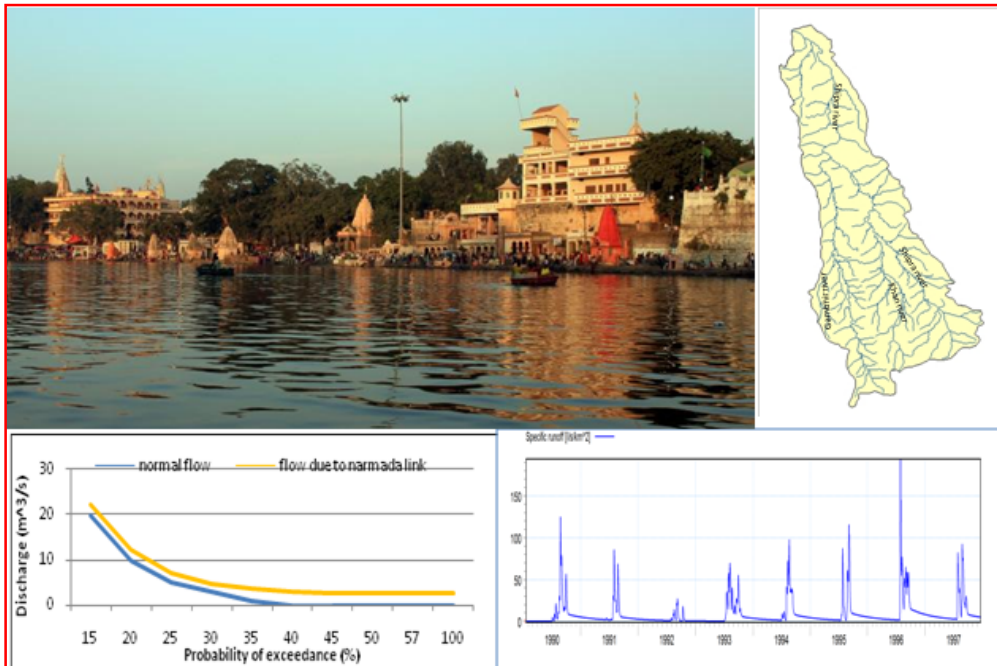


FINAL REPORT

DEVELOPMENT OF DECISION SUPPORT SYSTEM (DSS) APPLICATIONS AND HYDROLOGICAL ANALYSIS FOR SHIPRA RIVER BASIN OF MP



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PREFACE

The water resources management and planning has become increasingly complex, involving social, economical and environmental issues. Development of an appropriate Decision Support System (DSS) can be the key to address such complex issues. The DSS is a software based system intended to help decision makers to compile useful information from raw data, documents, personal knowledge, and/or models to identify and solve problems and make decisions. In India, the Ministry of Water Resources, Government of India has recently completed DSS (P) project under the Hydrology Project Phase-II (HP-II) in year 2014. Madhya Pradesh state has developed DSS under HP-II for the upper Wainganga River Basin to support decisions in water resources development and management. The present study on development of DSS applications for Shipra river basin has been taken up under the sustainability program of DSS (P) project in collaboration with BODHI, Water Resources Department, Govt. of MP, Bhopal for integrated water resources planning, development and management in Shipra basin. It also includes hydrological analysis components like assessment of drought, climate change and declining river flow. For development of DSS in Shipra basin, the approach of Integrated River Basin Management (IRBM) and to perform the holistic analysis with multi-criteria optimization task and assessment of effects of measures, integrated modeling techniques are adopted. In this context, computer based hydrological modelling tools like Mike 11, Mike Zero and Mike Basin capable to manage the huge amount of data, perform analysis, simulation, multi-objective evaluation of results and providing the essential information required in decision making has been used. Present study aims to assessment of drought situation in Shipra basin for its mitigation planning, Assessment of climate change scenario which may be helpful for future water resources planning in the basin. The study envisages development of rainfall runoff model and Mike Basin model for Shipra river for development of user friendly DSS interfaces, which could be the facilitating tool for decision makers to address water resources related issues, solve problem and make appropriate decisions. Various applications were developed in DSS platform to address the issues like water availability, demand supply, surplus deficit analysis, etc. under changing hydrological and climatic conditions. Assessment of dwindling of lean period flow in Shipra using runoff and groundwater data and identification of its causes may be helpful for formulation of rejuvenation plan. The output of this study would be helpful to the Madhya Pradesh state for river basin planning, management and its revival.

This report has been prepared by Sh. Ravi Galkate, Scientist-E as a PI and Sh. R.K. Jaiswal, Scientist-D, Dr. T. R. Nayak, Scientist E and Dr. T. Thomas, Scientist-D as Co-PI from National Institute of Hydrology, Central India Hydrology Regional Centre, Bhopal. The study team from BODHI, Water Resources Department, Bhopal included Dr. Jitendra Jain, SE, Ground Water Survey, Bhopal, Sh. Sanjeev Das, Dy. Director, State Water Data Centre, Sh. Sanjay Kumar Gupta, Sr. Geophysicists, BODHI, Bhopal, Sh. Brajendra Baghel, Scientific Officer, Ground Water Survey, Bhopal. The report is the results of three and half years of collaborative research and field works conducted by both organizations.

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ABSTRACT

DSS is a software based system intended to help decision makers to compile useful information from raw data, documents, personal knowledge, and/or models to identify and solve problems and make decisions. The present study aims at development of DSS applications for Shipra river basin for integrated water resources planning, development and management in Shipra basin. It also envisages various hydrological analysis components like assessment of drought, climate change and declining river flow.

Shipra is one of the important river of Malwa region in Western Madhya Pradesh characterized by very high variability of rainfall, recurrent droughts, increasing water demands due to rapid urbanization and industrial growth of cities like Indore, Dewas and Ujjain; and inter-basin water transfer. The river experiences very high water demand especially during Kumbh mela called Simhastha organized periodically at Ujjain. To meet the increasing water demands in the basin, the state has made arrangement to supplement Shipra river through Narmada-Shipra link and also planned for Narmada-Gambhir link. The increasing complexity of water resources system in Shipra basin to fulfill various water demands has urged a need of development of DSS applications capable of handling the foreseen and unforeseen hydrological issues. It would help to address issues of sustainable water resources development, fulfillment of future water demands and optimal utilization of water resources under changing hydrological and climatic conditions.

In rainfall, meteorological and hydrological data was analyzed to achieve its objectives. The annual drought frequency analysis indicated that approximately one out of every three to four year is a drought year and the whole Shipra basin can be categorized as drought prone area. The low flow analysis indicated that the Shipra river experiences on an average one low flow situation every year, thus drought aspect needs to be taken for water resources development and planning in the basin. A GIS based MIKE BASIN model was developed for Shipra river basin and three different DSS application scenarios were developed to address water availability assessment, water demand, water deficit and its quality issues. The runoff simulation from ungauged sub-basin was taken care of by NAM rainfall runoff model. The result indicated that, under the condition when there is no Khan Diversion and no Narmada-Shipra link, the river has flow only in monsoon season and runs dry in non-monsoon season. To avoid polluted water entering in to Shipra, Khan river water was diverted through Khan diversion which caused to reduce dependable river flow at different probabilities and its magnitude was seen significant. When Narmada-Shipra link became operational, the water availability at Ujjain was found improved significantly during lean period.

The climate change assessment carried out using rainfall trend analysis indicated that around 60% rain gauge stations of the basin has shown falling trend for annual Rainfall and 50% stations shows falling trend for number of rainy days but the significant falling trend was observed only at Dewas station. Climate change will have severe impact on catchment hydrology and falling rainfall trend will not only reduce the runoff yield but also reduce the peak flows, low flows and it would have adverse impacts on the total water resource scenario of the basin.

For assessment of declining monsoon and lean period flow in Shipra, trend analysis of runoff data was carried out and results were compared with ground water levels contributing base to the river. During the beginning and end of monsoon months at Ujjain and Mahidpur and at the outlet of Shipra, the dependable river flow at various probability levels have seen experiencing falling trend whereas rising trend was observed during mid monsoon. Mann-Kendall test was also found supporting the same trend exhibited through linear or graphical method. Analysis of runoff data at Ujjain, Mahidpur and outlet of Shipra based on Wigley and Jones index clearly indicated decrease of weighted average rainfall during 1999 to 2012 as compared to the rainfall during 1985 to 1998. The index indicated similar declines in case of average annual runoff, runoff ration and relative change in runoff clearly indicating significant decline in rainfall and runoff in monsoon as well as non monsoon period in Shipra basin. To compare the results of declining river flow in Shipra with the ground water status of the area in basin a trend analysis of ground water levels data was carried out. The results indicated that the ground water levels in the Shipra basin upstream has shown falling trend at all the individual well locations and when regionalized, the falling trend was observed predominant in middle reach as compared to upstream and downstream area in the basin. Declining of ground water levels causing reduction of base flow is the main reason for reduction of lean period flow in the river.

For river rejuvenation and augmentation of base flow various measures can be adopted such as range management, upland vegetation management, riparian vegetation management, afforestation in catchment area, upland runoff detention and retention, and the use of instream structures in sub watersheds. For the revival of river flow, measures such as integrated watershed management programs, ground water recharging by natural and artificial methods, water conservation in fields, plantation of native trees, improving irrigation practices for increasing base flow, demand management, etc can be helpful for the rejuvenation of river and improving lean period flow in the river.

CHAPTER 1

DEVELOPMENT OF DECISION SUPPORT SYSTEM (DSS) APPLICATIONS AND HYDROLOGICAL ANALYSIS FOR SHIPRA RIVER BASIN OF MP

1.1 Introduction

The ultimate purpose of modern water resources management is to ensure the supply and demand of water resources, protection of water environment and maintaining ecological balance, to meet the needs of contemporary human life and socio-economic development of water and out of the living space for future generation (Kepeng and Juncang, 2013). Water resources management and planning is becoming increasingly complex, involving social, economical and environmental issues. The challenges for water resources management and planning due to increasing, conflictive water demands call for appropriate concepts of management and development of a Decision Support System (DSS) for integrated water resources management. A DSS is defined as an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to aid decision makers in solving relatively large, unstructured problems (Watkins 1995). Thus DSS is a software based system intended to help decision makers to compile useful information from raw data, documents, personal knowledge, and/or models to identify and solve problems and make decisions.

