	2030-31	167696	67.33	82.63	104.06	33.67	41.32	52.03
9	2040-41	201745	81.00	99.41	125.18	40.50	49.71	62.59
10	2050-51	235794	94.67	116.19	146.31	47.34	58.09	73.16

From the Table 10.1, it was observed that the existing population of Raipur city (2010-11) was 10.28 lakhs and it will become 23.57 lakhs by the year 2050-51. Present domestic water demand of Raipur city as per existing arrangement is 41.28 MCM which will become 94.67 MCM by the year 2050-51. If the domestic water supply is planned as per UDPFI guidelines the water demand will become 146.31 MCM. In that case the 73.16 MCM water will be needed from Kharun river to fulfill 50% demand of the Raipur city. This information will help the planners to make necessary arrangement for augmenting water availability to meet domestic water demand at various development stages in future as per different guidelines and norms considering the improved life style and increased use of water in future.

10.1.2 Industrial water demands

Kharun also provides water supply to Urla and Siltara industrial area located near Raipur city through Murethi-I and Murethi-II anicuts. The total industrial water demand of both industrial areas could not be estimated due to unavailability of required information and data with the concerned agencies. As per the information available with Water Resources Department has proposed to provide 52.54 MCM water for the industrial use but state is not in a position to fulfill the complete demand and providing only 38.29 MCM of water from Kharun river. The remaining water demand of the industries is fulfilled from ground water and other local sources. The details of industries and their water demands are given in Table 10.2.

Table 10.2: Industrial water demand on Kharun River

S.No.	Name of Establishment / Industry	Location	Annual Water Demand (MCM)
1	M/s Jaswal Niko Ltd.	Siltara	13.28
2	M/s Monet Ispat Ltd. Mandir Hassod	Mandir Hassod	3.20
3	Ispat Gagawri Ltd.	Siltara	1.66
4	CSIDC, Raipur	Mandir Hassod Siltara	4.98
5	Chhattisgarh Electricity Company Ltd.	Industrial Development Centre	3.32
6	M/s Bajrang Power & Steel Ltd.	Urla Extension	1.50
7	SKS Steel Pvt. Ltd. Proposed steel & Captive Power Plant	Siltara	1.80
8	API Steel & Power Tech (P) Ltd.	Siltara	0.84
9	CSIDCK Borjhra Urla	Urla	4.48
10	CSITC Siltara Industrial Area Expansion	Siltara	3.32
11	M/s P.D. Industries (P) Ltd.	Siltara	0.11
12	Baldev Alliance (P) Ltd. Spung Iron Unit	Siltara	0.52
13	C.G. Steel Gauge Ltd.	Siltara	13.53
	Total Demand		**52.54**

10.1.3 Railway water demand

Railway has constructed an Anicut on Kharun river and extracting water to meet its various need. As the information on water being extracted from Kharun river is not available hence it is assumed that the Railway is consuming water at the rate of 0.2 m^3/sec i.e. 4.5 MCM throughout the year and projected accordingly for future estimation.

10.1.4 Other demands

Water from river is also being utilized for Nistari purpose (village tank supply) and recreational activities. Water is not being directly diverted from Kharun river for nistari but water available at three anicuts, Raipura, Atari and Gomchi is being used for nistari purpose i.e. for the bathing, washing by local peoples. It augments the groundwater recharge and helps in rising of water table in nearby area, which ultimately helps the local people to meet their potable water demand. Nistari water is also used as a source of drinking water for animals. The water is not directly supplied from the source for nistari hence the water demand is taken as minimum as 0.1 m^3/sec considering the losses and utilization. Various agricultural, commercial activities like Brick Kiln Furnaces, small scale industrial units, etc are directly extracting or lifting water from Kharun river, these extractions are accounted and are considered in other demands. As the information of these petty demands is not available the other demands are assumed as 1.5 MCM per annum and are projected accordingly for future estimation.

10.1.5 Total water demand

For the analysis purpose the present domestic water demand of Raipur city has also been estimated as per the Water supply norms of National Building Code (NBC), Indian Standards suggesting 135 lpcd and future demands for next 40 years are estimated as per Urban Development Plan Formulation and Implementation (UDPFI) Guidelines suggesting 170 lpcd. The total water demands to be fulfilled from Kharun river in next five decades were estimated and are shown in Table 10.3.

Table 10.3: Total projected water demand to be fulfilled from Kharun

Projected period	Demands (MCM)				
	Domestic	Industries	Railways	Others	Total
2010-11 As per existing arrangement @ 110 lpcd	20.64	38.29	4.73	1.56	65.21
2010-11 As per norms of NBC, Indian Standards @ 135 lpcd	25.32	38.40	4.73	1.56	69.90
2010-11 As per norms of UDPFI Norms @ 170 lpcd	31.89	52.55	6.31	1.56	92.31
2020-21 As per norms of UDPFI Norms	41.46	60.00	7.88	1.56	110.90
2030-31 As per norms of UDPFI Norms	52.03	70.00	9.46	1.94	133.43
2040-41 As per norms of UDPFI Norms	62.59	80.00	9.46	1.94	154.00
2050-51 As per norms of UDPFI Norms	73.16	90.00	9.46	1.94	174.56
When Demand Becomes 200 MCM	88.50	100.00	9.50	2.00	200.00
When Demand Becomes 250 MCM	106.50	132.00	9.50	2.00	250.00

From the Table 10.3, it has been observed that, the present total water demand of Kharun river was 65.21 MCM which will become 174.56 MCM by the year 2050-51. The water demands for domestic water supply and industrial water supply are two main water demands on the Kharun river which plays important role in water resources planning strategies of the basin.

10.2 Water Supply

The Kharun is one of the important river near Raipur city to meet the domestic, industrial and other water demand. Kharun river has series anicuts along the river to provide water supply to various users. Seven anicuts are in operation, three are under construction and six more anicuts are proposed on the river as shown in Figure 7.1 of chapter 7. Kharun flows to the west of Raipur town and supply water to Raipur city through Bhatagaon and Ghughuwa anicuts. At the downstream, it also supplies water to the Urla and Silthara industrial area from Murethi-I and Murethi-II anicuts. It also caters the water for Railways and other users through various anicuts constructed along the river. Kharun river is of intermittent nature, the flow in the river prevails during June to December only and becomes dry during lean season. The water availability analysis shows that the Kharun river has sufficient annual water yield to meet all the water use demands in the basin. But due to its intermittent nature and unavailability of water storage structure on the river, it is unable to provide water during lean season. The river has almost flat topography in the basin and suitable location for construction of dam is not available. To overcome this situation, an arrangement has been made to supplement Kharun river from Ravishankarsagar reservoir located in Dhamtari district on Mahanadi river. The water from Ravishankarsagar reservoir is being released into Kahrun river from Mahanadi Feeder Cannal (MFC) through Deorani Jethani Nala. The Mandhar Branch Canal (MBC) a major distributor of Mahanadi Main Cannal (MMC) directly releases water into Kharun river. Thus, the water transferred into Kharun river is utilized to meet various water demands. The water transfer system of Kharun river is discussed in detail in Section 7 of this report. This is the classic example of inter-basin transfer being in operation since last 30-40 years in the state. The irrigation demand in the basin is being fulfilled by the separate canal system of Ravishankarsagar reservoir on Mahanadi river and Tandula reservoir on Tandula river.

10.3 Demand Supply Analysis

Despite having sufficient annual water yield, Kharun river is unable to provide water during lean season, due to its intermittent nature and unavailability of water storage structure at the upstream location of the river. The river has sufficient water during monsoon season to meet various demands but it runs dry during non-monsoon season. The water supplemented from Ravishankarsagar Reservoir to Kharun helps to overcome this situation and to meet the various on-stream demands to some extent. The various water demands on Kharun are expected to be boost up in next few decades due to rapid population and industrial growth. In this context it is important to study the future supply-demand scenario and surplus-deficit estimates for the River Basin Management and planning which will helps in setting directions for policy formulation and system planning. In view of this, demand supply analysis has been carried out by estimating the surplus or deficit volumes in the river on ten-daily basis at various probability levels. The ten-daily dependable flow volumes at various probability levels are estimated using Flow Duration Curve technique.

10.4 Generation of Flow Data using MIKE BASIN

To study the supply-demand analysis, the observed daily discharge data at Patherdihi G/D site have been used. The Kharun river flow at Patherdihi is strongly influenced by regulation operations, as water is transferred from Ravishankarsagar reservoir to the river at the upstream location and supplied for various usages through the series of anicuts. All important water users are mainly located 20 to 25 km at upstream and downstream side of Patherdihi G/D site. The anicuts supplying water to Raipur city and railways are located at the upstream and the anicuts supplying water to industrial area are located at the downstream of Patherdihi G/D site. Though the water is being supplied from various locations but for the analysis purpose it is assumed that the water is supplied to all the water users from single point i.e. Patherdihi. As per the assumption, a new flow time series at Patherdihi was prepared using equation 10.1 in MIKE BASIN software which was then used for demand supply analysis. The time series for water demand was prepared from the total water demand information. As the water is being diverted from upstream location of Patherdihi for Raipur city and Railways, the water supply time series has been used to obtain new discharge time series at Patherdihi by adding diverted water to the observed flow at Patherdihi. The new flow time series was generated by using following equation 10.1.

$$Qp = Qobs + Q_{RC} + Q_{RL} \qquad \ldots (10.1)$$

Where, Qp = Generated Flow at Patherdihi (m^3/s)
$Qobs$ = Observed Flow at Patherdihi (m^3/s)
Q_{RC} = Flow diverted for Raipur City (m^3/s)
Q_{RL} = Flow diverted for Railways(m^3/s)

A small schematic river basin model was prepared in MIKE BASIN software, the water supply time series to Raipur city and Railways were added to Patherdihi observed flow by assuming regular supply of $0.73 m^3/sec$ for theses two uses. The new discharge time series was generated at Patherdihi site by running the MIKE BASIN Model simulation. The new time series, thus generated was then used for assessing the supply scenario at Patherdihi. As it is assumed that all the demands on Kharun river are to be fulfilled from one location Patherdihi, the annual demand time series are prepared and compared with the newly generated discharge time series at Patherdihi. The MIKE BASIN Model prepared for generation of new time series is shown in Figure 10.1.

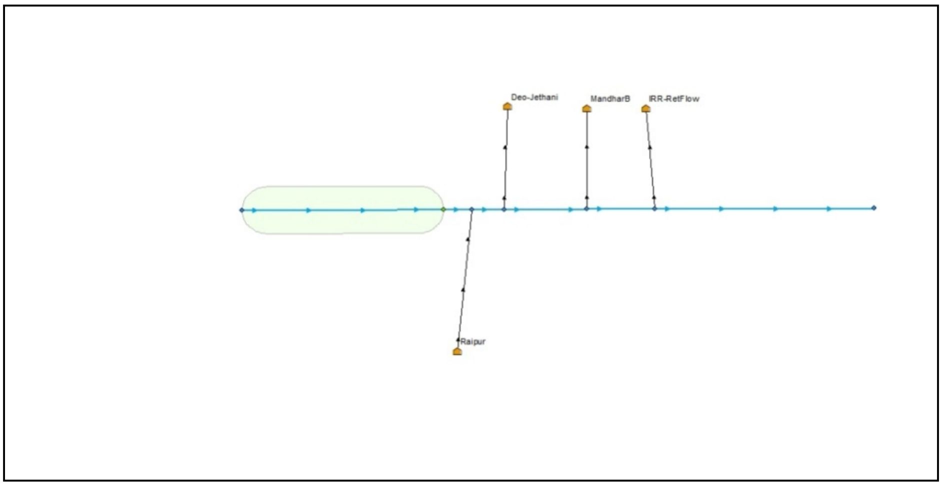


Figure 10.1: MIKE BASIN Model setup for estimation new flow time series at Patherdihi

10.5 Estimation of Dependable Flow Volumes

Assessment of dependable flows along with their distribution in time is essential for planning and development of water supply schemes. Especially the study of the lean season flow characteristics is important to determine the probability of the river system to provide adequate and assured water supply for meeting the expected demands. In the analysis of low flow during lean season, the hydrologists are mainly concerned with the magnitude of flow, its duration and the frequency of occurrence of low flows. The magnitude of low flow is the quantity of water flowing through a given section of stream for a specified period of time and it determines the amount of water available for use.

It is generally observed that the flow characteristics of the streams are highly dependent upon watershed topography, climate and land use. The flow duration depends on natural conditions as well as man-made effects and may reflect some specific water use practices (Chang and Boyer, and Clausen and Pearson). The duration also depends on period of water deficit tolerable to the user or some other requirements; the frequency of occurrence of low flow reflects the risk of failure of a water supply scheme. In dependable flow analysis, therefore, data are normally specified in terms of the magnitude of flow for a given period of time within a year or a season. The time periods usually considered in flow duration analyses are 1 day, 7 days, 10 days or 30 days. The present study aims to assess the availability of dependable flows (Supply) volumes in the Kharun river at Patherdihi on Ten-Daily basis within a year at various probability levels and estimation of Ten-Daily surplus or deficit volume with respect to the water need (Demand) during the specified period.

The Ten-Daily dependable flow volumes at 70%, 90% and 95% probability of exceedance are estimated using flow duration curve technique. For hydrological studies dealing with water supply especially during the lean flow season, many researchers have recommended 90% or 95% probability level for determining assured water supply. These levels of probability are considered safe if the lean season flows are essentially contributed by base flow. The daily flow data of 18 years from 1990 to 2007 was grouped under different Ten-Daily periods. Every month has three Ten-Daily periods, the first 10-10 days of all months are considered as first and second Ten-Daily periods whereas in case of the month having 31 days, the third Ten-Daily period is taken as of 11 days and in case of February the third Ten-Daily period is taken as of 8 or 9 days as shown in Table 10.4. The average flow volumes for each Ten-Daily periods were computed. The Flow Duration Curves (FDC) was derived for the average flow volume of particular Ten-Daily period over the period of 18 years, the sample data of 1st Ten-Daily period of June is shown in Table 10.5 and the Flow Duration Curves (FDC) is shown in Figure 10.2. This exercise was carried out for all the 36 Ten-Daily periods within the year and the dependable flow volumes for all periods at 75%, 90% and 95% probability of exceedance were estimated.

Table 10.4: Grouping of daily flow data for estimation of average 10-Daily flow Volumes

Month	10-daily periods		
	First	Second	Third
Month having 30 days	1-10	11-20	21-30
Month having 31 days	1-10	11-20	21-31
Month having 28 or 29 days	1-10	11-20	21-28 or 21-29

Table 10.5: Sample data analysis for deriving FDC for First Ten-Daily period of January

Year	Rank	Flow (m3/s)	Sorting in Descending order	Corresponding Flow Volume (MCM)	Probability of exceedance (%)
1990	1	1.746	4.156	3.590	5.26
1991	2	2.480	3.160	2.730	10.53
1992	3	2.175	2.749	2.375	15.79
1993	4	1.824	2.496	2.157	21.05
1994	5	2.496	2.480	2.143	26.32
1995	6	2.749	2.211	1.910	31.58
1996	7	3.160	2.175	1.879	36.84
1997	8	2.211	2.144	1.853	42.11
1998	9	4.156	2.089	1.805	47.37
1999	10	1.994	1.994	1.723	52.63
2000	11	2.144	1.914	1.654	57.89
2001	12	0.854	1.824	1.576	63.16
2002	13	1.792	1.792	1.548	68.42
2003	14	0.854	1.780	1.538	73.68
2004	15	1.914	1.746	1.509	78.95
2005	16	1.311	1.311	1.133	84.21
2006	17	2.089	0.854	0.738	89.47
2007	18	1.780	0.854	0.738	95.00

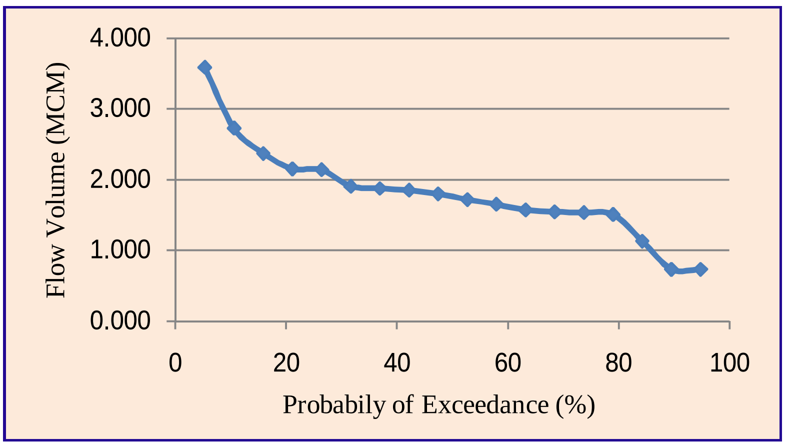


Figure 10.2: Flow Duration Curve for first Ten-Daily period of January

After estimation of 10 Daily dependable flow volumes at 75%, 90% and 95% probability levels for each Ten-Daily periods of the year, the water demands at Patherdihi for all 36 Ten-Daily periods of the year were estimated using the annual water demand information given in Table 10.3. The dependable flow volumes at Patherdihi at various probability levels derived for all 36 Ten-Daily periods of the year are shown in Table 10.6. From Figure 10.2 is observed that the flow duration curve for 1st 10-Daily period of January illustrates the regulated flow condition in the river, the dependable flow volume at 80% probability is almost same as dependable flow volume at 50%. This is due to the addition of water from Ravishankarsagar reservoir in to the river during lean season.

Table 10.6: Dependable 10-Daily Flow Volumes (MCM) at various Probability Levels at Patherdihi

Month	10-Daily Period	Probability of Exceedance				Month	10-Daily Period	Probability of Exceedance			
		75%	80%	90%	95%			75%	80%	90%	95%
June	Ten Daily I	0.91	0.91	0.91	0.91	December	Ten Daily I	1.71	1.61	0.74	0.74
	Ten Daily II	1.18	0.91	0.91	0.91		Ten Daily II	1.55	1.42	0.74	0.74
	Ten Daily III	3.39	2.95	1.51	0.82		Ten Daily III	1.36	1.34	1.66	0.67
July	Ten Daily I	1.69	1.61	1.10	0.98	January	Ten Daily I	1.53	1.43	0.74	0.74
	Ten Daily II	5.19	2.55	1.59	1.21		Ten Daily II	1.27	1.15	0.74	0.74
	Ten Daily III	34.48	31.79	14.19	1.19		Ten Daily III	1.16	1.10	0.74	0.74
August	Ten Daily I	35.00	24.17	5.81	3.74	February	Ten Daily I	1.04	0.97	0.74	0.74
	Ten Daily II	38.93	33.96	26.98	21.97		Ten Daily II	1.06	1.04	0.74	0.74
	Ten Daily III	78.08	66.67	29.27	21.22		Ten Daily III	0.79	0.74	0.74	0.74
September	Ten Daily I	43.13	28.05	18.37	14.34	March	Ten Daily I	0.74	0.74	0.74	0.74
	Ten Daily II	26.90	15.69	8.03	4.57		Ten Daily II	0.74	0.74	0.74	0.74
	Ten Daily III	17.10	12.81	1.89	1.82		Ten Daily III	0.78	0.78	0.75	0.75
October	Ten Daily I	12.98	9.59	0.93	0.83	April	Ten Daily I	0.91	0.91	0.91	0.89
	Ten Daily II	13.21	12.96	10.24	0.83		Ten Daily II	0.91	0.91	0.91	0.91
	Ten Daily III	13.31	10.43	6.50	0.74		Ten Daily III	0.91	0.91	0.91	0.91
November	Ten Daily I	5.34	4.92	2.79	0.74	May	Ten Daily I	0.91	0.91	0.91	0.91
	Ten Daily II	2.51	2.35	1.80	0.74		Ten Daily II	0.91	0.91	0.91	0.91
	Ten Daily III	2.30	1.79	1.31	0.74		Ten Daily III	0.91	0.91	0.91	0.91

The assessment of amount of water available in the river system at 90% or 95% probability level is important for determining assured water supply. From the analysis of Ten-Daily Period flow volumes at various probability levels at Patherdihi given in Table 10.6, it is observed that, the water availability in Kharun river becomes very low (0.74 MCM) during the period from 1st January to 31st March at 90% and 95% probability and it becomes highest during 3rd and 2nd Ten-Daily period of August i.e. 29.27 MCM and 21.97 MCM respectively. The quantity of water available in the river during lean period till the beginning of monsoon season is due to the water added from various sources to the river to meet its demands.

10.6 Surplus Deficit Analysis and Results

The total annual water demand at Patherdihi was grouped in 36 groups on Ten-Daily bases in the similar way the dependable flow volumes were grouped. The surplus or deficit volumes were estimated on every Ten-Daily bases within the year by subtracting Ten-Daily water demand from the Ten-Daily flow volume. The calculations and analysis of estimation of surplus or deficit for each Ten-Daily period was carried out using the following logic.

If Supply > Demand then Supply – Demand = Surplus

If Demand > Supply then Demand – Supply = Deficit

Thus the water surplus and deficits were estimated for dependable flow volumes at various probability levels. The sample surplus and deficits excel sheet is shown in Table 10.7 for the annual water demand of 65.213 MCM. Similar analysis was carried out for all the present and future projected water demands given in Table 9.3. An example for estimation of surplus and deficit flow volumes, their periods, initiations and termination using simple EXCEL are shown in Table 10.7.

Table 10.7: Estimation of surplus and deficit flow volumes

ANALYSIS AS PER ACTUAL SUPPLY FROM KHARUN RIVER

ACTUAL SCENARIO **CASE - 1**	**Yr 2010-11**						
Ripur Population	1028000.000	0.654	m^3/sec	20.637	MCM	0.20
Per Capita Wtr supply (LPD)	110.000	0.15	m^3/sec	4.730	MCM	
Half Demand of city fullfilled from Kharun				38.290	MCM	
				63.658	MCM	
Annual demand =	65.213 MCM	0.174	MCM/day			
(Annual + summer demand)		0.192	MCM/day			

			75% Dependable flow			90% Dependable Flow			95% Dependable Flow		
Month	**Ten-Daily**	**Demand**	**Flow**	**Surplus**	**Deficit**	**Flow**	**Surplus**	**Deficit**	**Flow**	**Surplus**	**Deficit**
June	Ten Daily I	1.92	0.91	0.00	1.01	0.91	0.00	1.01	0.91	0.00	1.01
	Ten Daily II	1.92	1.18	0.00	0.74	0.91	0.00	1.01	0.91	0.00	1.01
	Ten Daily III	1.92	3.39	1.48	0.00	1.51	0.00	0.40	0.82	0.00	1.09
July	Ten Daily I	1.74	1.69	0.00	0.00	1.10	0.00	0.64	0.98	0.00	0.77
	Ten Daily II	1.74	5.19	3.45	0.00	1.59	0.00	0.15	1.21	0.00	0.53
	Ten Daily III	1.92	34.48	32.57	0.00	14.19	12.27	0.00	1.19	0.00	0.73
August	Ten Daily I	1.74	35.00	33.26	0.00	5.81	4.06	0.00	3.74	2.00	0.00
	Ten Daily II	1.74	38.93	37.19	0.00	26.98	25.23	0.00	21.97	20.22	0.00
	Ten Daily III	1.92	78.08	76.16	0.00	29.27	27.35	0.00	21.22	19.30	0.00
September	Ten Daily I	1.74	43.13	41.39	0.00	18.37	16.63	0.00	14.34	12.60	0.00
	Ten Daily II	1.74	26.90	25.16	0.00	8.03	6.29	0.00	4.57	2.82	0.00
	Ten Daily III	1.74	17.10	15.36	0.00	1.89	0.15	0.00	1.82	0.08	0.00
October	Ten Daily I	1.74	12.98	11.23	0.00	0.93	0.00	0.00	0.83	0.00	0.92
	Ten Daily II	1.74	13.21	11.47	0.00	10.24	8.50	0.00	0.83	0.00	0.92
	Ten Daily III	1.92	13.31	11.40	0.00	6.50	4.59	0.00	0.74	0.00	1.18
November	Ten Daily I	1.74	5.34	3.59	0.00	2.79	1.04	0.00	0.74	0.00	1.01
	Ten Daily II	1.74	2.51	0.77	0.00	1.80	0.05	0.00	0.74	0.00	1.01
	Ten Daily III	1.74	2.30	0.56	0.00	1.31	0.00	0.43	0.74	0.00	1.01
December	Ten Daily I	1.74	1.71	0.00	0.03	0.74	0.00	1.01	0.74	0.00	1.01
	Ten Daily II	1.74	1.55	0.00	0.20	0.74	0.00	1.01	0.74	0.00	1.01
	Ten Daily III	1.92	1.36	0.00	0.55	1.66	0.00	0.26	0.67	0.00	1.25
January	Ten Daily I	1.74	1.53	0.00	0.21	0.74	0.00	1.01	0.74	0.00	1.01
	Ten Daily II	1.74	1.27	0.00	0.47	0.74	0.00	1.01	0.74	0.00	1.01
	Ten Daily III	1.92	1.16	0.00	0.76	0.74	0.00	1.18	0.74	0.00	1.18
February	Ten Daily I	1.74	1.04	0.00	0.71	0.74	0.00	1.01	0.74	0.00	1.01
	Ten Daily II	1.74	1.06	0.00	0.69	0.74	0.00	1.01	0.74	0.00	1.01
	Ten Daily III	1.40	0.79	0.00	0.61	0.74	0.00	0.66	0.74	0.00	0.66
March	Ten Daily I	1.74	0.74	0.00	1.01	0.74	0.00	1.01	0.74	0.00	1.01
	Ten Daily II	1.74	0.74	0.00	1.01	0.74	0.00	1.01	0.74	0.00	1.01
	Ten Daily III	1.92	0.78	0.00	1.13	0.75	0.00	1.16	0.75	0.00	1.16
April	Ten Daily I	1.92	0.91	0.00	1.01	0.91	0.00	1.01	0.89	0.00	1.02
	Ten Daily II	1.92	0.91	0.00	1.01	0.91	0.00	1.01	0.91	0.00	1.01
	Ten Daily III	1.92	0.91	0.00	1.01	0.91	0.00	1.01	0.91	0.00	1.01
May	Ten Daily I	1.92	0.91	0.00	1.01	0.91	0.00	1.01	0.91	0.00	1.01
	Ten Daily II	1.92	0.91	0.00	1.01	0.91	0.00	1.01	0.91	0.00	1.01
	Ten Daily III	2.11	0.91	0.00	1.20	0.91	0.00	1.20	0.91	0.00	1.20
Annual MCM		65.23	354.84	305.02	15.41	149.39	106.17	22.00	92.54	57.02	29.71

Water Surplus Period   Water Deficit Period

From the Table 10.7 of supply demand analysis it is observed that, when the water surplus volume becomes zero, the deficit begins and vice-versa. The ‘beginning’ and ‘termination’ period of water deficit were identified and are used to study the demand supply scenario. To identify the total period of water deficit, the first date of first 10-Daily deficit period is considered as date of ‘beginning’ of deficit period and last date of last 10-Daily deficit period is considered as ‘termination’ date of deficit period. From the surplus deficit analysis for present and future demand, the dates of ‘beginning’ and ‘termination’ of water deficit period identified and are given in Table 10.8. The graph showing the dates of ‘beginning’ and ‘termination’ of water deficit period at Patherdihi at 75%, 90% and 95% are shown in Figure 10.3, 10.4 and 10.5 respectively. The supply demand analysis helps in estimating the amount of water surplus and deficit at the desired location and the also gives the idea about the beginning, termination and durations of these surplus and deficit period which assist the planners to judiciously manage the supply from river and to make possible alternate plan to manage the demands. It also provides the estimate of additional amount of water required to meet the desired demands. The scenario of water demands and corresponding water deficit volumes in Kharun river are estimated and are shown in Table 10.9. The demand deficit curves showing water deficit to its corresponding demand are given in Figure 10.6. The graph illustrating amount of additional water required to meet various demand is shown in Figure 10.7.