In the 1960s researchers began systematically studying the use of computerized quantitative models to assist in decision making and planning (Raymond, 1966; Turban, 1967; Urban, 1967; Holt and Huber, 1969). In the 1980s many activities associated with building and studying DSS occurred in universities and organizations that resulted in expanding the scope of DSS applications (Power, D. J. 2007). Numbers of countries have developed customized DSS for water resources management like Egypt, United Kingdom, East Africa (Nile River Basin), West Africa (Volta River Basin), Germany, France, etc. Sieker et al. (2006) worked on the development of a methodology to guide and support an improved water resources management on the level of small watersheds (up to 300 km²) within the framework of a generic Decision Support System (DSS) in Germany. However sustainability of DSS is the major challenge for its successful extended implementation. Giupponi and Sgobbi (2013) conducted a survey of DSS implementation in developing countries with specific reference on Africa. They concluded that, in DSS developments priority efforts should not be focused on developing the tools, but rather on improving the effectiveness and applicability of integrated water resource management legislative and planning frameworks, training and capacity building, networking and cooperation, harmonization of transnational data infrastructures and, very importantly, learning from past experiences and adopting enhanced protocols for DSS development. In years to come, water, the need of life, is possibly to pose greatest challenge on account of its increased demand

with population rise, economic development, and shrinking supplies due to over exploitation and pollution.

In India, the Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India has completed DSS (P) project under the Hydrology Project Phase-II (HP-II) in year 2014 for integrated water resources development and management of water resource systems. The Madhya Pradesh state has developed DSS (P) for the upper Wainganga River Basin under HP-II to support decisions in water resources development and management. The present study for development of DSS applications for Shipra river basin has been taken up in collaboration with BODHI, Water Resources Department, Govt. of MP, Bhopal as the sustainability program of DSS (P) project completed in Madhya Pradesh.

Shipra is one of the important river of Malwa region in Western Madhya Pradesh covering 5612 sq km area. It has two main tributaries, Gambhir and Khan river. The Shipra river basin area is characterized by very high variability of rainfall, recurrent droughts, increasing water demands due to rapid urbanization and industrial growth in cities like Indore, Dewas and Ujjain and inter-basin water transfer. The river experiences very high water demand especially during Kumbh mela organized periodically at Ujjain. To meet the increasing water demands in the basin, the state has made arrangement to supplement Shipra river through Narmada-Shipra link and planned for Narmada-Gambhir link to be undertaken in future. Under such circumstances the development of DSS applications in DSS(P) software would help to address issues of sustainable water resources development, fulfillment of future water demands and optimal utilization of water resources under changing hydrological and climatic conditions. Beside development of DSS applications, various meteorological and hydrological aspects in Shipra basin such as analysis of drought and climate change scenario in the Shipra basin area were deliberated which may contributes to management of water in the basin and better resilience. It is reported that Shipra river was earlier had a flow throughout the year. Now it has lost its perennial nature and became intermittent. In view of this, analysis was carried out for assessment of declining monsoon and lean period flow in Shipra and attempts were made to suggest possible strategies for revival of Shipra River. The objectives of the study were as below.

- ✓ Assessment of droughts in Shipra river basin
- ✓ Rainfall runoff modeling for Shipra river basin
- ✓ Development of Mike Basin model for Shipra basin and development of DSS applications
- ✓ Assessment of climate change and its impacts on catchment hydrology
- ✓ Assessment of declining river low in Shipra
- ✓ Possible strategies for rejuvenation of Shipra River

1.2 Study Area

The Shipra, also known as the Kshipra, originates from Kokribardi hills in Vidhyan range near small village Ujjaini located 11 km in South-East of Indore city and flows north across the Malwa Plateau to join the Chambal river. It is one of the sacred rivers in Hinduism. The holy city of Ujjain is situated on its right bank. After every 12 years, the Kumbh Mela, also called Simhastha, takes place at Ujjain on the city's elaborate riverside Ghats, besides yearly celebrations of the river goddess Kshipra. Shipra river basin has been extended between 76° 06' 20'' and 75° 55' 60'' North Latitude and 22° 97' 00'' and 23° 76' 20'' East Longitude. As per the catchment delineated using Survey of India toposheets, river covers an area of 5679 sq km. The river traverses total course of about 190 km through four districts namely Dewas, Indore, Ujjain, and Ratlam before joining Chambal river near Kalu-Kher village. The majority of the Shipra basin area falls in Indore and Ujjain districts however small part come under Ratlam and Dewas districts. The areas of districts falls in Shipra basin are given in Table 1.1. The majority of the Shipra basin i.e. 76% area falls in Indore and Ujjain districts however small part i.e. 24% area falls under Ratlam and Dewas districts as shown in Figure 1.1.

Table 1.1: District wise area distribution of Shipra basin

S. No.	Name of District	Area under Shipra Basin (km ²)
1	Ujjain	2421
2	Indore	1855
3	Ratlam	714
4	Dewas	689
Total Basin Area		5679

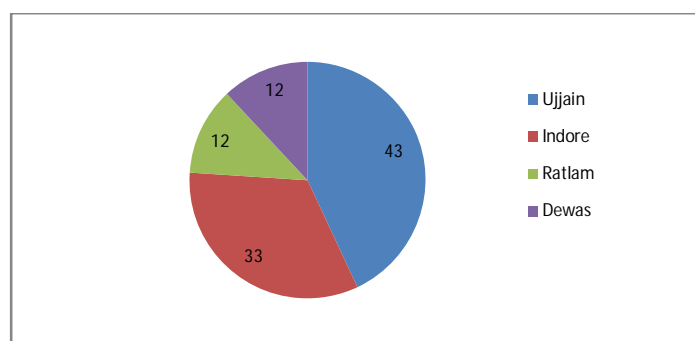


Figure 1.1: Area under different districts in Shipra Basin (%)

There are hundreds of Hindu shrines along the banks of the river Shipra. The photograph showing holy dip in Shipra at Ujjain during Simhastha 2016 is shown in Figure 1.2. The

photograph showing Shipra river ghat is shown in Figure 1.3. The index map of Shipra indicating its location is shown in Figure 1.4.



Figure 1.2: Holy dip in Shipra at Ujjain during Simhastha (Kumbh)

The river flows in a general north-westerly direction and has a very sinuous course. The main tributaries of Shipra are the Khan and Ghambir river. Khan confluences with Shipra near Ujjain and Gambhir confluences near Mahidpur. Over the years the river has lost its perennial nature and now runs dry during lean period. Earlier the Shipra river was source water to make use for drinking, industrial supply and lift irrigation purposes. It is reported that there is a normal practice of pumping water from the river for providing irrigation to surrounding agricultural fields. The deterioration of water quality of tributaries of Shipra has imposed threat to whole river system. The Shipra River Basin catchment and its drainage network are shown in Figure 1.5.



Figure 1.3: Shipra river ghat at Ujjain

1.2.1 Climate

The average annual rainfall of study area is about 931.87 mm. The rainfall in the area is due to the southwest monsoon which starts from the middle of June and ends in last week of September. The climate condition of the study area, particularly in December and January, are severely cold, whereas summer month of May and June are intensely hot. The mean monthly minimum air temperature during the winter period is around 11.5 °C, while the maximum mean air temperature during the hottest months (May and June) is around 47.7 °C. The relative humidity is low during April to June and high during July to September.

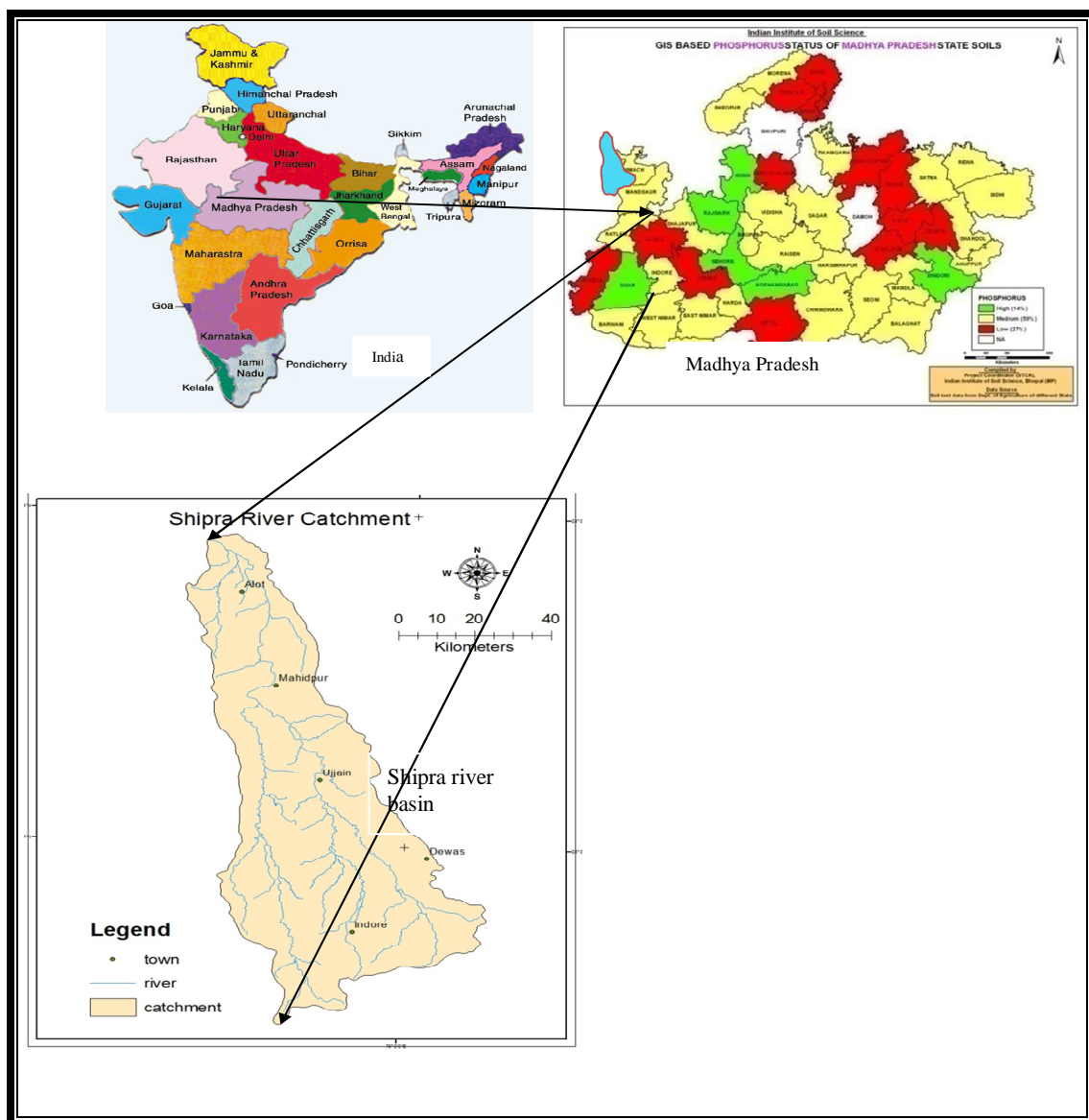


Figure 1.4: Index map of Shipra river basin

1.2.2 Topography and soil

The topography of Shipra basin is generally rolling to undulating having slope from south to north. Due to undulating topography, the upland areas have excessive surface runoff which results in soil erosion. The soil removed from upland areas gets accumulated on the valley land, which has moderate to poor drainage. The catchment area of River Shipra dominantly encompasses black cotton soils with shrinking and swelling property. This soil is mainly a clay soil and has moderate to low infiltration rates.