Table 10.8: Beginning and end of water deficit period at various probability levels at Patherdihi

Projected Period	Demand (MCM)	AT 75%		AT 90%		AT 95%	
		Deficit Starts	Deficit Ends	Deficit Starts	Deficit Ends	Deficit Starts	Deficit Ends
2010-11 @ 110 lpcd	65	01-Dec	20-Jun	21-Nov	20-Jul	01-Oct	31-Jul
2010-11 @ 135 lpcd	70	01-Dec	20-Jun	21-Nov	20-Jul	01-Oct	31-Jul
2010-11 @ 170 lpcd	92	21-Nov	20-Jun	11-Nov	20-Jul	21-Sep	31-Jul
2020-21	111	11-Nov	20-Jun	01-Nov	20-Jul	21-Sep	31-Jul
2030-31	133	11-Nov	10-Jul	01-Nov	20-Jul	21-Sep	31-Jul
2040-41	154	11-Nov	10-Jul	01-Nov	20-Jul	21-Sep	10-Aug
2050-51	175	11-Nov	10-Jul	01-Nov	20-Jul	11-Sep	10-Aug
When Demand Becomes 200 MCM	200	01-Nov	20-Jul	01-Nov	20-Jul	11-Sep	10-Aug
When Demand Becomes 250 MCM	250	01-Nov	20-Jul	21-Oct	20-Jul	11-Sep	10-Aug

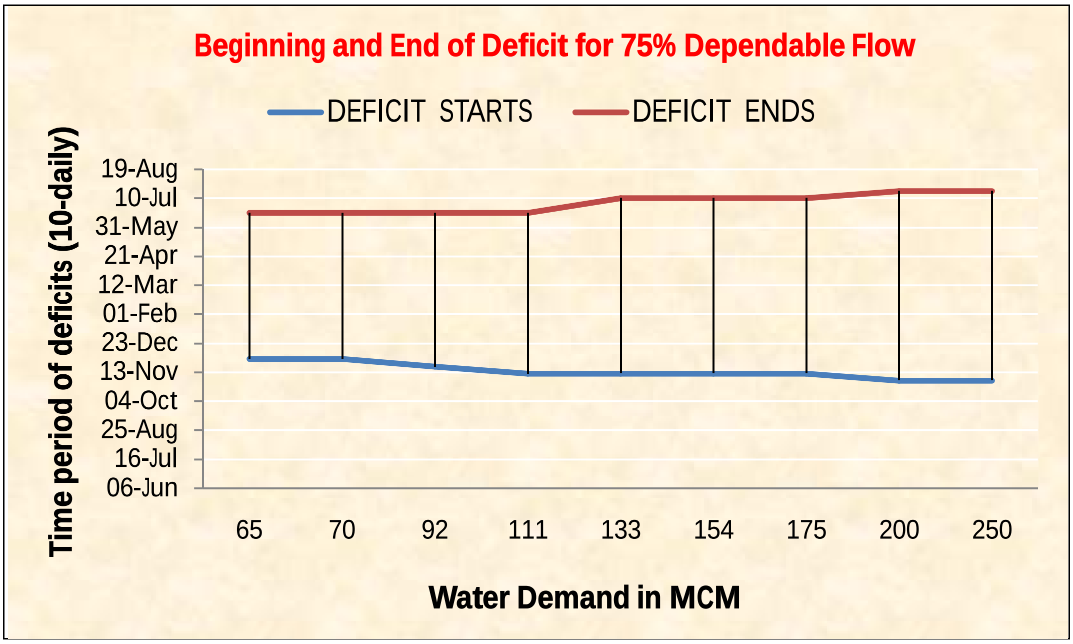


Figure 10.3: Beginning and end of deficit for 75% dependable flow

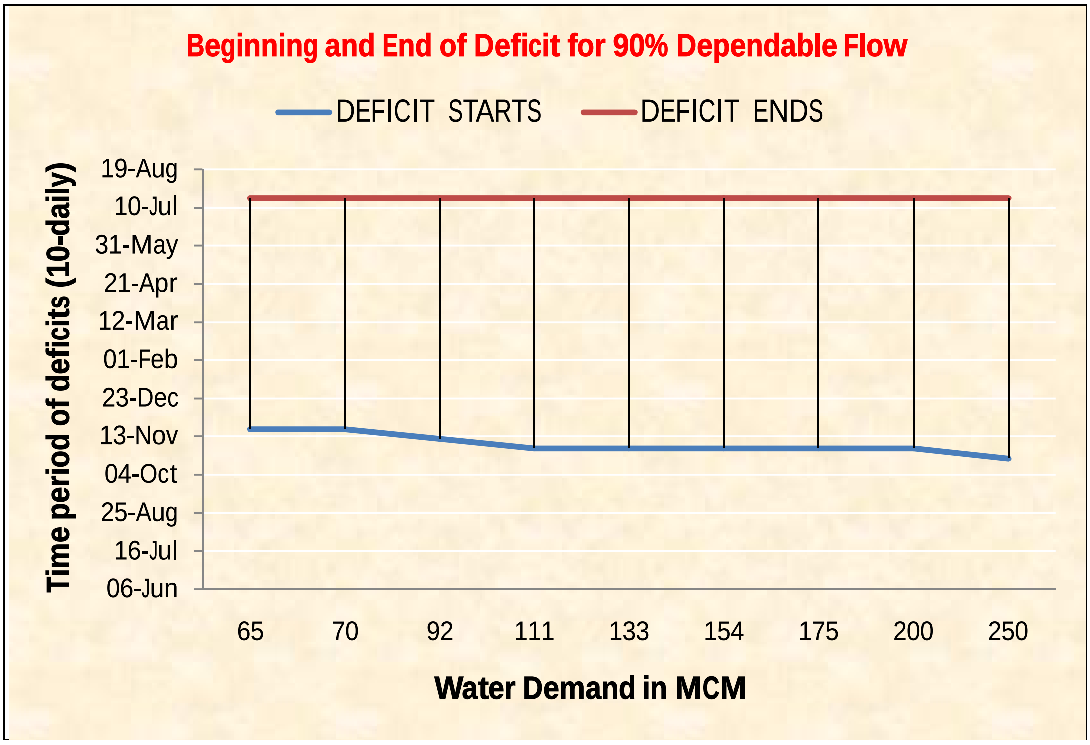


Figure 10.4: Beginning and end of deficit for 90% dependable flow

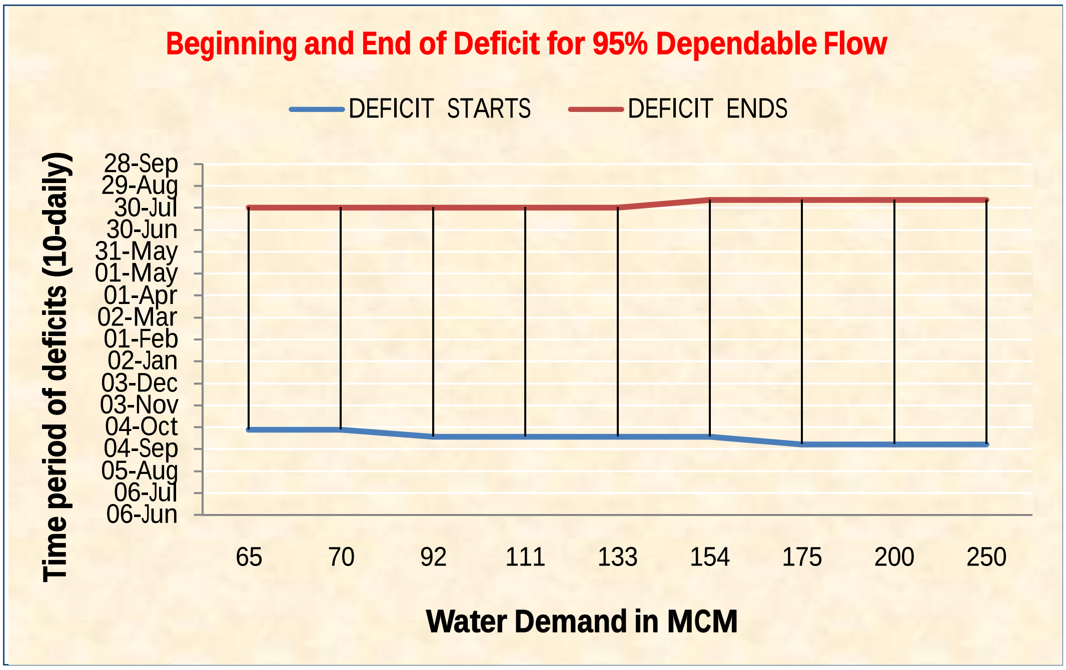


Figure 10.5: Beginning and end of deficit for 95% dependable flow

From the Table 10.8, Figures 10.3, 10.4 and 10.5 it was observed that, when the water availability in the river was planned to meet annual water demand of 65 MCM at 75% dependability, the deficit period was 233 days which begins on 1st December and terminates on 20th June. Whereas if water supply availability was planned at 95% dependability, the deficit period would be of 305 days which would begin much earlier i.e. on 1st October and terminates on 31st July. Form this analysis, it was concluded that, the period of water deficit prolongs when assured water availability was planned at higher probability level.

When the water availability in the river was planned at 90% dependability to meet the water demand of 65 MCM, the deficit period would start from 21st November, for the demand of 111 MCM the deficit period would start from 1st November and for the demand of 250 MCM the deficit period would start from 21st October. All the deficit periods were coming to an end on 20th July in monsoon season. Thus on comparison of water demand on river and deficit periods, it was observed that, as the water demand increased the deficit period also increased, the river experienced the deficit much earlier if the demands were increased.

From the Table 10.9 and Figure 10.7, it was seen that at 90% probability level, when water demand was 65 MCM the water deficit was 22 MCM. When the demand would increase to 133 MCM (in 2030-31) and 175 MCM (in 2050-51) the water deficit would becomes 73.56 MCM and 105.33 MCM respectively. In year 2050-51, the additional 105.33 MCM water would be required in Kharun river to fulfill the total demand. The demand deficit curve gives an idea about variation in water deficit with respect to the variation in total water demand and dependability of the river flow. From figure 10.6 and 10.7, it could be seen that as the demand increases, the demand deficit increases.

Table 10.9: Water demand deficit (MCM) at various probability levels at Patherdihi

Water Demand (MCM)	Water Demand Deficit (MCM)		
	At 75% Probability	At 90% Probability	At 95% Probability
65	15.41	22.00	29.71
70	18.13	25.32	33.67
92	31.33	41.99	52.94
111	43.12	56.06	68.94
133	57.97	73.56	88.38
154	71.60	89.45	106.49
175	85.24	105.33	124.91
200	101.86	124.53	148.00
250	137.75	165.23	193.76

The deficit also found increased with increase in probability level. Thus it could be concluded that water deficit increases with increase in demand and increase in probability level.

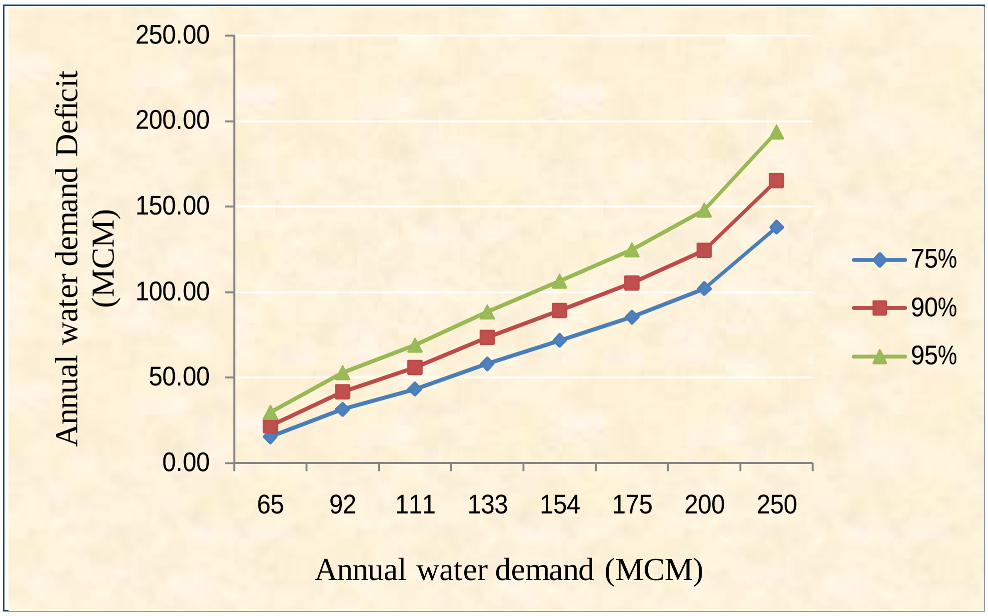
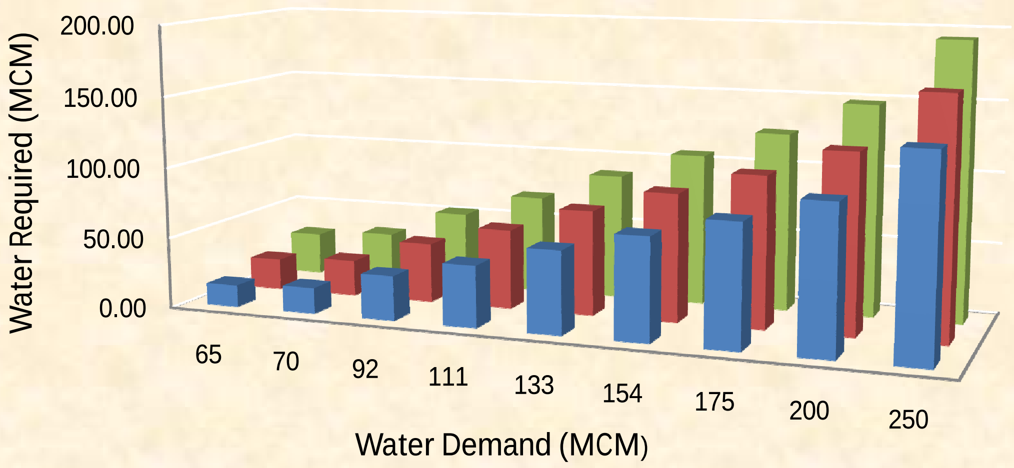


Figure 10.6: Demand - Deficit Curve at Various Dependable Levels

From the analysis of various supply-demand future scenarios at various probability, it becomes important for development and planning of water resources in Kharun river basin has to be undertaken by addressing the various issues such as demand management in the river basin, planning of water supply at appropriate level of probability, selection of flow volume of reasonable dependability and providing assured water supply to meet the total demands being fulfilled from the river.



	65	70	92	111	133	154	175	200	250
75%	15.41	18.13	31.33	43.12	57.97	71.60	85.24	101.86	137.75
90%	22.00	25.32	41.99	56.06	73.56	89.45	105.33	124.53	165.23
95%	29.71	33.67	52.94	68.94	88.38	106.49	124.91	148.00	193.76

Figure 10.7: Additional water supply required to meet the deficit at Patherdihi

From the analysis it could be seen that the deficit period at any probability level and even at higher demand ends in the month of July and August. The Kharun river has surplus water during monsoon season which flows out of basin due to non availability of storage structure and river is unable to meet the demands during lean season. The water supplemented from Ravishankarsagar reservoir to the Kharun river helps to increase the water availability in the river to meet the various demands.

10.7 Measures to be adopted to meet additional water demand

- The systematic approach of water resources management and water conservation measures can be adopted in Kharn basin to meet the future water demands.
- Construction of water storage structures i.e. small dams in the upstream of Raipur city on Kharun river will be helpful to meet the future demand to great extent. This approach has been studied under this PDS in next section. Small dams should be planned to achieve maximum storage with minimum submergence.
- The water from Ravishankarsagar reservoir can directly be added to Kharun river near Raipur city through pipe or canal instead of adding water through Deorani

Jethani nala. This arrangement may help in minimizing the seepage, percolation and evaporation losses and increase the water availability in river.

- The future domestic demand of Raipur city and industrial demands could also be managed from Ravishankarsagar reservoir by giving priority over irrigation.
- Systematic approach towards artificial recharge and development of groundwater in Raipur city and nearby areas would help to meet the major part of domestic water demands from groundwater.
- The regular monitoring and assessment of surface as well as groundwater quality would be important components in water resources development for future water demand fulfilment.

CONSULTANCY REPORT

(Submitted by Dr. Ashish Pandey Assistant Professor, Department of Water Resources Development & Management, Indian Institute of Technology, Roorkee)

11 PLANNING FOR WATER STORAGE STRUCTURES

11.1 Introduction

The water demands in Kharun river basin are increasing due to rapid urbanization and industrialization leading to water scarcity and over exploitation of the available water resources. The water availability analysis of the basin indicated that the Kharun river is originally a intermittent river having ample flow during monsoon season and low flow for 2-3 months thereafter. Lack of suitable water management measures in Kharun river leading to most of the precious water being drained down the rivers without being tapped causes more dependence on groundwater resources. To meet the various demands in Kharun basin, an arrangement has been made by which the water is being released in to the river from Ravishankarsagar reservoir and river experiences flow throughout the year under regulated flow condition. The present water demand on the Kharun river is 65 MCM the water deficit is 22 MCM. The water demand will increase to 175 MCM by the year 2050 and the water deficit will becomes 105.33 MCM. Under such circumstance there is need of systematic planning for water resources development of Kharun river basin for providing assured water supply to meet the increasing water demands. To study this aspect, the WRD, Raipur had awarded consultancy to WRDM, IIT, Roorkee on "Plan for water resources development in the Kharun river basin". Under the consultancy work, the investigation has been carried out by the consultants for identifications and planning for storage sites on Kharun river. Present consultancy report deals with the identification of possible storages sites on Kharun river, assessment of submergence area and possible storage capacity at these sites.

The research work carried out by various researchers on optimization of water resources was reviewed before proceeding for the present analysis. Cai, X. (2008) studied a holistic model embeds water resources and economic components into a consistent mathematical programming model, with the objective of maximizing economic profits from water uses in various sectors. Such a model can be used to address combined environmental-economic issues. Cai, X. et al. (2001) attempted a classical solution approach for combinatorial optimization problems, based on the ideas of partition and delayed constraint generation for the large scale water resource management problem. Chuang-lin, F. et al. (2001) conducted studies for water resources optimization and eco-environment protection for optimal utilization of water resources in judicious manner in Qaidam basin. Clark, C.O. (1945) suggested a method for the estimation of design flood hydrographs for rural catchments in Peninsular Malaysia. The procedure uses three components; the design storm, the rainfall-runoff relationship and the equations for Clark parameters in the development of design flood hydrographs. Rodriguez-Iturbe, et al. (1979) attempted a unifying synthesis of the hydrological response of a catchment to surface runoff by linking the IUH with the geomorphologic parameters of the basin. Sarma, (1976) carried out overall assessment of surface water resources in Godavari catchment by the water balance method. Simonovic, S.P. (1992) reviewed the mathematical models used in reservoir management and operations, to present conclusions reached by previous state-of-art reviews, and to provide two ideas for closing the gap between theory and practice. He presented a simple simulation optimization model for reservoir sizing as an example of system approach respond to practical need of water resources engineer and illustrated the benefits of knowledge based technology with regard to single-multipurpose reservoir analysis. Yen, B.C. at el. (1997) proposed a method in which, the geomorphic ratios of the Horton-Strahler stream ordering laws were incorporated in the GIUH model for UH generation.

11.2 Elevation-Area-Capacity Relations

The topographic maps of the Survey of India (SOI) are typically used to obtain elevation data for an area. Topographic map are available at 1:50,000 scales and the contour interval is 20 m. At this scale, the study area would fall in a very small region and the requisite details would not be available. A small scale map would be ideal to obtain elevation data for establishment of elevation area capacity curve. To overcome this problem, latest available data of Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data (pixel resolution 30m×30m) was utilized in this study for development of elevation area capacity curves.

Digital elevation model (DEM) is the raster representation of a continuous surface, usually referring to the surface of the earth. The DEMs have proved to be very efficient in extracting different topographical attributes (elevation, slope, aspect, relief, curvatures etc.) for modeling purposes. Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data (pixel resolution 30m×30m) has been used to generate Digital Elevation Model (DEM) (http://www.landcover.org/data/aster/……). Initially, a detailed contour map of the reservoir area was prepared. Finally, the ASTER DEM (cell size 30 m × 30 m) of the catchment was interpolated at 1m contour interval for the study of elevation-area-capacity relationship. The stream network, DEM and location of the reservoir sites is given in Figures 11.1 and 11.2. Finally, reservoir area at 1 m interval was computed. Storage volumes up to an elevation were estimated using trapezoidal rule. Increase in volume between two adjacent contours is computed as

$$\Delta V = h/2\ (A_1 + A_2) \qquad \ldots (11.1)$$

The elevation area capacity relationships for R1 (Amdi Site), R2, R3 and R4 are given in Table 11.1 to 11.4 respectively. The Elevation-area-capacity graph and corresponding DEM of all four sites are shown in Figures 11.3 to 11.6. All sites were located keeping in view availability of high banks, narrow width and wide storage of water.

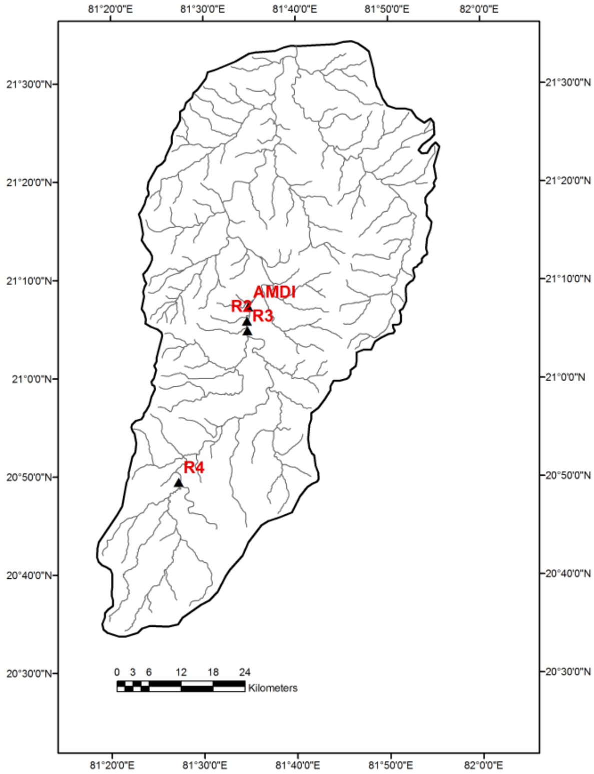


Figure 11.1: Drainage map and potential reservoir sites in Kharun river basin

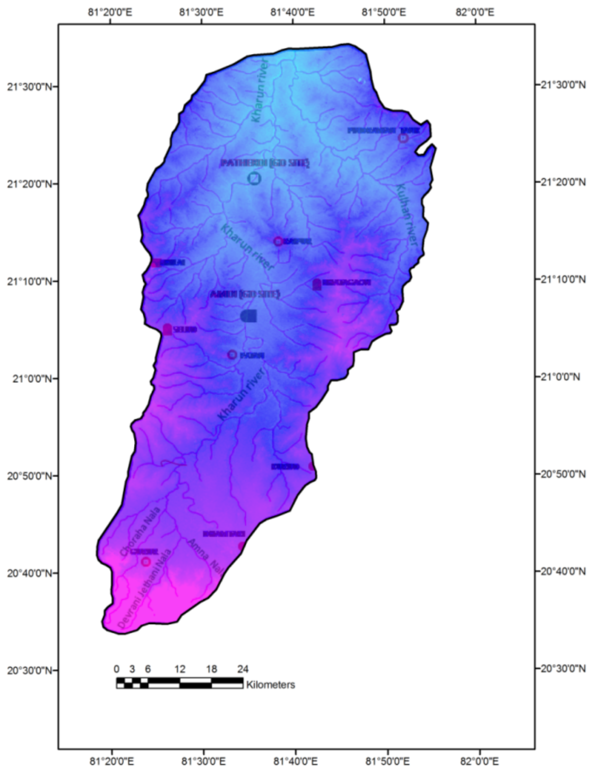


Figure 11.2: DEM overlaid with drainage of Kharun river basin

Table 11.1: Elevation-Area-Capacity relationship of R1 (Amdi) Site

Elevation	Area (sq km)	Capacity(MCM)
272.5	0.00	0.00
273.0	0.01	0.00
274.0	0.02	0.01
275.0	0.07	0.04
276.0	0.12	0.09
277.0	0.32	0.22
278.0	0.58	0.45
279.0	1.17	0.87
280.0	2.06	1.61
281.0	3.44	2.75
282.0	5.74	4.59
283.0	8.97	7.35
284.0	13.71	11.34
285.0	19.93	16.82
286.0	27.44	23.68
287.0	36.43	31.93
288.0	47.10	41.76
289.0	58.96	53.03
290.0	73.05	66.00

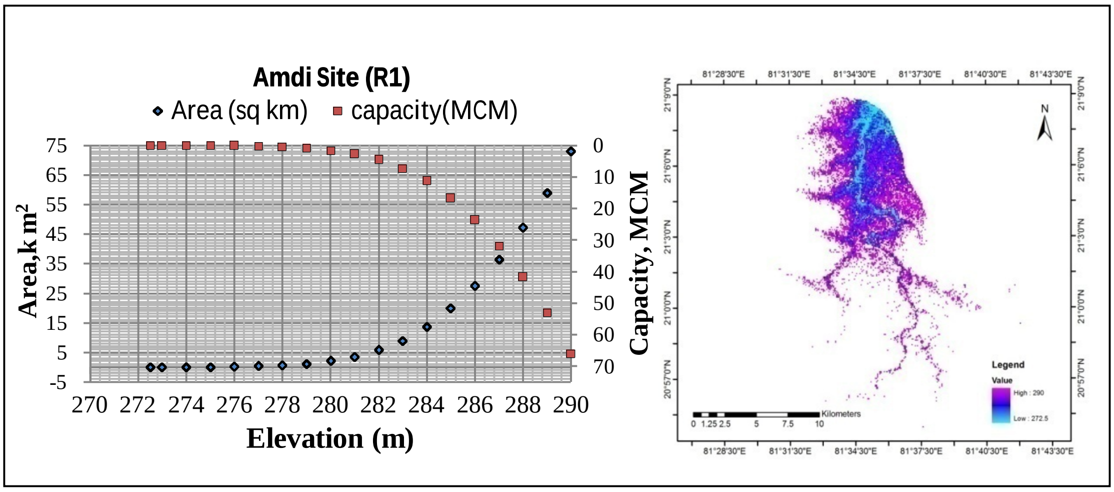


Figure 11.3: Elevation-area-capacity graph and corresponding DEM at R1 (Amdi) Site

Table 11.2 : Elevation-Area-Capacity relationship of R2 site
(2 km upstream of Amdi Site)

Elevation	Area (sq km)	capacity(MCM)
273.0	0.00	0.00
275.0	0.02	0.01
276.0	0.04	0.03
277.0	0.07	0.05
278.0	0.12	0.09
279.0	0.31	0.21
280.0	0.65	0.48
281.0	1.14	0.89
282.0	1.85	1.49
283.0	3.26	2.55
284.0	5.59	4.42
285.0	8.91	7.25
286.0	13.11	11.01
287.0	18.45	15.78
288.0	25.74	22.09
289.0	34.53	30.13
290.0	45.44	39.98

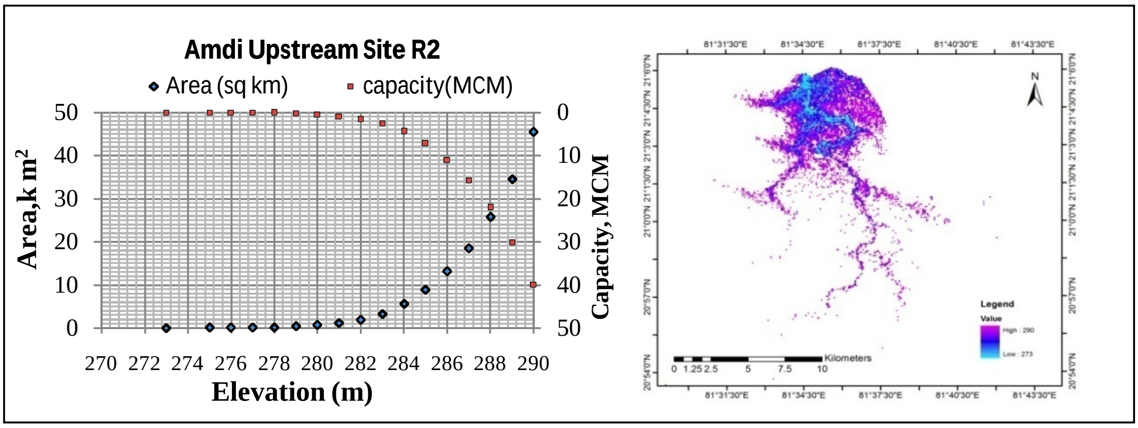


Figure 11.4: Elevation-area-capacity graph and corresponding DEM at R2 site

Table 11.3: Elevation-Area-Capacity relationship of R3 site
(4 km upstream of Amdi Site)

Elevation	Area (sq km)	capacity(MCM)
275	0.00	0.00
276	0.01	0.00
277	0.02	0.01
278	0.05	0.03
279	0.17	0.11
280	0.39	0.28
281	0.75	0.57
282	1.25	1.00
283	2.05	1.65
284	3.26	2.65
285	5.03	4.15
286	7.49	6.26
287	10.70	9.10
288	15.42	13.06
289	21.72	18.57
290	30.41	26.06

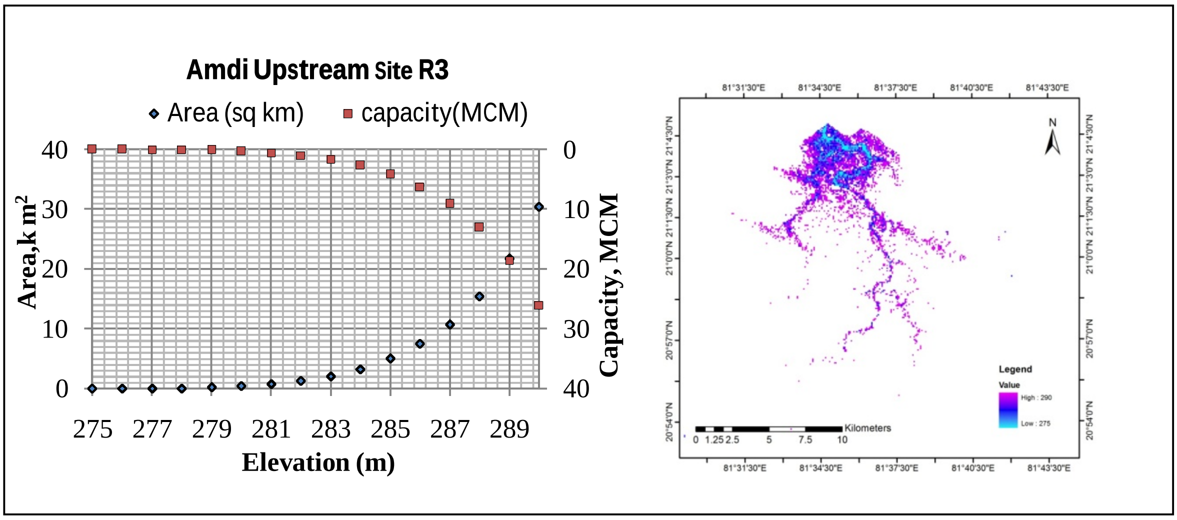


Figure 11.5: Elevation-area-capacity graph and corresponding DEM at R 3 site (4 km. upstream of Amdi Site)

Table 11.4: Elevation-Area-Capacity relationship of Site-R4

Elevation	Area (sq km)	capacity(MCM)
300	0.00	0.00
302	0.02	0.01
303	0.12	0.07
304	0.22	0.17
305	0.38	0.29
306	0.95	0.66
307	2.15	1.55
308	4.01	3.08
309	8.26	6.13
310	15.30	11.78
311	25.14	20.22
312	38.95	32.04
313	55.56	47.25
314	75.19	65.37
315	97.12	86.15
316	120.98	109.05
317	144.54	132.76
318	167.30	155.92
319	188.62	177.96
320	207.89	198.25