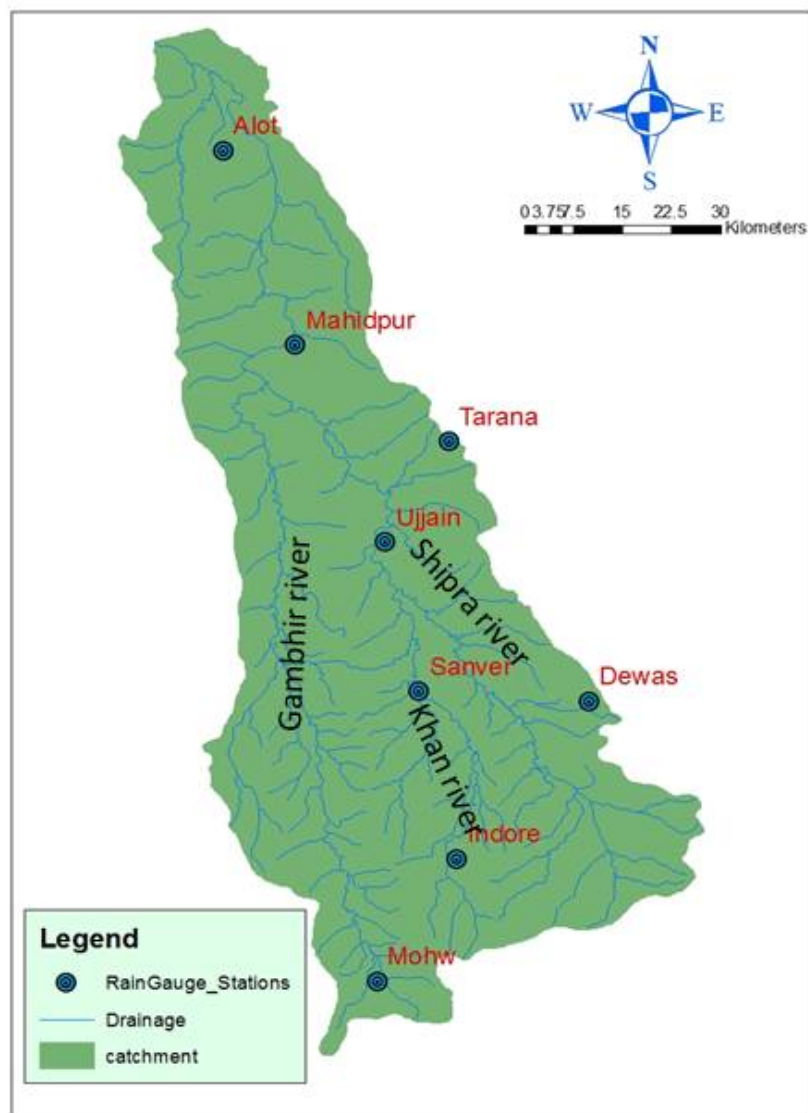


Figure 1.5: Shipra River Basin catchment, drainage and raingauge network

1.2.3 Report outline

The report comprises of chapters elaborating various aspects such as drought assessment, drought characterization, climate change, rainfall runoff modelling, development of DSS applications and assessment of declining monsoon and lean period flow in Shipra as given below.

1. Preliminary analysis of meteorological and hydrological data.
1. Assessment of drought situation in Shipra basin and Quantification of precipitation deficit using Standardized precipitation index (SPI)
2. Trend analysis of meteorological and hydrological data using Mann-Kendall test for assessment of climatic changes.
3. Rainfall runoff modeling using MIKE11 NAM model.
4. Development of Shipra River Basin Model using MIKE BASIN/MIKE HYDRO software
5. Development of DSS applications using MIKE BASIN/MIKE HYDRO or DSS software
6. Sub-basin wise water availability study using flow duration curve technique.
7. Supply demand analysis using Shipra basin Mike Basin Model.
8. Assessment of declining flow in Shipra.
9. Possible remedial measures for sustainable Shipra river basin revival.

1.2.4 Data collection

The collection and compilation of comprehensive long term data is one of the important task in DSS development. During the first year attempts were made for collection of meteorological, hydrological data, agricultural, demographic, relevant statistical information and geographical data, which was further, used for hydrological analysis and generating DSS scenarios. The data and information required for the study has been collected from various State and Central departments 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 is explained in details in this section.

1.2.5 Rainfall and meteorological data

The daily rainfall data of eleven rain gauge stations, falling in and around Shipra river basin, has been collected from IMD, Pune and State Water Data Centre, Water Resources Department, Govt. of Madhya Pradesh, Bhopal. The meteorological data of Indore observatory like relative

humidity, wind speed, sunshine hours, mean and maximum temperature, etc. was collected from IMD Pune. The daily rainfall data of various blocks of the districts were also collected from O/o Superintendent of Land Records of three districts Indore, Dewas and Ujjain. The rainfall data availability of study area is given in Table 1.2.

Table 1.2: Rainfall data availability

S. No.	Station	Daily Rainfall data Availability
1	Dewas	1989 – 2013
2	Indore	1989 – 2013
3	Ujjain	1989 – 2013
4	Mahidpur	1989 – 2013
5	Alot	1989 – 2013
6	Depalpur	1963 – 2013
7	Mhow	1951- 2012
8	Sanver	1960 – 2012
9	Badnagar	1958 – 2012
10	Khachrod	1959 – 2012
11	Tarana	1960 – 2012

1.2.6 Gauge-discharge data

The daily gauge-discharge data of Ujjain and Mahidpur sites on Shipra river for the period from 2084 to 2014 was collected with the permission of Chief Engineer (Yamuna Basin), Central Water Commission, New Delhi from the O/o Executive Engineer, Chambal Division, CWC, Jaipur. This information was used for hydrological drought analysis, climate change analysis and to develop the rainfall runoff model and to set the Shipra River Basin model in MIKE BASIN.

1.2.7 Ground water data

Approximately of 30 years ground water data of four districts Dewas, Ujjain, Indore, Ratlam falling fully or partially in Shipra basin was collected from Ground Water Survey, State Ground Water Data Centre, WRD, Bhopal. The long term ground water data included water table level readings for four periods of the year, pre-monsoon (May), mid-monsoon (August), post-monsoon (November) and winter season (January). The status of ground water level data and piezometric data availability in four districts is given in Table 1.3.

Table1.3: Ground water data status

Sr. No.	District	Data Type	Number of stations	Data availability period
1	Dewas	Ground water data	100	1984-2014
		Piezometric data	29	1999-2014
2	Indore	Ground water data	76	1985-2008
		Piezometric data	29	1998-2014
3	Ratlam	Ground water data	99	1984-2014
		Piezometric data	23	1999-2014
4	Ujjain	Ground water data	100	1984-2014
		Piezometric data	23	2000-2014

1.2.8 Generation of maps

Various layers of information on catchment, locations of rain gauge stations, gauge discharge sites, drainage network, etc. were prepared using Arc GIS for the further use in hydrological analysis. These layers were prepared using 1:250000 Survey of India toposheets No. 46M, 46N, 55A and 55B.

CHAPTER 2

ASSESSMENT OF DROUGHTS IN SHIPRA BASIN

2.1 Introduction

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 Malwa region of Madhya Pradesh is facing the problems of recurrent droughts which are unpredictable phenomena both in their occurrence and duration; hence prevision and preparation against droughts are key elements for minimizing their impact. There are mainly four types of drought. Meteorological drought usually defined based on the degree of dryness in comparison to some “normal” or average and the duration of the dry period. Drought onset generally occurs with a meteorological drought. Hydrological drought usually occurs following periods of extended precipitation shortfalls that impact water supply i.e., stream flow, reservoir and lake levels, ground water, potentially resulting in significant societal impacts. Agricultural drought links various characteristics of meteorological and hydrological drought to agricultural impacts, focusing on precipitation shortages, soil water deficits, reduced ground water or reservoir levels needed for irrigation. Socioeconomic drought refers to the effect of deficit water supply on people and economic activities of the region.

The drought assessment in Shipra basin is based on the analysis of rainfall includes annual departure analysis, seasonal departure analysis and frequency analysis to identify drought years. Probability distribution of annual rainfall has been carried out for identification of drought prone subareas in basin. The low stream flows and reduced reservoir storages are indicative of hydrological drought situations hence low flow analysis has been carried out using flow duration curves technique. During last 50 years, several indices were developed to study and detect the onset and severity of drought. A drought index integrates various hydrological and meteorological parameters like rainfall, temperature, evapotranspiration, runoff and other water supply indicators into a single number and gives a comprehensive picture for decision-making. In present study droughts events were also quantified using Standardized Precipitation Index

(SPI) for various time scales. The information on various aspects of drought can provide the important inputs to the planners for water resources development and management in the region and making decisions under the water scarcity situation.

2.2 Methodology

For assessment of drought and to study the magnitude and frequency of drought in terms of rainfall deficiency in Shipra basin, the rainfall data of 35 years from 1972 to 2006 of eight rain gauge stations falling in Shipra basin namely, Dewas, Indore, Ujjain, Sanver, Badnagar, Khachrod, Mahidpur, Tarana has been used. The selection of stations for analysis was based on the long term and continuous data availability. The station wise rainfall distribution and statistics in Shipra River basin is given in Table 2.1 and monthly rainfall distribution in Shipra basin is shown in Figure 2.1.