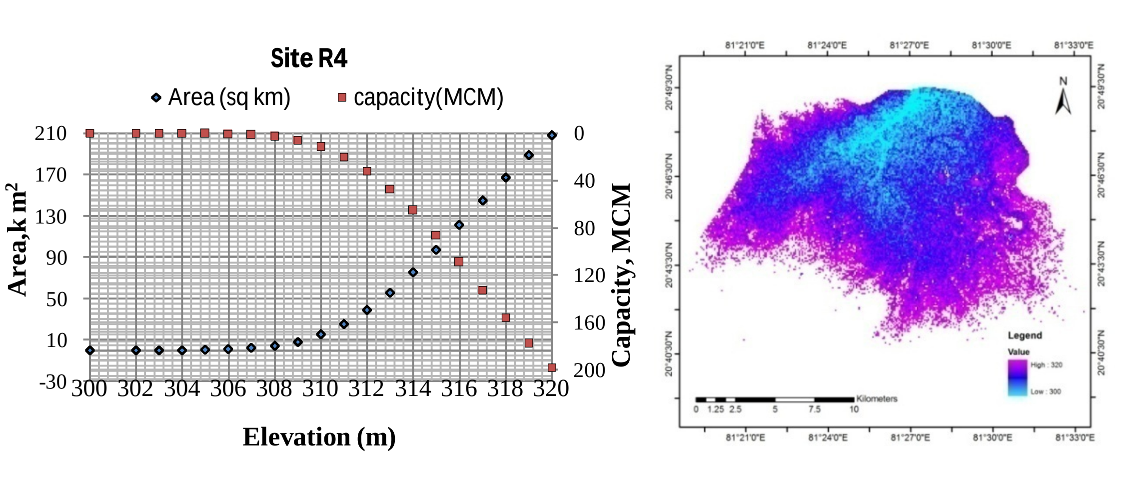


Figure 11.6: Elevation-area-capacity graph and corresponding DEM at R4 Site

The comprehensive analysis was carried out using elevation-area-capacity relationships developed at all four locations on Kharun river considering dam height from 9 to 12 m only. If the dam height increased further, it may results in increased area under submergence, which will not be viable as the Kharun basin has a more or less flat topography. Thus the possible storage and submergence analyzed considering dam height between 9 to 12 m at all four locations. The total possible areas under submergence and their corresponding total storage capacities at different dam heights (9 to 12 m) are shown in Table no. 11.5. From the analysis it could be concluded that, the four dams can be constructed in series on Kharun river at the Amdi and its upstream locations. The results indicated that the four dams, each of height from 9 to 12 m height would store total 19.73 to 78.7 MCM water and submerge total 25.26 to 93.08 sq. km area. The combination of different dam heights at these four locations could also be the solution. This arrangement would help to meet growing water demand of Kharun basin in future.

Table 11.5: Possible submergence and storage capacity at proposed sites

Site	Bed Level (m)	Max Water Level (m)	Height of Dam (m)	Area of Submergence (sq. km.)	Storage capacity (MCM)
R1	272	281	9	3.44	2.75
		282	10	5.74	4.59
		283	11	8.97	7.35
		284	12	13.71	11.34
R2	274	283	9	3.26	2.55
		284	10	5.59	4.42
		285	11	8.91	7.25
		286	12	13.11	11.01
R3	275	284	9	3.26	2.65
		285	10	5.03	4.15
		286	11	7.49	6.26
		287	12	10.70	9.10
R4	301	310	9	15.30	11.78
		311	10	25.14	20.22
		312	11	38.95	32.04
		313	12	55.56	47.25
Total of all sites			***9***	***25.26***	***19.73***
			10	***41.50***	***33.38***
			11	***64.32***	***52.90***
			12	***93.08***	***78.70***

11.3 Results

The water storage in these tanks should be planned such that i) submergence affects are minimized, ii) adequate runoff is available from catchment and iii) topography permits adequate storage. To meet the growing water demand in Kahrun basin, four dam sites are found suitable for construction of small dams on Kharun river. From the analysis it could be concluded that, the four dams can be constructed in series on Kharun river at the Amdi and its upstream locations. The dam height of 12 m at all four dams would store 78.7 MCM water and dam height of 11 m would store total 52.9 MCM water respectively. DEM analysis shows that Site 2 seems to be more viable from storage point of view. Recent topographic survey maps at fine scale should be used in preparation of detailed project report, if any, and while deciding the site of reservoir. G&D observations in Kharun river at or near the identified sites of dams should be started at the earliest. Accurate estimation of agricultural land coming under submergence would require detailed village level survey.

12 EVALUATION OF INFILTRATION CHARACTERISTICS OF SOIL

12.1 Introduction

Soil moisture movement studies provide potential information in the field of hydrology. Infiltration is a dynamic process, variable in time and space and plays an essential role in the replenishment of soil water which is responsible for the growth and development of crops. Where infiltration is high, runoff generation is usually low with consequent low erodibility of the soils (Duiker et al., 2001). The rate at which a given soil can absorb water at given time is called infiltration rate and it depends on soil characteristics such as soil texture, hydraulic conductivity, soil structure, vegetation cover etc. (Jagdale and Nimbalkar, 2012). The infiltration rate is an important parameter in soil, hydrological, ecological and agricultural studies. Cumulative infiltration is the total quantity of water that enters the soil in a given time. Thus, infiltration rate and cumulative infiltration are two parameters commonly used in evaluating the infiltration characteristics of soil. The main factors, which affect the infiltration rate of soil, are texture and structure. Infiltration rates are generally lower in soils of heavy texture than on soils of light texture. The vegetal cover also influences infiltration rates. On grassland the infiltration rates are substantially higher than bare uncultivated land. Additions of organic matter increase infiltration rate substantially. As a function of time it defines the infiltration curve and is a measure of the speed at which soil is able to absorb water. It is one of the most important soil parameters required in the design and evaluation of irrigation system, drainage system,development of rainfall-runoff model and prediction of surface runoff (Zerihun et al., 1996; Oyonarte et al., 2002 and Idike, 2002). It is the key to soil and water conservation and irrigation management because it determines the amount of runoff over the soil surface during rainfalls or irrigations (Oku and Aiyelari, 2011 and Mishra et al., 2003). Infiltration capacity is the maximum rate at which soils and rocks can absorb rainfall. The infiltration capacity tends to decrease as the soil moisture content of the surface layers increases. It also depends upon such factors as grain size and vegetation cover.

For estimation of infiltration characteristics of soil, numbers of empirical and physical models have been developed by the researchers. The empirical models include Kostiakov, Modified Kostiakov, Horton, and approximate physically based models like those of Green-Ampt and Philip. Empirical models tend to be less restricted by assumptions of soil surface and soil profile conditions, but more restricted by the conditions for which they were calibrated, since their parameters are determined based on actual field-measured infiltration data (Hillel, 1998; Skaggs and Khaleel, 1982). The researchers like Linsely et al., (1949), Christiansen (1944) and Musgrave and Horton (1964) have conducted studies on effect of rainfall intensity and landuse cover on infiltration rate of soil. In the study reported herein, the performance of five infiltration models namely Kostiakov, modified Kostiakov, Green-Ampt, Philip and Horton in different type of soils was evaluated in Kharun river basin of Chhattisgarh state. The objective of the study was to test the competence of the five models to predict water infiltration in different soil type.

12.2 Methodology

The study area was first divided in nine equal grids and infiltration test sites were identified on the basis of prevailing soil type in each grid. Nine test sites, well distributed over the catchment area of Kharun river namely, Raipur, Bhilai, Selud, Patan, Bargaon, Dharsiwa, Pindrawan Tank, Gurur and Arkar were selected for carrying out infiltration tests. The infiltration tests were conducted using the constant head Double Infiltrometer. The double ring Infiltrometer requires two rings, an inner and an outer ring. It works by directing water onto a known surface area due to the parameters of the inner ring. Infiltration can be measured by either a single or double ring infiltrometer, with preference usually lying with the double ring because the outer ring helps in reducing the error that may result from lateral flow in the soil. The rate of infiltration is determined by the amount of water that infiltrates into the soils per surface area, per unit of time. Figure 12.1 shows the location map of nine test sites selected for the study.

Figure 12.1: Location map of different test sites selected for the infiltration study.

12.3 Infiltration Models

The observed infiltration data of nine test sites was used to develop Kostiakov, Modified Kostiakov, Horton, Green-Ampt and Philip's two-term model for monitoring infiltration process in Kharun basin. These models are explained in detail as below.

12.3.1 *Kostiakov's equations*

Kostiakov (1932) proposed a simple empirical infiltration equation based on curve fitting data. It relates infiltration to time as a power function as presented by equation 12.1.

$$f_p = K_k \times t^{-\alpha} \quad \text{... (12.1)}$$

Criddle et al. (1956) used the following logarithmic form of the equation to determine the parameters K_k and α of model.

$$\log f_p = \log K_k - \alpha \log t \quad \text{...(12.2)}$$

where, f_p is the total infiltration volume, t is time elapsed from start of ponding of water, K_k and α are parameters, which depend on the soil and initial conditions and may be evaluated using the observed infiltration rate–time relationship and $K_k > 0$ and $0 < \alpha < 1$. Clearly, as $t \to 0, f \to \infty$ and as $t \to \infty, f \to 0$. Because of its simplicity, the model is frequently used in irrigation studies.

12.3.2 *Modified Kostiakov's equations*

A better representation of the depth infiltrated over a long period of time is given by the Modified Kostiakov equation expressed as

$$f_p = a \times t^{\alpha} + b \quad \text{... (12.3)}$$

Where, f_p is the infiltration rate at any time t, b is the asymptotic steady infiltration flux, a and $\propto$ are characterizing constants. To calculate the value of b, the following formula has been used.

$$b = \frac{y_1 \times y_2 - {y_3}^2}{y_1 + y_2 - 2 \times y_3} \quad \text{.... (12.4)}$$

Where, y_1 is the initial cumulative infiltration (mm) at initial time t, y_2 is the final cumulative infiltration at final time t and y_3 is calculated by coefficient of c and d with the square route of initial and final time t. The Kostiakov and modified Kostiakov equations tend to be the preferred infiltration models used for irrigation infiltration, probably because these models are less restrictive as to the mode of water application than some other models.

12.3.3 *Horton's Model*

Horton (1939, 1940) derived his equation for infiltration, assuming that the rate of infiltration decays exponentially and proportional to differences of infiltration capacity and final constant infiltration rate. The Horton's model is a three-parameter infiltration model wherein it was hypothesized that the infiltration is similar to the exhaustion process according to which the rate of performing work is proportional to the amount of work remaining to be performed. The rate of performing work is *df/dt* and the amount of work remaining to be performed is $f - f_c$. Since f decreases with time,

$$\frac{df}{dt} = -k(f - f_c) \qquad \text{... (12.5)}$$

Where, k is a parameter which controls the rate of decrease of infiltration capacity and depends on soil type and initial moisture content. The initial condition can be taken as $f = f_0$ (initial infiltration rate) at $t = 0$ and f_c is approximately constant rate of infiltration at the end of the storm. Integrating Eqn. 1 gives,

$$f_t = f_c + (f_0 - f_c) \times e^{-kt} \qquad \text{... (12.6)}$$

Where, f_t is the infiltration capacity at time t. The parameters f_o, f_c, and k must be evaluated using the observed infiltration data. The principal weakness of the model is in determination of reliable values of its parameters, which are estimated by curve fitting on the field observations. Horton's equation is applicable only when the effective rainfall intensity is greater than f_c.

12.3.4 *Green-Ampt Model*

An analytical solution technique was also followed in this research based on the original work done by Green & Ampt (1911), because of its simplicity and easiness to obtain the required input data and its practical applicability to non-uniform soil moisture distributions.

$$f = ic + b \times I^{(-1)} \qquad \text{... (12.7)}$$

Where, f is the infiltration rate at any time t, I is the cumulative infiltration, ic and b are the constant values.

12.3.5 *Philip's equation*

Philip two-term model simulates vertical infiltration of water into a homogeneous sandy soil profile. The water depth is much greater than the water penetration depth. For a uniform soil with a uniform soil moisture content and excess water supply rate at the surface, Phillip (1957) found a solution to the flow equation in the form of an infinite series. Because of rapid convergence, the first two terms of the series are considered sufficient to constitute Phillip two-term model,

$$F = s\, t^{1/2} + At \qquad \text{... (12.8)}$$

$$f = \frac{1}{2} s t^{-1/2} + A \qquad \text{... (12.9)}$$

Where, f is the volume of infiltration at time t, s is sorpitivity, which is a function of initial and surface water contents of the soil and soil-water diffusivity; A is a parameter depending on the soil properties. Although the parameters s and A have precise physical meaning, it is difficult to determine them in the field.

12.4 Development of Regional Models

The infiltration characteristics are influenced by the inherent properties of soil, land use, initial moisture condition and rainfall pattern. Isolation of these effects will enable an assessment of infiltration capacity under different conditions in the study area. An attempt was made to develop regional infiltration models based on different soil types in the study area. The entire catchment was delineated into three groups based on the soil classes are namely Kanhar soil, Matasi soil and Sandy-murrum soil. The soil testing sites Raipur, Bhilai and Patan fall in the Kanhar soil, Dharsiwa, Pindrawan tank and Gurur falls in matasi soil and Bargaon, Selud and Arkar sites fall in the sandy-murrum soil. Each soil class had 3 test sites each. Thus the five regional infiltration models were calibrated using infiltration data of two test sites and validated with remaining one site in each soil class. Efforts have been made to identify the best suited regional model for each of the three different soil classes. The attempts were also made to develop regional infiltration model as a whole for Kharun basin. The observed average infiltration data of seven sites was used for calibration of all five infiltration models and then these models were validated with the observed average infiltration rate of the remaining two sites.

12.5 Performance Evaluation of Model

The performance of different models was judged with the help of different criterion including root mean square error (*RMSE*), coefficient of determination (R^2) and Efficiency. The *RMSE* is an indicator for representation of the overall error of the evaluated function and should approach to zero for the best model performance. The use of the coefficient of determination is to test the goodness of fit of the model and to assess how well a model explains and predicts future outcomes. It is expressed as a value between zero and one. The efficiency of soil testing service depends upon the care and skill with which soil samples are collected. The equation for computation of different performance evaluators have been given below.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(q_o - q_s)^2}{N}} \qquad \dots (12.10)$$

where, q_o= observed value, q_s= simulated value and N is the no. of data.

$$R^2 = \frac{\sum_{i=1}^{n}(q_o-\bar{q}_o)(q_s-\bar{q}_s)}{\sqrt{[\sum_{i=1}^{n}(q_o-\bar{q}_o)^2][\sum_{i=1}^{n}(q_s-\bar{q}_s)^2]}} \qquad \dots (12.11)$$

$$E = 1 - \frac{(q_o - q_s)^2}{(q_o - \bar{q}_o)^2} \qquad \dots (12.12)$$

Where, q_o= observed infiltration rate, $\bar{q}_o$= mean value of observed infiltration rate, q_s= simulated infiltration rate and n = number of data points.