Table 2.1: Station wise rainfall distribution and statistics in Shipra River Basin

Name of Station	Average Annual rainfall (mm)	Std. Deviation For Annual Rainfall (mm)	Monsoon Rainfall (mm)	Non-Mon rainfall (mm)	Rainy Days
Ujjain	923	306	867	56	41
Dewas	998	353	936	42	43
Indore	988	248	941	47	46
Depalpur	907	312	875	32	40
Mhow	785	279	762	23	41
Sanver	905	299	862	43	39
Badnagar	862	292	820	42	38
Khacharod	903	348	873	30	37
Mahidpur	890	306	857	33	38
Tarana	925	350	886	39	38
Average	909	309	870	39	40

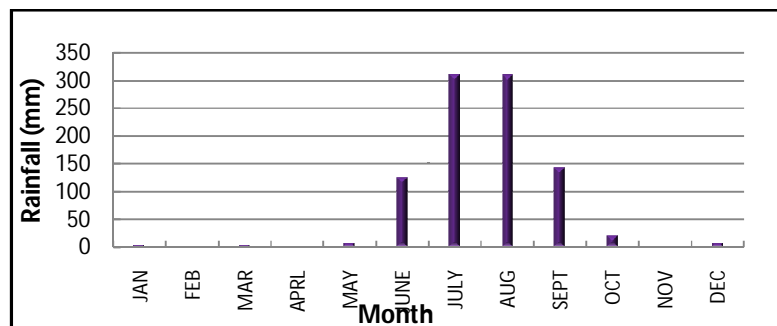


Figure 2.1: Monthly rainfall distribution in Shipra basin

2.2.1 Rainfall departure Analysis

The departure analysis of rainfall data indicates the meteorological drought aspects of the area. 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. India meteorological Department defined seasonal drought as the period with the seasonal rainfall deficiency more than 25% from its normal value. It is further classified as “moderate drought” if the rainfall deficit is between 26 and 50% and “severe drought” when it exceeds 50%. About 85% of the annual rainfall in the Shipra River Basin is received from southwest monsoon that occurs during June to September. For the seasonal rainfall departure analysis, seasonal rainfall data of 35 years from year 1972 to 2006 of all eight rain gauge stations of Shipra basin have been used and drought years have been identified and also average frequency of drought was calculated. The seasonal rainfall departure analysis comprises of the following steps.

- Determination of Mean (Xm) for a set of seasonal rainfall data.

$$Xm = \frac{\sum(x)}{n}$$

- Calculate departure (Di) by subtracting the mean (Xm) from the individual seasonal rainfall

$$Di = Xm - Xi$$

- From resulted departure (Di), the departure percentage ($Di\%$) is calculated as follows

$$Di(\%) = \frac{Di}{xm} \times 100$$

2.2.2 Probability distribution of annual rainfall

The probability analysis of annual rainfall is important to predict the relative frequency of occurrence in different group interval of annual rainfall with reasonable accuracy. The estimated probability of an event is taken as the relative frequency of occurrence of the event when the numbers of observations are very large. The percentage probability of occurrence of 75% of mean annual rainfall has been worked out to delineate the drought proneness of various stations of Shipra River Basin. An area can be considered as drought prone if the probability of occurrence of 75% of normal rainfall is less than 80% (CWC, 1982). The probability distribution of annual rainfall comprises of following steps:

- Computation of mean rainfall at each station

$$\text{Mean rainfall } Xm = \sum(Xi) / n$$

- Arranging the data set in the descending order on the basis of rainfall magnitudes

- Ranking the set of data, $m = 1, 2, 3$, up to last rainfall records.
- Determination of cumulative probability (Weibull's formula)

$$P = \frac{m}{N+1} \times 100$$

- Calculate 75% of the normal of the rainfall data

$$X_{75} = X_m \times 75/100$$

The probability of occurrence of the 75% of mean rainfall (X_{75}) is denoted as P_{75} , then

If $P_{75} < 80\%$, then the area is considered to be drought prone,

If $P_{75} > 80\%$, then the area is not considered as drought prone.

For probability distribution of annual rainfall, 35 years annual rainfall data of eight stations from year 1972 to 2006 have been used. The probability distribution curves have been draw by plotting the values of probability of exceedance against the corresponding annual rainfall values.

2.2.3 Low flow analysis

The low flow analysis indicates the hydrological drought aspects of a river basin or area. The surface water deficits are reflected through low stream flows and reduced reservoir storages. During the deficient rainfall condition the deviation from normal is greater for stream flows than the rainfall. The low stream flows and reduced reservoir storages are indicative of hydrological drought situations. When the 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 the analysis of stream flow. In low flow analysis hydrologists are mainly concerned with three main characteristics (i) magnitude of low flow (ii) duration of low flow and (iii) frequency of occurrence of low flow. To carry out the low flow studies in Shipra River Basin, daily flow data for the period of 15 years from 1990 to 2005 of Ujjain site has been analyzed.

2.2.4 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. Stream flow data are normally specified in terms of the magnitude of low flow for a given time interval within a year or a season. The flow duration

curve shows graphically the relationship between any given discharge and the percentage of time the discharge exceed. In other words, it is cumulative frequency curve that shows the percentage of time during which the specified discharge were equaled or exceeded during the period of record. The curve can be drawn for daily or monthly flow data or for any consecutive N days or month period.

In the present study flow data of Ujjain G/d site on Shipra has been used to plot monthly flow duration curves using Weibulls Formula of cumulative probability as per steps given below.

- 1 Arrange the daily flow data on monthly basis.
- 2 Arranging the daily flow in each monthly data set in the descending order on the basis of runoff magnitudes
- 3 Ranking the set of data, $m = 1, 2, 3$, up to last rainfall records.
- 4 Determination of probability of exceedance

$$P = \frac{m}{N+1} \times 100$$

Flow Duration Curve can be plotted by plotting the graph between flow arranged in descending order and probability of exceedance. Once the Flow Duration Curve are plotted, the flow volumes at various probability levels at Ujjain site have been obtained from it. The dependable flows at 70, 75, 85, 90, 100% probability of exceedance of each station for all 12 months of the year have been obtained from the monthly flow duration curves. The flow volumes at 75 % probability were 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.

2.2.5 Standardized Precipitation Index (SPI)

The drought severity is expressed in terms of drought index. Drought indices are easily understood, it carry physical meaning and are sensitive to wide range of drought conditions. Drought indices are quantitative measures that characterize drought levels by assimilating data from one or several variables (indicators) such as precipitation and evapotranspiration into a single numerical value. Such an index is more readily useable than raw indicator data. The nature of drought indices reflects different events and conditions; they can reflect the climate dryness anomalies (mainly based on precipitation) or correspond to delayed agricultural and hydrological impacts such as soil moisture loss or lowered reservoir levels. Some of the worldwide used drought indices are Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Surface

Water Supply Index (SWSI), Standardized Precipitation Index (SPI), Normalized Difference Vegetation Index (NDVT).

In present study Standardized Precipitation Index (SPI) has been used to study the severity of droughts and their characteristics in Shipra basin. The SPI was designed to quantify the precipitation deficit for multiple timescales. These timescales reflect the impact of drought on the availability of the different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, stream flow and reservoir storage reflect the longer-term precipitation anomalies. For these reasons, McKee and others (1993) originally calculated the SPI for 1, 3, 6, 12, 24 and 48 month timescales. The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way; thus, wet periods can also be monitored using the SPI. The SPI values and its classification are given in Table 2.2.

Table 2.2: SPI classification and their values

2.0 +	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be termed as the drought's "magnitude".

2.2.6 SPI procedure and governing equations used

- (1) Calculation of the mean for the normalized precipitation values of the log-normal (Ln) rainfall series and compute the shape & scale parameter β and α respectively by the equation given here under

$$\text{Log mean: } \bar{X}_{ln} = \frac{\sum \ln x}{N}$$

$$\text{Shape parameter: } \beta = \frac{1}{4U} \left[1 + \sqrt{\frac{4U}{3}} \right]$$

$$\text{Scale parameter: } \alpha = \frac{\bar{x}}{\beta}$$

Here U is the constant $U = \ln(\bar{X}) - \bar{X}_{ln}$

(2) The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in equation. The cumulative probability as given by Gamma distribution as follows

$$G(x) = \frac{1}{\alpha^\beta \Gamma\beta} \int_0^x x^{\beta-1} e^{-\frac{x}{\alpha}} dx$$

Letting $t = \frac{-x}{\alpha}$, this equation becomes the incomplete gamma function;

$$G(x) = \frac{1}{\Gamma\beta} \int_0^{t\alpha} t^{\beta-1} e^{-t} dt$$

Since the gamma function is undefined for $x=0$ and a precipitation distribution may contain zero, the cumulative probability becomes,

$$H(x) = q + (1 - q)G(x)$$

Where, q is the probability of a zero.

If m is the number of zeros in a precipitation time series, Thom (1966) states that q can be estimated by m/N . He used the tables of the incomplete gamma function to determine the cumulative probability $G(x)$. McKee et al. (1993) used an analytic method to determine the cumulative probability. The cumulative probability, $H(x)$, is then transformed to the standard normal random variable 'Z' with mean zero and variance one, which is the value of the SPI. The Z or SPI values is more easily obtained computationally using an approximation provided by Abramowitz and Stegun (1965) that converts cumulative probability to the standard normal random variable Z.

$$Z = SPI = - \left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \text{ For } 0 < H(x) \leq 0.5$$

$$Z = SPI = + \left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \text{ For } 0.5 < H(x) \leq 1.0$$

Where, $t = \sqrt{\ln \left\{ \frac{1}{(H(x))^2} \right\}}$ for $0 < H(x) \leq 0.5$

$$t = \sqrt{\ln \left\{ \frac{1}{(1.0 - H(x))^2} \right\}}$$
 for $0.5 < H(x) \leq 1.0$

$$c_0 = 2.515517, c_1 = 0.802853 \text{ and } c_2 = 0.010328$$

$$d_1 = 1.432788, d_2 = 0.189269 \text{ and } d_3 = 0.001308$$

The monthly rainfall data of 35 years of all eight rain gauge stations falling in Shipra River basin namely Dewas, Indore, Ujjain, Sanver, Badnagar, Khachrod, Mahidpur, Tarana from year 1972 to 2006 has been used to obtain SPI values on 1, 3, 6, 9 and 12 month timescales. The frequency and probability of occurrence of these events for all time scale have been analyzed.

2.3 Results and Discussion

2.3.1 Rainfall analysis and seasonal rainfall departure

From the analysis of rainfall data of eight raingauge stations in Shipra basin it was observed that the mean annual rainfall in Shipra river basin varies from 785 mm at Mhow to 998 at Dewas, which is indicative of wide variation in the rainfall distribution pattern over the basin. The mean annual rainfall of Shipra basin was estimated as 909 mm. The average monsoon rainfall in the basin has been estimated as 870 mm and non-monsoon rainfall 39 mm. The rainfall in the basin shows very high spatial variation i.e. 309 mm.

The results of departure analysis graphs of seasonal rainfall at eight raingauge stations of Shipra basin are prepared and analyzed. The seasonal rainfall departure graph for Indore and Ujjain are shown in Figure 2.2 and 2.3. The frequency of droughts evaluated from similar figures of all eight stations has been compiled and given in Table 2.3.

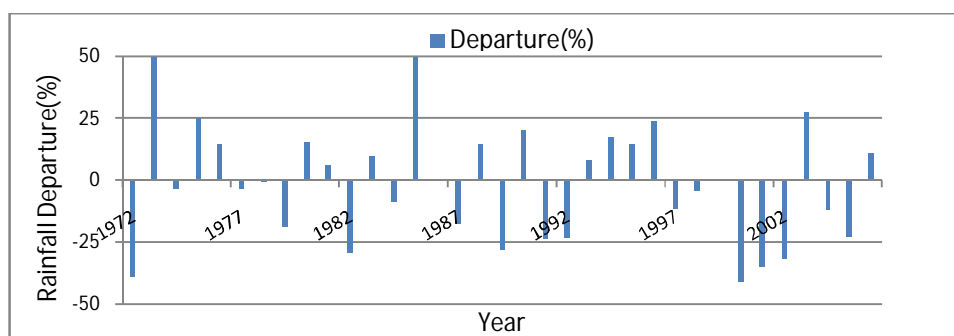


Figure 2.2: Seasonal Rainfall Departure (%) at Indore

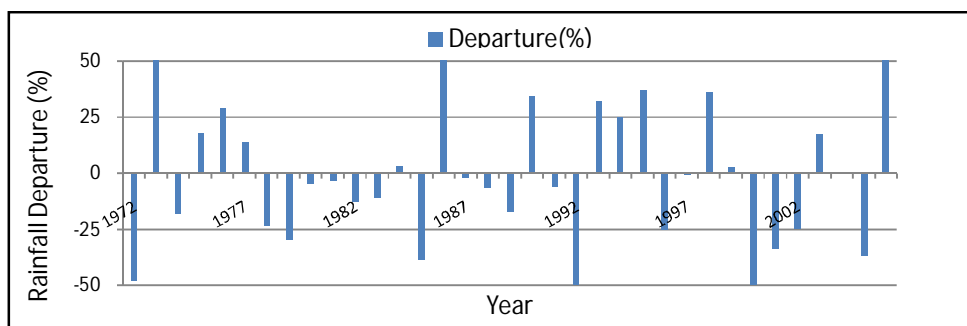


Figure 2.3: Seasonal Rainfall Departure(%) at Ujjain

Table 2.3: Frequency of drought years in Shipra river basin for seasonal rainfall

Sl. No.	Name of Station	Mean seasonal rainfall (mm)	Average drought frequency	Years with more than 25% deficiency in annual rainfall
1	Dewas	935	1 in every 3 to 4 yr	1979,1982,1985, 1989, 1992, 2000, 2001, 2004, 2005
2	Indore	941	1 in every 5 to 6 yr	1972,1982, 1989, 2000, 2001, 2002
3	Ujjain	867	1 in every 3 to 4 yr	1972, 1979, 1985,1992,1996, 2000, 2001, 2002, 2002, 2005
4	Sanver	862	1 in every 3 to 4 yr	1972, 1979, 1980, 1981,1982, 1983, 1991, 1992, 2000, 2001
5	Badnagar	820	1 in every 5 yr	1972, 1982, 1985, 1989, 2000, 2001, 2005
6	Khachrod	873	1 in every 3 to 4 yr	1979, 1982, 1985, 1987, 1989, 1991, 2000,2001, 2002, 2005
7	Mahidpur	857	1 in every 2 to 3 yr	1972,1979,1980,1981,1982, 1983, 1984, 1985, 1987, 1989, 1987, 1989, 2000,2001,2002
8	Tarana	886	1 in every 3 to 4 yr	1972, 1979, 1980, 1982, 1985, 1989, 1992, 2000, 2002, 2005

The seasonal rainfall departure analysis shows that average drought frequency was highest in Mahidpur and lowest in Indore. At Mahidpur the departure analysis indicated the one drought year after every 2 to 3 years. Droughts have also been seen evident at Dewas, Ujjain, Sanver, Khachrod and Tarana where observed 1 drought year after every 3 to 4 years. Whereas Badnagar and Indore were seems to be in better condition where observed 1 drought year after every 5 to 6 years. From the analysis it was observed that, major portion of Shipra basin experienced one

drought year after every 3 to 4 years which is rather an alarming situation from water resources management point of view. The seasonal rainfall departure analysis shows that in the year 1972 total 6 stations of the basin have faced drought condition and about 75% area of the basin were under drought. Similarly in 1985 around 6 stations of the basin leading to 75% of the area was affected due to drought, whereas in 2000, all the stations were subjected to drought conditions. Thus it could be seen that during years 1972, 1985 and 2000 the Shipra basin was covered under drought condition.

2.3.2 Probability distribution of annual rainfall

The probability distribution curves have been plotted for all the stations in the Shipra basin using annual rainfall data of all eight stations. The results of typical probability distribution curves at Indore and Ujjain are shown in Figure 2.4 and 2.5. The similar probability curves developed for eight stations were used to determine the probability of occurrence of 75% of normal values at all these stations as given in Table 2.4.

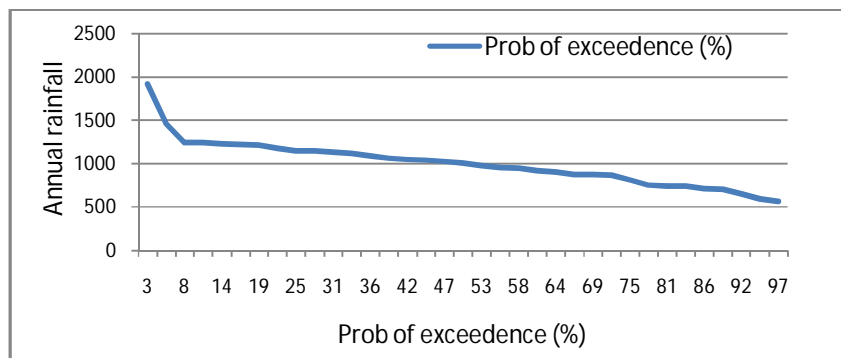


Figure 2.4: Probability distribution curves at Indore

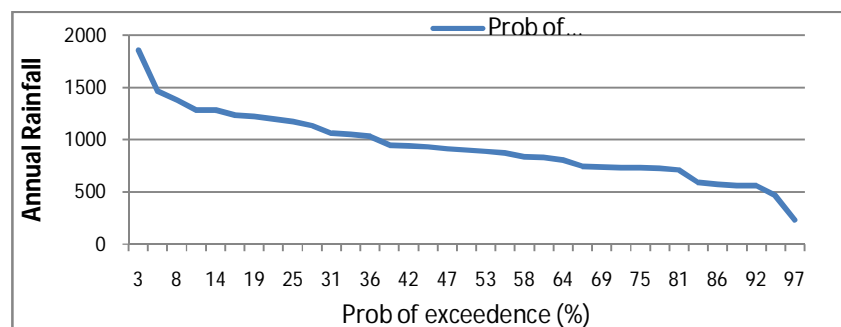


Figure 2.5: Probability distribution curves at Ujjain

Table 2.4: Probability of occurrence of 75% of normal rainfall

Sl. No.	Name of station	Mean annual rainfall (in mm)	RF at 75% probability level	Probability of occurrence of 75% of normal (%)	Status
1	Dewas	998	733	78	DP
2	Indore	988	753	78	DP
3	Ujjain	923	698	81	Not-DP
4	Sanver	905	671	74	DP
5	Badnagar	862	658	74	DP
6	Khachrod	903	662	71	DP
7	Mahidpur	890	644	62	DP
8	Tarana	925	712	74	DP

(DP: Drought Prone)

From the Table 2.4, the probability distribution analysis of annual rainfall it was observed that the probability of occurrence of rainfall equivalent to 75% of the normal annual rainfall in different stations of the basin varies from 62% to 81%. The average value of probability of occurrence of rainfall equivalent to 75% of normal for the Shipra basin as a whole was estimated about 74%. From the analysis it was observed that 7 stations out of 8 in the basin can be considered to be drought prone as the probability of occurrence of rainfall equivalent to 75% of normal annual rainfall was less than 80%. Mahidpur was seen to be severely drought prone station. Only Ujjain was observed as non-drought prone station as the probability of occurrence was observed more than 80%.

2.3.3 Low flow analysis

In analyzing the stream flow drought, one of the simplest techniques is to construct a flow duration curve for the given river. With the help of these curves the probability of occurrence of flow at the selected site can be established, which is helpful for planning of water resources projects. Low flow analysis for flow data of Ujjain on monthly basis was carried out using flow duration curves approach. The monthly flow duration curves of April and August months are shown in Figure 2.6 and 2.7. From the analysis of flow duration curves of all 12 months, the dependable flow at 75, 80, and 90% probability of exceedance were obtained and are given in Table 2.5.