12.6 Results and Discussions

The infiltration tests were conducted in Kharun basin at 9 selected locations and the data collected at these sites was analyzed and results are discussed as below.

12.6.1 Evaluation of Infiltration rate

The infiltration data obtained from nine test sites have been analyzed for evaluation of hydrologic properties of soil and development of regional infiltration model. The average cumulative infiltration and infiltration rate curve based on the three different soil is presented in Figure 12.2. The observed infiltration rate at each site and average infiltration rate in different soil types are given in Table 12.1. The contour map showing spatial variability of infiltration rate over the study area is shown in Figure 12.3.

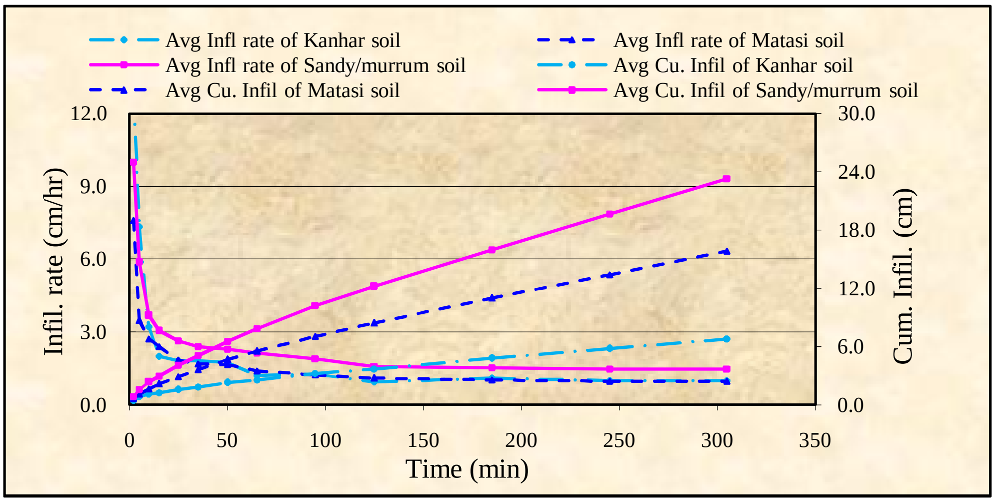


Figure 12.2: Avg. infiltration rate and cumulative infiltration rate in different soil type

Table 12.1: The infiltration rate and average infiltration rate in the different soils

S. No.	Name of the site	Soil details	Infiltration rate (cm/hr)	Average infiltration rate (cm/hr)
1	Raipur	Kanhar	1.5	1.0
2	Bhilai	Kanhar	1.1	
3	Patan	Kanhar	0.4	
4	Dharsiwa	Matasi	3.6	2.4
5	Gurur	Matasi yellow soil	3.1	
6	Pindrawan Tank	Matasi	0.6	
7	Bargaon	Sandy Murrum soil	4.3	3.7
8	Selud	Murram	3.5	
9	Arkar	Sandy soil	3.2	

From the analysis of Figure 12.2 it was observed that the infiltration rate was higher in the beginning and attain constant rate after some time and cumulative infiltration was observed increasing steadily. From the Table 10.1, it was observed that infiltration rate varies from 0.4 to 4.3 cm/hr in Kharun river basin. The lower infiltration rate of the soil 0.4 cm/hr was observed at Patan. The highest infiltration rate 4.3 cm/hr was observed at Bargaon, which may be due to presence of sandy murrum soil. The Kharun river basin has mainly three main types of soil i.e. Kanhar, Matasi and Sandy Murrum or sandy soil. Kanhar is the dark brown to black clay and low land soil, slightly heavier than Matasi. Wheat and Paddy are grown in this soil and average infiltration rate observed in this soil type was 1.0 cm/hr. Matasi is the yellow, loam to clay loam or loamy clay soil generally found in upland or level lands yielding good paddy. The average infiltration rate observed in this soil type was 2.4 cm/hr. In Sandy Murrum or sandy soil the average infiltration rate observed in this soil type was 3.7 cm/hr.

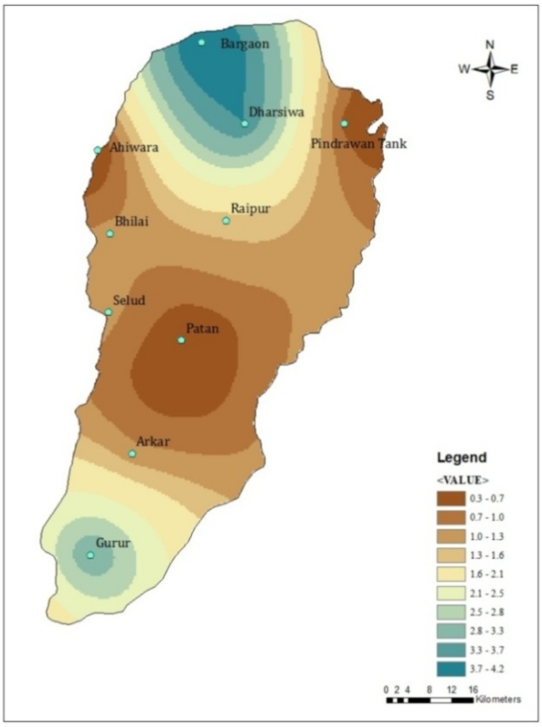


Figure 12.3: Spatial variability of infiltration rate over the study area

Thus the infiltration rate and cumulative infiltration of sandy-murrum soil were observed higher than that of the Kanhar soil. The higher clay content of the Kanhar might be the responsible factor for the significantly lower infiltration values observed. The swelling and dispersion of clay particles might have caused the sealing of the soil pores leading to low infiltration rate. This is in agreement with the results of Liu et al. (2003). From the contour map shows in figure 5 it was observed that the northern and southern part of the basin has higher infiltration rate ranging from 3.1 to 4.3 cm/hr whereas central part of the basin has lower infiltration rate ranging from 1.1 to 1.5 cm/hr.

12.6.2 Regional models

For the development of regional model the nine test sites had been separated into three classes namely Kanhar, Matasi and Sandy murrum soil. The 5 regional models developed for each soil type and for the whole basin separately and their accuracies tested during calibration are given in Table 12.2 - 12.5. The comparison of the observed infiltration rate and the computed infiltration rates of 5 regional models for each of the three classes as Kanhar, Matasi, Sandy-murrum soil are shown in Figure 12.4 – 12.7.

Table 12.2: Development of Regional model for Kanhar soil

Model	Equation	Accuracy during calibration		
		R^2	*Efficiency*	*RMSE*
Kostiakovs	$f_p = 12.82 \times t^{-0.44}$	0.876	0.9987	0.407
Mod. Kostiakovs	$f_p=0.295\times t^{1.061}+4.423$	0.698	0.9961	0.703
Horton's	$F_t = 1.3 + (5.487\text{-}1.3) \times e^{-0.031*t}$	0.760	0.9958	0.737
Green-Ampt	$f = -0.098 + 6.074\times \Gamma^{1}$	0.919	0.9994	0.277
Philip	$f = ½\ 0.65\ t^{-1/2}+0.01$	0.873	0.9978	0.531

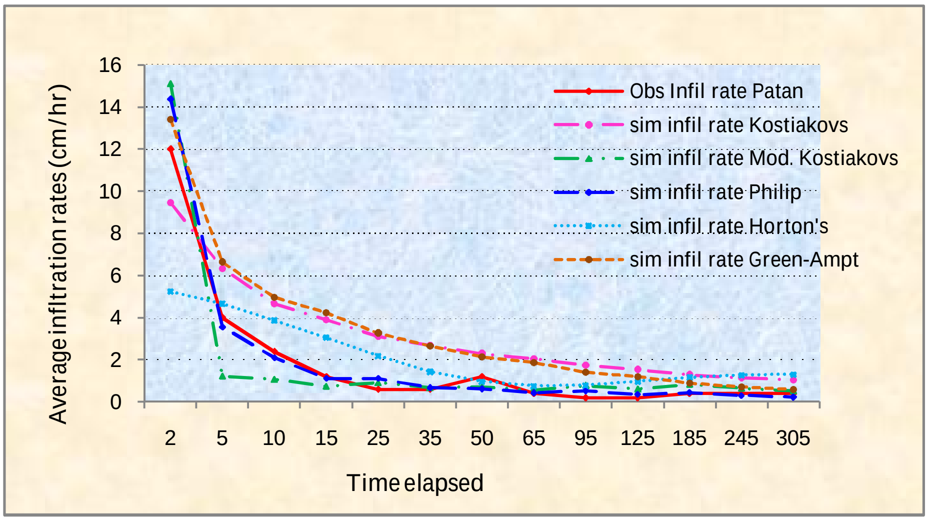


Figure 12.4: Comparison of the simulated and observed infiltration rate for Kanhar soil

From the analysis of results it was found that the regional model based on Phillip's two-term model was observed as the best suited model for evaluation or estimation of infiltration rate in the Kanhar soil. The coefficient of determination (R^2) was seen varying between 0.698 to 0.919.

Table 12.3: Development of Regional model for Matasi soil

Model	Equation	Accuracy during calibration		
		R^2	*Efficiency*	*RMSE*
Kostiakovs	$f_p = 13.61 \times t^{-0.34}$	0.964	0.9997	0.239
Mod. Kostiakovs	$f_p=0.165\times t^{1.286}+4.467$	0.308	0.9971	0.800
Horton's	$F_t = 2.1 + (7.087\text{-}2.1) \times e^{-0.021*t}$	0.738	0.9987	0.538
Green-Ampt	$f = -1.892 + 4.976\times \Gamma^{1}$	0.976	0.9999	0.127
Philip	$f = ½\ 0.55\ t^{-1/2}+0.035$	0.924	0.9980	0.656

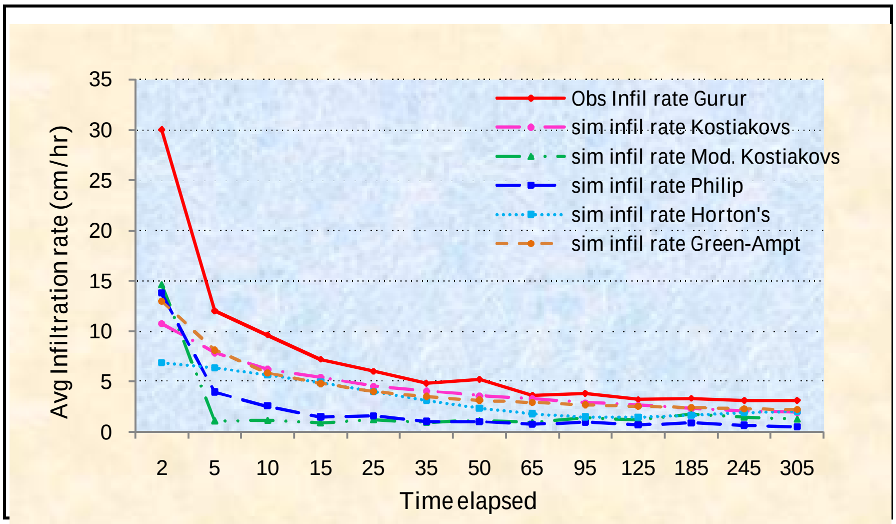


Figure 12.5: Comparison of simulated and observed infiltration rate for Matasi soil

For the Matasi soil with the regional model based on Green-Ampt equation was found best for estimation of infiltration rates. The coefficient of determination of the model was observed 0.976. The Kostiakov's model also found suitable for Matasi soil.

Table 12.4: Development of Regional model for Sandy- murrum soil

Model	Equation	Accuracy during calibration		
		R^2	*Efficiency*	*RMSE*
Kostiakovs	$f_p = 25.82 \times t^{-0.38}$	0.913	0.9994	0.649
Mod. Kostiakovs	$f_p=0.434\times t^{1.184}+8.906$	0.540	0.9968	1.495
Horton's	$F_t = 3.7 + (11.48\text{-}3.7) \times e^{-0.023*t}$	0.729	0.9974	1.349
Green-Ampt	$f =-2.305 + 12.03\times I^{-1}$	0.972	0.9983	1.096
Philip	$f = ½\ 1.216\ t^{-1/2}+0.045$	0.907	0.9981	1.158

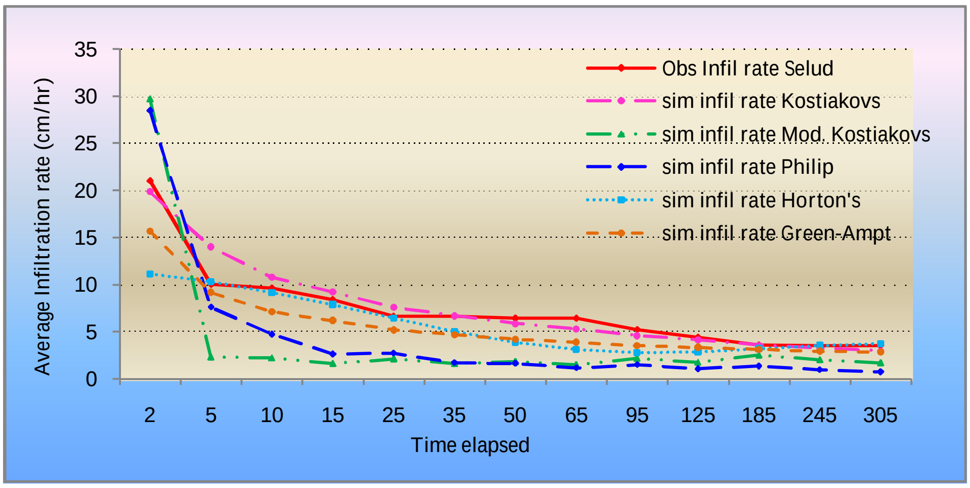


Figure 12.6: Comparison of simulated and observed infiltration rate for sandy/murrum soil

For the Sandy murrum soil, the regional model based on Kostiakov's model was found best fitted in study area. Green-Ampt model was seen as the well suited model for sandy/murrum soil. The coefficient of determination was observed varying between 0.540 to 0.972.