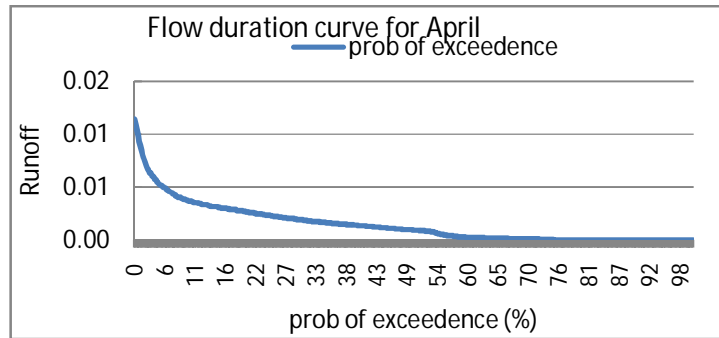


Figure 2.6: Flow duration curve for April

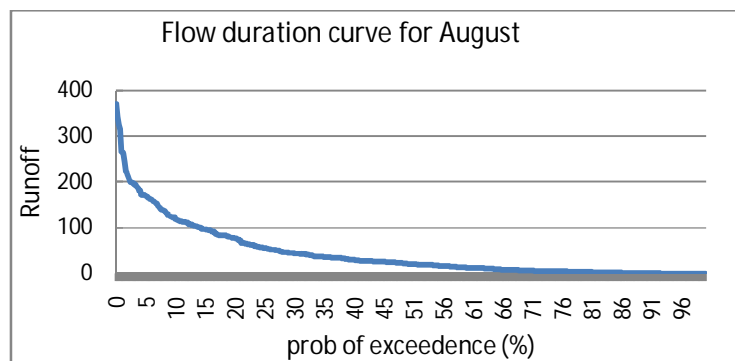


Figure 2.7: Flow duration curve for August

For the analysis of low flows in the flow regime, the derived dependable flow at 75% probability of exceedance was considered as a truncation level to obtain the low flow epoch. From the analysis of Table 2.5 showing derived truncation level at different dependability levels at site Ujjain on Shipra river, it was observed that the maximum 75% dependable flow was 5.09 m³/s in the month of August whereas the minimum 75% dependable flow was 0.0 during February to June. It indicates that the Shipra river has flow during monsoon season only and has no flow during lean period.

Analysis has also been carried out to obtain deficit volume and severity of low flow at Ujjain site and results are given in Table 2.6. It was observed that during 15 years, for flow data from 1990 to 2005 the river experienced 17 low flow events of different duration and severity. Hence it can be concluded that the Shipra river experience on an average one low flow event every year.

Table 2.5: Derived truncation level at different dependability levels at site Ujjain

Months	Volume in Cumec		
	At 75% dependability	At 80% dependability	At 90% dependability
January	0.01	0	0
February	0	0	0
March	0	0	0
April	0	0	0
May	0	0	0
June	0	0	0
July	0.48	0.19	0
August	5.09	3.58	1.16
September	4.19	2.81	0.02
October	0.67	0.18	0
November	0.08	0.02	0
December	0.01	0	0

Table 2.6: Severity of low flow and its duration at site Ujjain (Flow data of period from January 1990 to December 2005)

Sl. No.	Event	Onset of Event	Termination of Event	Severity (MCM)	Duration (days)
1	1st	01/01/1990	31/01/1990	0.03	31
2	2nd	11/08/1991	21/08/1991	2.15	11
3	3rd	18/09/1991	30/09/1991	1.26	13
4	4th	01/07/1992	14/07/1992	0.55	14
5	5th	14/09/1992	08/10/1992	5.86	25
6	6th	22/10/1992	31/01/1993	0.76	102
7	7th	01/07/1996	20/07/1996	0.83	20
8	8th	24/08/1999	02/09/1999	3.07	10
9	9th	31/07/2000	10/08/2000	4.06	11
10	10th	31/08/2000	31/01/2000	11.28	154
11	11th	23/08/2001	31/01/2002	15.8	162
12	12th	08/07/2002	18/07/2002	0.34	11
13	13th	01/07/2004	17/07/2004	0.62	17
14	14th	01/07/2005	26/07/2005	1.06	26
15	15th	12/08/2005	07/09/2005	7.72	27
16	16th	27/09/2005	30/11/2005	2.35	65
17	17th	06/12/2005	31/12/2005	0.22	26

From the analysis it was seen that the severity of low flow at Ujjain varies from 0.026 to 15.8 MCM and duration of low flow epoch ranges from 11 to 162 days. The year 2005 experienced maximum four events of low flows with total severity of 11.347 MCM and total duration of 144 days. The maximum severity with 15.8 MCM for 162 days duration has been observed during

2001 to 2002. Therefore it can be concluded that 2001 and 2005 were years of significant deficit runoff volume at Ujjain.

2.3.4 Standardized Precipitation Index (SPI)

The monthly rainfall data of 35 years from 1972 to 2005 of all 8 raingauge station of Shipra basin was used to evaluate SPI on five timescales 1, 3, 6, 9 and 12 month. The SPI graphs for Dewas stations for 1, 3, 6, 9 and 12 month timescales are shown in Figures 2.8 to 2.12. The evaluated SPI values at Dewas station on different time scales were categorized based on their severity and their frequency and probability have been worked out as given in Table 2.7 to 2.11.

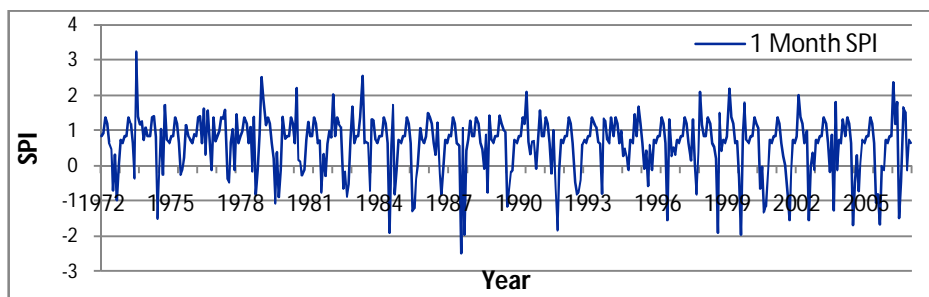


Figure 2.8: Graph showing 1-month SPI at Dewas

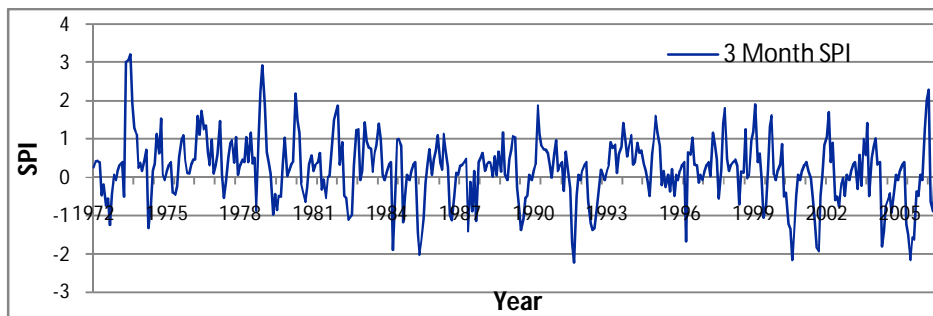


Figure 2.9: Graph showing 3-month SPI at Dewas

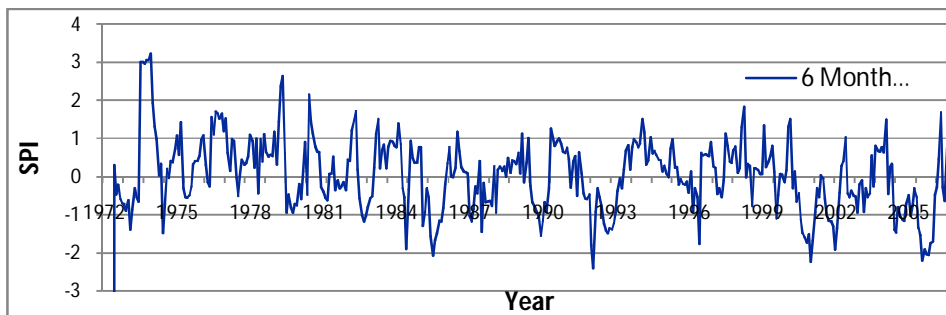


Figure 2.10: Graph showing 6-month SPI at Dewas

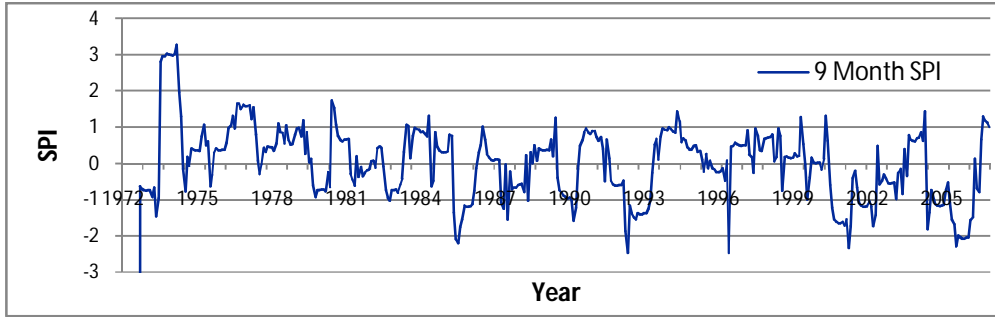


Figure 2.11: Graph showing 9-month SPI at Dewas

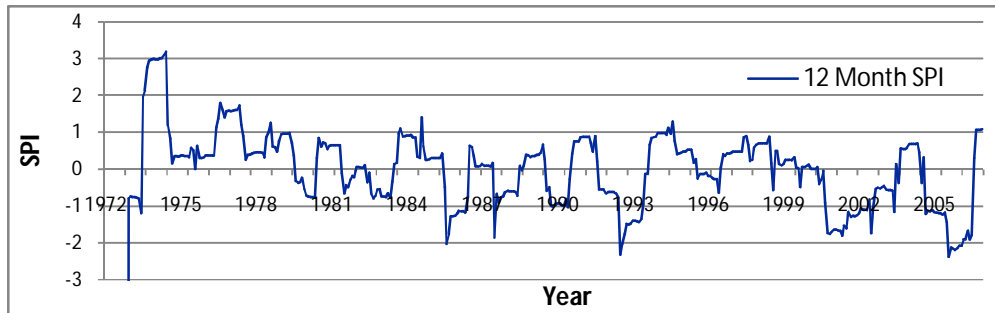


Figure 2.12: Graph showing 12-month SPI at Dewas

Table 2.7: 1-Month SPI at Dewas

SPI	Category	Number of time in given period	Severity of event	Probability (%)
2 and above	Extremely Wet	10	1 in 42	2.38
1.5 to 1.99	Severely Wet	16	1 in 26	3.81
1.00 to 1.49	Moderately Wet	101	1 in 4	24.05
0.99 to -0.99	Near Normal	272	1 in 2	64.76
-1.0 to -1.49	Moderate Dry	9	1 in 47	2.14
-1.5 to -1.99	Severely Dry	11	1 in 38	2.62
-2 or less	Extremely Dry	1	1 in 420	0.24

Table 2.8: 3-Month SPI at Dewas

SPI	Category	Number of time in given period	Severity of event	Probability (%)
2 and above	Extremely Wet	9	1 in 46	2.14
1.5 to 1.99	Severely Wet	14	1 in 30	3.33
1.00 to 1.49	Moderately Wet	43	1 in 10	10.24
0.99 to -0.99	Near Normal	316	1 in 1	75.24
-1.0 to -1.49	Moderate Dry	21	1 in 20	5.00
-1.5 to -1.99	Severely Dry	11	1 in 38	2.62
-2 or less	Extremely Dry	4	1 in 105	0.95

Table 2.9: 6-Month SPI at Dewas

SPI	Category	Number of time in given period	Severity of event	Probability (%)
2 and above	Extremely Wet	9	1 in 46	2.14
1.5 to 1.99	Severely Wet	14	1 in 30	3.33
1.00 to 1.49	Moderately Wet	33	1 in 13	7.86
0.99 to -0.99	Near Normal	303	1 in 1	72.14
-1.0 to -1.49	Moderate Dry	35	1 in 12	8.33
-1.5 to -1.99	Severely Dry	15	1 in 28	3.57
-2 or less	Extremely Dry	6	1 in 69	1.43

Table 2.10: 9-Month SPI at Dewas

SPI	Category	Number of time in given period	Severity of event	Probability (%)
2 and above	Extremely Wet	9	1 in 46	2.14
1.5 to 1.99	Severely Wet	11	1 in 37	2.62
1.00 to 1.49	Moderately Wet	24	1 in 17	5.71
0.99 to -0.99	Near Normal	297	1 in 1	70.71
-1.0 to -1.49	Moderate Dry	39	1 in 11	9.29
-1.5 to -1.99	Severely Dry	21	1 in 20	5.00
-2 or less	Extremely Dry	11	1 in 37	2.62

Table 2.11: 12-Month SPI at Dewas

SPI	Category	Number of time in given period	Severity of event	Probability (%)
2 and above	Extremely Wet	11	1 in 37	2.62
1.5 to 1.99	Severely Wet	10	1 in 40	2.38
1.00 to 1.49	Moderately Wet	15	1 in 27	3.57
0.99 to -0.99	Near Normal	301	1 in 1	71.67
-1.0 to -1.49	Moderate Dry	42	1 in 10	10.00
-1.5 to -1.99	Severely Dry	20	1 in 20	4.76
-2 or less	Extremely Dry	10	1 in 41	2.38

Similar analysis was carried out for all eight stations of the basin and was summarized and probability of occurrence of different time scale SPI at these stations under different categories depicting drought severity such as near normal, moderately dry, severely dry and extremely dry are given in Table 2.12 to 2.15.

From Table 2.12 it was observed that in case of 1-Month SPI probability of near normal events was highest at Indore i.e. 79.76% and was lowest 62.62% at Badnagar, whereas in case of 12-Month SPI the probability was observed 72.38% at Indore and is lowest 60.71% at Mahidpur. From above table it can be concluded that probabilities of occurrence of near normal events were highest at Indore station for almost all time scale. It can also be concluded that probabilities of occurrence of near normal events for SPI of all time scale was seen more than 60% at all the stations.

Table 2.12: Probability of occurrence of near normal events (%)

Station	SPI 1	SPI 3	SPI 6	SPI 9	SPI 12
Dewas	64.76	75.24	72.14	70.71	71.67
Indore	79.76	74.52	70.95	72.86	72.38
Ujjain	77.38	75.24	69.29	69.76	65.71
Sanver	58.57	78.81	73.10	69.29	70.95
Badnagar	62.62	75.00	70.48	68.81	69.29
Khachrod	63.57	74.52	69.52	67.38	66.43
Mahidpur	63.81	76.67	70.71	65.24	60.71
Tarana	57.86	75.95	68.81	63.81	65.48

Table 2.13: Probability of occurrence of Moderate dry events (%)

Station	SPI 1	SPI 3	SPI 6	SPI 9	SPI 12
Dewas	2.14	5.00	8.33	9.29	10.00
Indore	2.86	8.10	9.76	11.19	11.19
Ujjain	3.81	5.48	9.05	7.86	8.81
Sanver	2.14	3.57	7.62	10.71	7.38
Badnagar	5.00	5.24	8.81	5.71	4.29
Khachrod	4.05	4.76	8.57	8.57	9.05
Mahidpur	4.29	6.19	10.00	13.81	18.33
Tarana	2.86	5.00	9.76	13.81	11.90

From Table 2.13 it was observed that in case of 1-Month SPI probability of moderate dry events was highest 4.29% at Mahidpur and lowest 2.14% at Dewas and Sanver, whereas in 12-Month SPI it was seen that the highest probability was 18.33% at Mahidpur and lowest 4.29% at Badnagar. From above table it could be concluded that the probability of occurrence of moderate dry events was high at Mahidpur station for almost all SPI of different time scale.

From Table 2.14 we observed that in SPI 1 probability of severely dry events was highest 2.62% at Dewas and lowest 1.43% at Indore, Ujjain and Mahidpur, whereas in SPI 12 we can see highest probability was 5.71% in Sanver and lowest 1.43% at Tarana. From above table we

concluded that the probability of occurrence of severely dry events was maximum at Dewas station.

Table 2.14: Probability of occurrence of Severely dry events (%)

Station	SPI 1	SPI 3	SPI 6	SPI 9	SPI 12
Dewas	2.62	2.62	3.57	5.00	4.76
Indore	1.43	2.38	5.24	4.76	4.76
Ujjain	1.43	2.38	5.24	4.76	4.76
Sanver	1.90	1.90	3.10	3.81	5.71
Badnagar	2.14	0.95	2.62	3.57	2.86
Khachrod	1.67	3.10	3.10	5.71	7.14
Mahidpur	1.43	1.90	2.86	3.57	1.67
Tarana	2.14	2.86	3.10	2.38	1.43

Table 2.15: Probability of occurrence of extremely dry events (%)

Station	SPI 1	SPI 3	SPI 6	SPI 9	SPI 12
Dewas	0.24	0.95	1.43	2.62	2.38
Indore	0.95	1.19	1.67	1.67	1.67
Ujjain	0.48	0.95	0.95	1.90	1.90
Sanver	0.48	1.67	1.67	1.90	0.48
Badnagar	0.24	2.38	2.86	4.76	5.24
Khachrod	0.95	1.43	2.62	2.62	0.95
Mahidpur	0.48	0.95	0.95	0.71	0.00
Tarana	0.48	1.19	1.67	2.62	2.62

From Table 2.15 we observed that in SPI 1 probability of extremely dry events was highest 0.95% at Indore and Khachrod and lowest 0.24% at Dewas and Badnagar, whereas in SPI 12 we can see highest probability 5.24% at Badnagar and lowest 0% at Mahidpur. From above table we concluded that probability of occurrence of extremely dry events is maximum at Badnagar station.

2.4 Conclusions

- The mean annual rainfall of Shipra River basin is 909 mm. The drought frequency analysis indicated that approximately one out of every three to four year is a drought year, which needs to be taken care while planning for irrigation and other water resources development projects in the basin.
- The year 1972, 2000 and 2001 were most severe drought years as most of the area of the Shipra basin was under drought as revealed from the annual and seasonal rainfall departure analysis.
- As the probability of occurrence of rainfall equivalent to 75% of normal rainfall is less than 80% for most of the stations, the whole Shipra basin can be categorized as drought prone area.

- The low flow analysis indicated that, the river experiences maximum 75% dependable flow in the month of August whereas minimum 75% dependable flow during February to June. The severity of low flow varies from 0.026 to 15.8 MCM at Ujjain and the duration of low flow epoch ranges from 11 to 162 days and Shipra river experiences on an average one low flow situation every year.
- SPI analysis indicated that moderate dry, severely dry and extremely dry events were generally more in 6 Month SPI, 9 Month SPI and 12 Month SPI as compared to 1 Month SPI and 3 Month SPI where wet events were more. From the overall analysis of SPI values at all eight stations in Shipra basin, particularly for 3-Month, 6-Month and 12-Month SPI it could be seen that the 'Severely dry events' and 'Extremely Dry events' are showing relevance with the drought identified using departure analysis.
- Mahidpur station has observed very high drought frequency i.e. one drought year in every 2 to 3 years. It also found the severe drought prone station. From the SPI-12 basis it could be seen that the Mahidpur was found mostly prone to moderate drought events however it did not experience any extreme drought.

CHAPTER 3

RAINFALL RUNOFF MODELLING

3.1 Rainfall Runoff Modelling

Rainfall runoff modeling forms an important component of hydrological studies and plays an essential character in water resource planning and management of river basins. The widely known rainfall-runoff models are the rational method (Mcpherson 1969), Soil Conservation Services (SCS) Curve Number method (Maidment 1993), and Green-Ampt method (Green and Ampt 1911). Nash (1958) prepared a conceptual rainfall runoff models by routing a unit inflow through the reservoirs.

In the present study, for development of DSS applications, a river basin model of Shipra basin has been prepared using MIKE BASIN with all hydrological information like discharge and groundwater levels, rainfall data, demographic information for demand estimation and various features like dams, diversions, users, etc. In this exercise the simulation of discharge or runoff from ungauged sub-basin was one of the important aspects for further analysis. Thus the rainfall runoff modeling has been carried out in Shipra basin at the locations where the observed discharge data was available. Once the model was developed and found suitable for the basin, it can be used for simulation of runoff in other sub-basin. In present study rainfall-runoff modeling has been carried out using MIKE 11 NAM Model in Shipra River basin using observed flow data of Ujjain G/D site. The catchment area of Shipra river basin up to Ujjain is 2102 km². The map showing view of Shipra river basin, catchment area up to Ujjain, its Thiessen polygon map, location of rain gauge station and gauge discharge sites is shown in Figure 3.1.

3.2 NAM Rainfall runoff model

NAM is the abbreviation of the Danish “Nedbor-Afstromnings-model”, meaning precipitation-runoff-model. MIKE11 NAM is professional engineering software developed by Danish Hydraulic Institute (DHI), Denmark. It is deterministic, lumped and conceptual 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). The physical processes involved for runoff simulation in the model are shown in Figure 3.2. Fleming (1975); Kjelstrom and Moffat (1981); Kjelstrom (1998), Arcelus (2001), Shamsudin and Hashim (2002) and many other researchers have carried out rainfall runoff modeling studies using MIKE 11 NAM model. The NAM model was successfully used for runoff simulation from the ungauged catchments in DSS(P) model under Hydrology Project phase II.