Table 12.5: Development of Regional model for the whole study area

Model	Equation	Accuracy during calibration		
		R^2	*Efficiency*	*RMSE*
Kostiakovs	$f_p = 14.36 \times t^{-0.49}$	0.941	0.9984	0.641
Mod. Kostiakovs	$f_p=0.261\times t^{1.192}+5.564$	0.520	0.9970	0.889
Horton's	$F_t = 2.19 + (7.38\text{-}2.19) \times e^{-0.022*t}$	0.705	0.9975	0.806
Green-Ampt	$f = -1.21 + 8.493\times I^{-1}$	0.984	0.9999	0.135
Philip	$f = ½\ 0.742\ t^{-1/2}+0.028$	0.934	0.9982	0.695

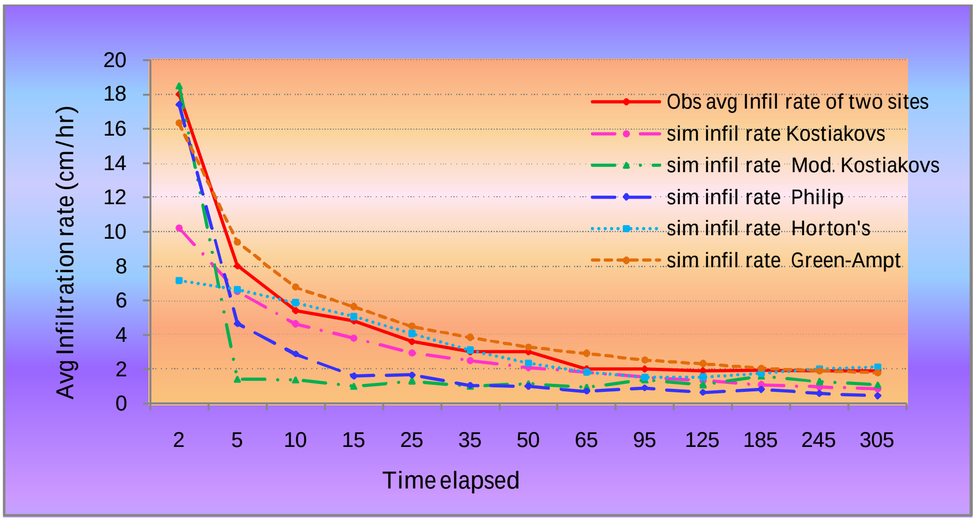


Figure 12.7: Comparison of simulated and observed infiltration rate for Kharun basin

For the whole Kharun basin, the regional model based on Green-Ampt was observed matching well. The Philip's two-term model was also found perfect model for estimation of infiltration rate.

13 DISSEMINATION OF KNOWLEDGE

One of the important aims of the PDS was the dissemination of knowledge, findings and application of the developed methodology and models to field engineers and common people through preparation of manual, leaflets, booklets and by organizing workshops or seminars every year. Under the present PDS programme the leaflets and booklet in the form of ‘Executive Summery’ were prepared by WRD, Raipur and it was widely circulated amongst all the line departments like WRD, Field offices, Agricultural Department, Raipur Corporation, etc. in the state, to the stakeholders and to most of the beneficiaries. Two workshops were organized at Raipur for dissemination of knowledge among filed engineers and various stakeholders and beneficiaries.

13.1 First PDS Workshop

The first PDS workshop was organized on 9th December, 2011 at State Water Data Centre, WRD, Raipur. In which the plan and progress of PDS work was presented among the senior officials of various line departments who were directly or indirectly beneficiaries of the PDS output such as Water Resources Department, Agricultural Department, Municipal Corporation, Industrial Department, etc. The other participating organizations were College of Agricultural Engineering, Central Ground water Board, National Institute of Hydrology, National Institute Technology, Indian Meteorological Department, etc. During the interaction session the SE, WRD stressed the need to assess the water availability of Kharun river under regulated and virgin condition both. It was suggested to refine the River Basin model of Kharun river by collecting more information and data from the field. The suggestion given by the participants were taken into consideration during the remaining period of study. Photographs of the first workshop are given below.

Engg-In-Chief, WRD, CG addressing the First PDS Workshop at Raipur in Dec, 2011

NIH scientist & PI-PDS delivering lecture in First PDS Workshop in Dec, 2011

13.2 Second PDS Workshop

The second PDS workshop was conducted on 28th June, 2013 at Sate Water Data Centre, WRD, Raipur with an aim to share the output of PDS study among the stakeholders and take their views and suggestion before completion of final report. The workshop was attended by the field engineers of Water Resources Department and representatives of Agricultural Department, Municipal Corporation, Industrial Department, and College of Agricultural Engineering. The officers and representatives from Central Ground water Board, National Institute of Hydrology, Regional Centre, Bhopal, National Institute Technology, Raipur, Indian Meteorological Department, etc. also participated in the workshop. The PI of PDS and SE, WRD gave the presentation and explained the role of PDS under HP-II program and achievements of the PDS study. The PI from NIH also presented the technical work carried out by NIH under the PDS study. All the PDS components, objectives, their methodology and results were presented in the workshop. During the interaction session, the house and participants appreciated the comprehensive analysis carried out on Kharun river basin which will be useful for future water resources planning of the basin. The field officers form WRD; Raipur expressed the need of proper implementation of recommendation and suggestion given under the study. The Engineering-in-Chief and Chief Engineers were of the opinion that results, output and recommendations given in PDS will be referred during future planning of Kharun river basin. The member from IMD suggested that, though this area is not a drought prone area but study may be conducted to assess intermittent dry spells occurring during the monsoon season in this area. Dean, College of Agricultural Engineering suggested WRD Raipur to take necessary steps for the implementation of the output of the study for better utilization of water resources of the Kharun river. It was also suggested to carry out detail analysis for assessing various water demands in the region being fulfilled by surface and groundwater separately. Some of the photographs of the second PDS workshop are given below.

Engg-In-Chief, WRD, CG addressing the Second PDS Workshop at Raipur in June, 2013

Interaction session during the Second PDS Workshop at Raipur in June, 2013

Interaction session during the Second PDS Workshop at Raipur in June, 2013

14 SUMMERY AND CONCLUSIONS

In present PDS study attempts were made for assessment of water availability, its scarcity status, water demands, surplus deficits scenario and to formulate water management plans to address the hydrological issues of Kharun river basin in Chhattisgarh state. The output from rainfall runoff modeling, water availability study and study of supply and demand scenario will be of great help for the water resources development and management plan for the Kharun river basin, for Seonath river and for the state as a whole. The analysis carried out in the PDS was found helpful to understand the hydrological behavior of river basins to harness the available water resources optimally using scientific hydrological approach. Water demand and supply scenarios for the present and future conditions were created and the water demand deficit was estimated in the basin which could be useful for systematic development of water resources in the region.

14.1 Assessment of Drought

Drought studies can provide an important input to water resources planners for water conservation and water management purposes. The study indicated that the Kharun river basin experiences two drought years in every 10 years period with 20% frequency. All drought events observed in the basin were the moderate drought events i.e. rainfall deficit was 25 to 50% of normal rainfall. From this analysis it could be concluded that meteorological droughts are not the big threat for water resources development of Kharun basin. Low flow analysis technique helps in assessing the hydrological drought severity, frequency and its duration in the river basin using long term stream flow data. The Kharun river generally experiences 1 or 2 low flow condition every year. The low flow events in this basin were found beginning during July to October and terminate during November to December and it can be the matter of concern for water resources planning and allocation in the basin. The truncation approach appears to be more effective in the investigation of drought characteristics of the river system.

14.2 Development of Mike Basin Model of Kharun River

The MIKE BASIN model for Kharun river was developed to study the hydrological behavior of the river. The MIKE BASIN is a mathematical representation of the river basin. It was found as a powerful tool to generate runoff time series at desired locations, which were then further used in Rainfall Runoff modeling, water availability study and demand supply analysis. From the study it was observed that the Kharun river was unable to provide water during lean season due to its intermittent nature and unavailability of water storage structure at the upstream. To tackle this situation the water from Ravishankarsagar reservoir is being released into Kahrun river from Mahanadi Feeder Cannal (MFC) through Deorani Jethani Nala. The Mandhar Branch Canal (MBC) a major distributor of Mahanadi Main Cannal (MMC) directly releases water into Kharun river then water is being supplied for various usages through the series of anicuts. Thus the flow regime in Kharun has been found strongly influenced by regulation operations associated with the river.

14.3 Rainfall Runoff Modeling using MIKE11 NAM

In Chhattisgarh state, network of gauging stations is limited to major rivers and many small and medium rivers are still un-gauged. Rainfall runoff estimation from a river basin is of vital importance as these values are required in most hydrologic analysis for the purpose of water resources planning. Therefore, the development of reliable rainfall runoff model, which could predict the runoff for the un-gauged catchments in the state was an important task. The Rainfall-Runoff Modeling in the Kharun river basin was carried out using MIKE11 NAM model. The flow data of 15 years period (1993-2007) at Patherdihi gauge discharge site on Kharun river was used for development of model. The catchment area of the Kharun basin up to Patherdihi site is 2442 km^2. From the analysis it was observed that the MIKE11 NAM can be developed in a number of different modes depending on the requirement and model has a capability of simulating series of daily runoff using daily rainfall data and potential evapotranspiration.

It was observed that the flow regime at Patherdihi has been strongly influenced by regulation operations associated with water transfer from Ravishankarsagar reservoir and its supply for various usages through the series of anicuts, therefore the virgin flow time series at Patherdihi was estimated from the regulated observed flow by using MIKE BASIN model of Kharun river. The potential evapotranspiration (*ETo*) of the study area was estimated using Modified Penman Method. The total annual *ETo* in the study area was 1548 mm and the *ETo* during monsoon and non-monsoon seasons were 503 mm and 1045 mm respectively.

The NAM model was calibrated using the flow data of 8 years duration from 1993 to 2000. The flow data of 7 years from 2001 to 2007 was used for the validation of model. The coefficient of determination (R^2) value of model calibration, which provides a measure of how well future outcomes are likely to be predicted by the model, was observed as 0.858, which indicated the good agreement between the average simulated and observed catchment runoff in terms of the peak flows with respect to timing, rate and volume. The R^2 value of model validation was observed as 0.764, which indicated that the model parameters obtained during model calibration were best suited for the rest of the period and model can be used for predicting the runoff time series for the extended time period in the Kharun basin and it can also be used for predicting runoff time series of another basin of similar characteristics using the rainfall data. From the graphical comparison between observed and simulated discharge, it was seen that the observed and simulated discharge at Patherdihi were matching very well, the beginning and termination of observed and simulated flow events were matching well but in case of amplification of the flows i.e. peaks, it was observed that model could predict the peak flow with moderate accuracy.

The reliability of MIKE11 NAM Model was evaluated based on its Efficiency. The Efficiency of the model was obtained as 81% which shows that the choice of the model parameters was relevant and the model was capable of simulating the stream flow in the Chhattisgarh region with a high degree of accuracy. The sensitivity analysis of the model parameters indicated that three model parameters, maximum water content in lower zone/root storage (*Lmax*), overland flow coefficient (C_{QOF}) and timing constant for overland flow and interflow (C_{K1K2}) were the most influencing parameters of the model. The overall comparison and analysis shown that the MIKE11 NAM Model can be a suitable model for Kharun river basin and predicting runoff with high degree of accuracy and can be applied for other similar basins in Chhattisgarh state. It was also observed that, the model was capable of producing time series of catchment runoff, subsurface flow contributions to the stream and information about other elements of the land phase of the hydrological cycle, such as soil moisture content and groundwater recharge.

14.4 Water Availability Study

The MIKE BASIN of Kharin river was used to simulate river flow time series at various locations in the river and to assess the water availability at desired locations. The study indicated that the Kharun river is originally a intermittent river having flow during monsoon season and 2-3 months thereafter. The average annual rainfall of 1147.57 mm produces 1802.88 MCM of annual runoff in Kharun. The river has sufficient annual water yield but due to lack of big storage structures on river, the water demands in the basin cannot be fulfilled by the river. The Ravishankarsagar reservoir and other sources add around average 116.22 MCM water in to the Kharun river and the average annual regulated flow becomes 1919.1 MCM which is supplied meet various water demands. Due to addition of water, the river experiences considerable water availability during lean period even at higher probability.

14.5 Demand Supply Analysis

Chhattisgarh state is experiencing rapid population growth, industrial growth and agricultural development which have increased the water demands. The water from Kharun river is being utilized mainly to meet domestic and industrial water demand in the basin. The water is also being utilized to meet water demands of railways, Nistari (tank supply), recreational activities, etc. All these water demands are expected to be boost up in next few decades due to rapid population and industrial growth. The water demand-supply analysis was found useful in assessing the future water surplus deficit scenario. The annual domestic water demand of Raipur city as per existing arrangement was observed 41.28 MCM in year 2010-11 which will become 94.67 MCM by the year 2050-51, similarly industrial water demand will also increase from 38.29 to 90 MCM. When the water supply to meet these demands was planned at 90% probability level, the total water demand was observed 65 MCM in 2010-11 and the deficit was 22 MCM. When the demand would increase to 133 MCM (in 2030-31) and 175 MCM (in 2050-51) the water deficit would becomes 73.56 MCM and 105.33 MCM respectively. In year 2050-51, the additional 105.33 MCM water would be required in Kharun river to fulfill the total demand.

Flow Duration Curve technique was found useful in studying the lean season flow characteristics which are important to determine the probability of the river system to provide adequate and assured water supply for meeting the expected demands. It was observed that the water availability in Kharun river becomes very low during the months from January to March and it becomes highest during the month of August. The quantity of water available in the river during lean period till the beginning of monsoon season was observed due to the water added from various sources to the river to meet its demands. The surplus-deficit analysis indicated that the period of water deficit prolongs if assured water availability is planned at higher probability level. As the water demand increases, the water deficit period increases and the river starts experiencing the water deficit much earlier. Thus it could be concluded that water deficit increases with increase in demand and increase in probability level of planning.

The development of future supply-demand scenarios at various probabilities would be useful for setting guidelines for addressing various issues such as demand management in the river basin, planning of water supply at appropriate level of probability, selection of flow volume of reasonable dependability and providing assured water supply to meet the total demands. The water deficit period of the river at any probability level and even at higher demand was found ending in the month of July and August. The water supplemented from Ravishankarsagar reservoir to the Kharun river was found helpful to increase water availability in the river to meet the various demands during lean period.

14.6 Planning for Water Storage Structures

The study was carried out for identification of possible storages sites on Kharun river and for assessment of submergence area and possible storage capacity at these sites. Four best possible dam sites were identified on Kharun river basin for construction of small storage structure using DEM data. Each dam of 9 to 12 m height would store total 19.73 to 78.7 MCM water and submerge total 25.26 to 93.08 sq. km area. The combination of different dam heights at these four locations could also be the solution. This arrangement would help to meet growing water demand of Kharun basin in future.

14.7 Evaluation of Infiltration Characteristics of Soil

From soil infiltration study carried out, it was broadly concluded that generalization of soil properties for an area was difficult since the soil and land use type varied drastically from one point to another in a short distance. This study would help in understanding the infiltration mechanism for the development of regional scale infiltration models for different soil types in Kharun basin. The model outputs on the instantaneous infiltration rates and cumulative infiltration were evaluated using the observed field infiltration data. The study area, which comprises of different types of soils, has been separated broadly into three classes. It was found that the regional infiltration models were able to simulate the infiltration rates with a fair degree of accuracy. The regional infiltration model based on the Phillip's two-term model was found best suited and was able to simulate the infiltration process very well for the Kanhar soils. Kostiakov's and Green-Ampt model could be applied for simulating the infiltration rate of Matasi and Sandy-murrum soil. However the regional model based on Green-Ampt model was found best suited for the whole Kharun basin. Thus it was concluded that the regional models developed were capable of representing the infiltration rates of the soils in the study area. These regional infiltration models may therefore be used to simulate the infiltration process for spatially variable soils under the field conditions. The results of infiltration and the developed models could be comprehensively used for the effective management and conservation of the catchment area of Kharun river basin. The goodness of fit criterions including *RMSE*, *Efficiency* and R^2 were found within the range at most of the sites.

15 RECOMMENDATIONS AND APPLICATIONS

Chhattisgarh state has been experiencing rapid population and industrial growth which has increased the water demands and are expected to boost up in next few decades. Though the occurrence droughts is not a big threat in the region, water crises in rural as well as urban areas during every summer has become common in the state. Hence there is an urgent need of long term planning to undertake appropriate water resources development and management strategies in river basins of state for the optimum utilization of water which is being drained down the rivers without being tapped causing more dependence on groundwater. State need to develop mechanism for regular monitoring and assessment of water demands and water availability to meet future challenges. It is recommended that the state WRD should maintain adequate network for hydrometeorlogical data monitoring which is key for long term planning of water resources. To meet the local water demands state WRD should plan for small dams on rivers such that submergence affects are minimized, adequate runoff is available from catchment and topography permits adequate storage. The water resources planning should includes issues such as demand management in the river basin, planning of water supply at appropriate level of probability and providing assured water supply to meet demands. WRD should adapt scientific approach like hydrological modeling and use of modern softwares for planning purposes. There is a need to undertake regular awareness programs for field officers, various water users and stakeholders for judicious use of precious water resources.

16 ACKNOWLEDGEMENT

The authors and members of Kharun PDS team from NIH, RC, Bhopal and WRD, Raipur gratefully acknowledged their sincere gratitude to Sri R.D Singh, Director, National Institute of Hydrology, Roorkee and Sri H.R. Kutare, Engineer-In-Chief, Water Resources Department, Govt. of Chhattisgarh for providing the opportunity to conduct this purpose driven study and all support during the PDS. The authors are extremely thankful to the Project Coordination Secretariat (PCS), MoWR, Technical Advisory and Monitoring Committee (TAMC) and World Bank for providing funding to the study and timely monitoring. We express our sincere thank to Dr. N. C. Ghosh, Coordinator, NIH, RC, Bhopal and Sri R. N. Divya, Chief Engineer, Mahanadi- Godavari Basin, WRD, Raipur (C.G.) for their constant technical/administrative support and encouragement during the course of study. We express our sincere thanks to Dr. Rakesh Kumar, Coordinator, HP-II, Dr. C.P. Kumar, Coordinator, PDS for their technical help, monitoring and suggestions. The authors wish to express their gratitude to Dr. Ashish Pandey, Astt. Professor, IIT Rrorkee for consultancy works in the PDS. We express our sincere thanks to Dr. R.P. Pandey, Sc-F for suggestions and support.

We are also thankful to Dr. Vinay Paney, Professor, Indira Gandhi Krishi Vishvavidiylaya, Raipur for providing requisite data and suggestions. We would like to acknowledge the support of Sri T.R. Nayak, Sc-D and Head, RC, Bhopal during the course of study. We wish to express our sincere thanks to Surface Water and Groundwater Division, WRD, Raipur for providing necessary help during collection of data, field surveys and soil infiltration tests. We are also thankful to Ku. Palak Mehata and Ku. Shilpi Chourasia, JRF under PDS for their support. Last but not the least, we are thankful to the Engineers from WRD Raipur and others who have directly or indirectly provided support and contribution to the study.

From

PDS Study Group

REFERENCE

Blackie, J.R. and Eles, C.W.O. 1985. Lumped Catchment Models, M.G. Anderson and T.P. Burts (eds), Hydrologic Forecasting, Wiley, New York.

Cai, X. 2008. Implementation of holistic water resources-economic optimization models for river basin management-reflective experiences. Environmental Modelling & Software. Volume 23, Issue 1 January, 2008: 2-18.

Cai, X., McKinney, D.C., Lasdon, L.S., Watkins, D. W. 2001. Solving large non-convex water resources management models using generalized benders decomposition. Operations Research, Vol. 49, No. 2 (Mar. - Apr., 2001): 235-245

Chang, M. and Boyer, D.G. 1977. Estimates of low flow using watershed and climatic parameters. Water Resources Research, vol 13, no 6, 1977, 977-1001.

Chiew, F.H.S. Stewardson, M.J. and McMahon, T.A. 1993. Comparison of six Rainfall-Runoff Modelling Approaches, J. Hydrol. 147. 1-36.

Christiansen, J. E. 1944. Effect of entrapped air upon the permeability of soils, Soil. Sci. Vol.58.pp 355-365.

Chuang-lin, F. and Chao, B. 2001. Water resources optimization and eco-environment protection in Qaidam basin. Journal of Geographical Sciences. Vol. II, No.2. 231-238

Clark, C.O., 1945, ‘Storage and the unit hydrograph’, Trans., ASCE, 110¸ 1419-1446.

Clausen, B. and Pearson, C.P. 1995. Regional frequency analysis of annual maximum streamflow drought. Journal of Hydrology, vol 173, 1995, 111-130.

Criddle, D. W., Davis, S., Pair, C. H. and Shockley, D. G., 1956. Methods for evaluating irrigation systems, USDA Soil Conservation Service, U. S. Government Printing Office.

DHI. 2003. MIKE Basin: Rainfall-Runoff Modeling Reference Manual, Danish Hydraulic Institute, Copenhagen,Denmark. 60 p.

Doornbos, J. and Pruitt, W.O. 1977. Guidelines for predicting crop-water requirements. FAO Irrigation and Drainage Paper 24 (Revised), FAO, Rome, pp. 144.

Duiker, S. W., Flanagan, D.C. and Lal, R. 2001. Erodibility and infiltration characteristics of five major soils of southwest Spain. Catena 45:103-121.

Fleming, G. 1975. Computer Simulation techniques in hydrology. Elsevier: New York. Pp 18-53, 239-252.

Galkate, R.V., Thomas, T., and Jaiswal, R. K. 2010. Low flow analysis in Kharun river of Chhattisgarh State. International Workshop on River Management (IWRM), Dec 14-16, 2010, New Delhi.

Galkate, R.V., Mehta, P., Jaiswal, R.K. and Thomas, T. 2012. Water availability assessment in Kharun river under regulated and virgin flow conditions using MIKE BASIN. National Symposium WARMICE-2012 at NIH, Roorkee, Feb. 8-9, 2012.

Galkate, R.V., Thomas, T., Pandey, R.P., Singh, S. and Jaiswal, R.K. 2010. Drought study in Chhindwara district of Madhya Pradesh, India**.** Third International Conference on Hydrology and Watershed Management (ICHWAM-2010), February 3-6, 2010, JNTU**,** Hyderabad, India.

Gbeckor-Kove, N. 1995. Main climatic events affecting agricultural production. 4 Eme Symposium International Sur1' Assurance Agricole. WMO, Switzerland.

Green, W. H. and Ampt G. A. 1911. Studies on soil physics, Part I, the flow of air and water through soils, *J. Agric. Sci.*,vol. 4,no. 1, pp. 1-24.

Hendricks D.W., Janonis B.A., Gerlek, S., Goldbach, J.C. and Patterson, J.L. 2007. Modeling of water supply demand in the South Platte river basin, 1970–2020. Journal of American Water Resources Association. Volume 18 Issue 2: 279-288.

Hillel, D. 1998. Environmental soil physics Academic Press. San Diego, CA.

Horton, R. E. 1939. Analysis of runoff plot experiments with varying infiltration capacity. Transactions of the American Geophysicists Union, Part IV, pp 693-694.

Horton, R. E. 1940. An approach towards a physical infiltration capacity. Soil Science Society of America Proceedings, Vol. 5, pp 399-417.

Hughes, D.A. 1995. Monthly rainfall-runoff models applied to and semi-arid catchments for water resource estimation purposes, Hydrol Sci. J., Vol. 40, pp. 751-769.

Idike, F. I. 2002. Experimental evaluation of infiltration equations for Nsukka soil. J.Agric. Engin. Technol., 10:28-34.

Jagdale Satyawan Dagadu and Nimbalkar, P. T. 2012. Infiltration studies of different soils under different soil conditions and comparison of infiltration models with field data. International Journal of Advanced Engineering Technology, 35 IJAET, Vol 3, Issue II 2012, 154-157

Kjeldsen, T.R., Allan, Lundorf and Dan, Rosbjerg. 2000. Use of Two component exponential distribution in partial duration modeling of hydrological droughts in Zimbabwean rivers. Hydrological Sciences Journal, 45(2), 285-298.

Kostiakov, A. N. 1932. On the dynamics of the coefficient of water-percolation in soils and on the necessity for studying it from a dynamic point of view for purposes of amelioration, Transactions Congress International Society for Soil Science, 6th, Moscow, Part A, 17-21.

Linsley, R. L. 1982. Rainfall-runoff models—an overview. In Rainfall-runoff relationship, proceedings of the International Symposium on Rainfall-Runoff Modeling, May 18-21, 3-22.

Linsely, R. K., Kohlar, M.A. and Paulhus, J.L.H. 1949. Applied Hydrology. McGraw Hill Book Co., NY., p 689.

Liu, C.W., Chang, S.W., Yu, W.S. and Cheu, S.K. 2003. Water infiltration rate in cracked paddy soil. Geoderma. 117: 169-181.

Mehrotra, R. 1996. Comparison of monthly rainfall runoff models, National Institute of Hydrology Report, CS(AR)-211.

Melching, C. S. 1995. Reliability estimation in computer models of watershed hydrology. In Singh, V. P., ed., Reliability estimation in computer models of watershed hydrology. Water Resources, 69-118.

Mimikov, M.A., Hatjisava, P.S.,. Kouvopoulos, Y.S. and Anagnostou, E.N. 1992, The influence of basin aridity on the efficiency of runoff predicting models, Nordic Hydrol., Vol. 23, pp. 105-120.

Mishra, S. K., Tyagi, J. V. and Singh, V. P. 2003. Comparison of infiltration models. Journal of Hydrological Processes. 17: 2629 – 2652

Musgrave, G.W. and Horton, H.N. 1964. Infiltration, A handbook of applied hydrology (Ed. V. T. Chow), Sec. 12, McGraw Hill Book Co., NY.

National commission on Agriculture. 1979. Climate and Agriculture, Part-IV. Govt. of India, Ministry of Agriculture and Irrigation, New Delhi.

National Institute of Urban Affair. 2006. Appraisal of City Development Plan: Raipur City Municipal Infrastructure. NIUA Report, March, 2006, Delhi.

Oku, E. and Aiyelari, A. 2011. Predictability of Philip and Kostiakov infiltration model under inceptisols in the Humid Forest Zone, Nigeria. Kasetsart Journal (Natural Science), 45: 594 -602

Oyenarte, N.A., Mateos, L, Palomo, M.J. 2002. Infiltration variability in furrow irrigation. J. Irrig. Drain. Eng. ASCE 128: 26-33.

Pandey, R.P. and Ramasastri, K.S. 2003. Estimation of lean season water availability in streams with limited data. Institute of Engineers (I) Journal, Vol. 84, November 2003, 149-152.

Pandey, R.P., Sharma, K.D., Mishra, S.K., Singh, R. and Galkate, R.V. 2008. Assessment of Streamflow Drought Severity Using Ephemeral Streamflow Data. International Journal of Ecological Economics & Statistics (IJEES), Vol. 11, No. S08, 77-89.

Philip, J. R. 1957a. The theory of infiltration: 1- The infiltration equation and its solution, Soil Science, 83, 345–357.

Philip, J. R. 1957b. The theory of infiltration: 4. Sorptivity and algebraic infiltration equations, *Soil Science*, 84, 257-264.

Philip, J. R. 1957c. The theory of infiltration: 5. The influence of initial water content, *Soil Science* 84, 329-339.

Philip, J. R. 1957. The theory of infiltration 4. Sorptivity and algebraic infiltration. Soil. Sci. 84: 257-264.

Rodriguez-Iturbe, I. and Valdes, J.B. (1979). The Geomorphological structure of hydrologic response. Water Resources Research, 15 (6): 1409 –1420.

Sarma, V.V. 1976. A simple approach for an overall assessment of surface water resources by the water balance method. Vayu Mandal, 1, No. 4

Sastry, P.S.N. 1986. Meteorological Drought. Jal Vigyan Smiksha, Publication of High Level

Simonovic, S.P. 1992. Reservoir system analysis: closing gap between theory and practice. J. Water Resources Planning and Management, ASCE, 118 (3): 262-280.

Skaggs, R. W., and Khaleel, R., 1982. Chapter 4: Infiltration, In Hydrology of small watersheds, St Joseph, Mich.: ASCE.

Sorooshian, S., Gupta, V.K., and Fulton J.L. 1983. Evaluation of Maximum Likelihood Parameter Estimation Techniques for Conceptual Rainfall-Runoff Models – Influence of Calibration Data Variability and Length on Model Credibility. Water Resources Research, 19(1): 251-259.

WMO. 1975. Drought and Agriculture, WMO Technical Note No. 138, Geneva.

Wubet, F.D., Seleshi, B.A. and Moges, S.A. 2009. Analysis of water use on large river basin using MIKE BASIN model – A case study of the Abbay river basin, Ethiopia. International Result Dissemination Workshop, Feb. 5-6, 2009, Addis Ababa, Ethiopia.

Yen B.C. and Lee, K.T. 1997. Unit hydrograph derivation for ungauged watersheds by stream order laws. Journal of Hydrologic Engineering, Vol. 2, No. 1.

Zerihun, D., Feyen, J., Reddy, J.M. 1996. Sensitivity analysis of furrow-irrigation performance parameters J. Irrig. Drain. Eng. ASCE 122: 49-57.

National Institute of Hydrology Regional Centre, Bhopal	Water Resources Department Govt. of Chhattisgarh, Raipur
Director: Dr. R.D. Singh	EnC: Sh. H.R. Kutare,
Coordinator: Dr. N.C. Ghosh	CE: Sh. R.N. Divya
Head: Sh. T.R. Nayak	PI: Sh. S.K. Awadhiya, SE
PI: Sh. Ravi Galkate, Scientist-D	CO-PI: Sh. D. K. Sonkusale, Dy. Director
CO-PI: Sh. T. Thomas, Scientist-C	CO-PI: Sh. Akhilesh Verma, Asst. Engineer
CO-PI: Sh. R.K. Jaiswal, Scientist-C	CO-PI: Sh. R. K. Sharma, SDO
CO-PI: Dr. Surjeet Singh, Scientist-D	CO-PI: Sh. T.L. Chandrakar, Sub Engineer
	CO-PI: Sh. J. K. Dass, Sub Engineer
Address: **Regional Centre** National Institute of Hydrology Regional Centre WALMI Campus, Kolar Road Bhopal – 462016 (MP) Ph: 0755-2491243 Fax: 0755-2491218 Email: nihrcbhopal@yahoo.com rgalkate@yahoo.co.in **Head Quarter** National Institute of Hydrology Jalvigyan Bhawan Roorkee -247667 (UK) Ph: 01332-249201 Fax: 01332-272123 Web: www.nih.renet.in	**Address:** State Water Data Centre Water Resources Department Govt. Of Chhattisgarh Civil Lines, Raipur – 492001 (CG) Ph & Fax: 0771-2445091 Email: sdc_cg@yahoo.co.in dks1963@gmail.com