NAM is prepared with 9 parameters, representing surface zone, root zone and ground water storage as shown in Figure 3.2. U_{max} denotes the upper limit of the amount of water in the surface 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 . L_{max} denotes the upper limit of the amount of water in this storage. Evapotranspiration demands are first met at the potential rate from the surface storage. When the surface storage, U 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.

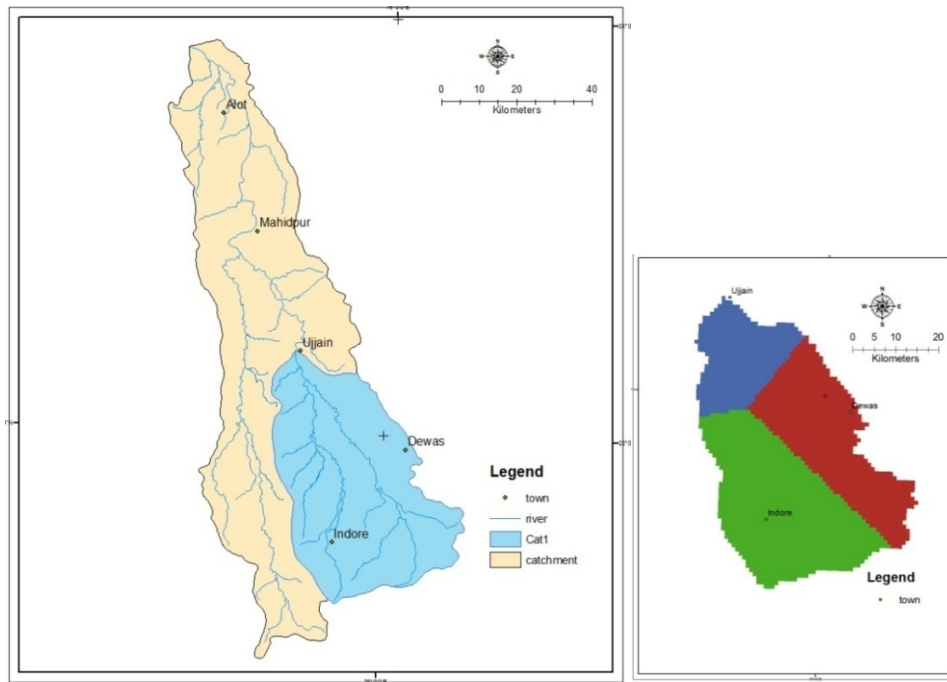


Figure 3.1: Catchment area up to Ujjain G/d site and its Thiessen polygon map

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. 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. The amount of infiltrating water, G recharging the groundwater storage depends on the soil moisture content in the root zone. The base flow, BF from the groundwater storage is calculated as the outflow from a linear reservoir with time constant C_{KBF} .

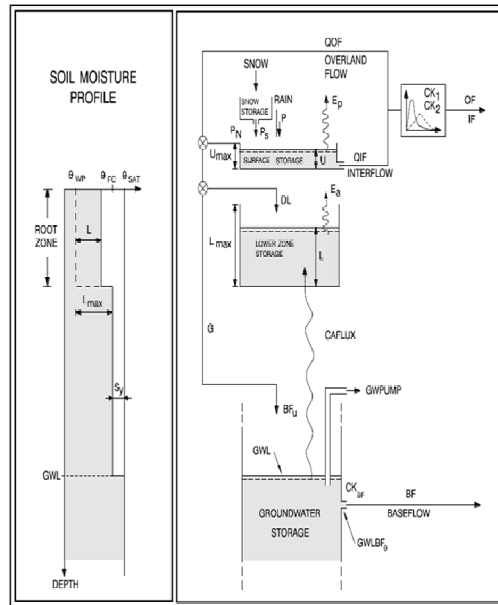


Figure 3.2: Process of NAM Model

3.3 Model Set up

MIKE 11 NAM model was setup to carry out rainfall runoff modeling in Shipra river sub-basin at Ujjain G/d site. The input data required for modelling was rainfall, observed discharge, potential evapotranspiration and boundary conditions. The daily rainfall data of five influencing raingauge stations Ujjain, Indore, Dewas, Mhow and Sanver was used to develop the model. The daily observed discharge data of Ujjain G/d site for the period of 11 years from 1996 to 2006 was used for the model calibration and validation purposes. The daily discharge data of Ujjain G/d was collected from Chambal Division, CWC, Jaipur. The average monthly potential evapotranspiration values of Indore station were used in the model. The NAM parameters were applied and model was then calibrated, validated and tested for assessing its suitability in selected sub-basin.

3.4 Potential Evapotranspiration (ET_0)

Estimation of evapotranspiration rates is important in rainfall runoff modeling for determining expected rates of stream discharge. In the present study the potential evapotranspiration (ET_0) has been estimated using CROPWAT 8.0 software which make use of Modified Penman Method (1963). The ET_0 (mm/day), on monthly basis was calculated based on long term meteorological data of Indore IMD observatory such as air temperature, wind velocity, relative humidity, sun shine hours and radiation. The estimated monthly ET_0 for Shipra basin is given in Table 3.1 and monthly ET distribution is shown in Figure 3.3. From the analysis of Table and Figure it can be seen that, the potential evapotranspiration of the study area has been observed highest in the

month of April (201.0 mm) and May (230.64 mm) and lowest during January (97.96 mm) and December (114.32 mm).

Table 3.1: Estimation of monthly *ET_o* for Shipra basin and average values of climatic data (Station: Indore, Altitude: 545 m, Latitude: 22.43 °N, Longitude: 75.49 °E)

Month	Min Temp °C	Max Temp °C	Humidity %	Wind Speed km/day	Sunshine Hours	Radiation MJ/m ² /day	ET _o mm/day	Monthly Total ET _o (mm)
JAN	11.0	25.7	70	56	8.6	16.6	3.16	97.96
FEB	12.1	29.5	67	72	10.1	20.6	4.11	115.08
MAR	16.6	34.2	68	93	10.7	23.9	5.26	163.06
APR	22.2	40.0	68	136	11.4	26.6	6.70	201.0
MAY	25.6	42.5	70	184	11.5	27.3	7.44	230.64
JUNE	26	39.0	74	243	9.6	24.4	6.53	195.9
JULY	23.1	30.5	82	223	5.7	18.4	4.27	132.37
AUG	23.5	30.1	84	191	4.9	16.9	3.81	118.11
SEPT	22.5	30.6	81	116	5.8	17.2	3.89	116.7
OCT	20.8	33.0	74	69	8.1	18.5	4.38	135.78
NOV	15.5	30.3	70	56	9.0	17.5	3.87	116.1
DEC	10.5	29.3	66	47	10.4	18.0	3.72	114.32

The rate of Potential evapotranspiration has been observed highest in the month of May i.e. 7.44 mm/day and lowest in the month of January i.e. 3.16 mm/day. From the analysis it was observed that the total annual *ET_o* in the study area is 1738 mm and the *ET_o* during monsoon and non-monsoon seasons were 503 mm and 1235 mm respectively.

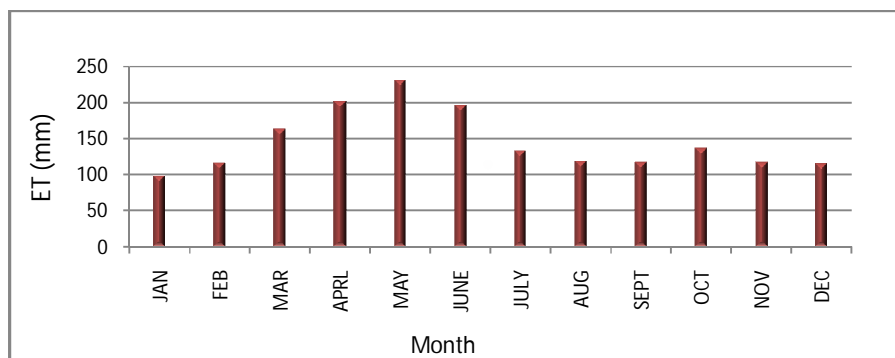


Figure 3.3: Monthly ET distribution in Shipra basin

3.5 Model calibration

Calibration is the process 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 modelling and it is understood that every hydrologic model should be tested against observed data, preferably from the watershed under study, to understand the level of reliability of the model (Linsley1982). NAM model was calibrated for 6 years period from 1996 to 2001. The model output simulation results during calibration were checked for coefficient of determination (R^2) value and graphically analyzed for degree of agreement between simulated and observed runoff. The model parameters were again adjusted one by one using trial and error method to obtain the set of best fit model parameters.

3.6 Model validation

Model validation means judging the performance of the calibrated model over the portion of historical records which have not been used for the calibration. It tests the ability of model to estimate runoff for the periods other than those used for the calibration process. Thus the validation data must not be the same as those used for calibration but must represent a situation similar to that in which the model is to be applied operationally. Once the model was calibrated as discussed above, the NAM model was then validated for the remaining period of 5 years from 2002 to 2006. During validation the set of model parameters obtained during the calibration were used to simulate runoff. The output of the model was checked to verify the capability of the model to simulate the runoff for the extended period of time.

3.7 Results and Discussion

Once the MIKE 11 NAM rainfall runoff model was set, the model was run to simulate discharge using input information and model was calibrated to obtain best match between observed and simulated discharge. The simulation statistics of hydrological components obtained during model calibration is given in Table 3.2. Once the MIKE 11 NAM rainfall runoff model was set, the values of model parameters were finalized during the model calibration and are given in Table 3.3.

Table 3.2: Model calibration result showing water balance

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* * RAINFALL RUNOFF SIMULATION * * PARAMETER FILE : Model.rr11 * * SIMULATION DATE : 8-FEB-2016 13:12:04 * * *****													
SIMULATED PERIOD : From: 1996/ 1/ 1 12:00 To: 2001/11/30 12:00													
TIMESTEP : 24.00 HOURS													
(Accumulated values in mm)													
Catchment: MODEL, Area= 2102.00 km2													
Period	Q-obs	Q-sim	%diff	Rainfall	PotEvap	ActEvap	CapFlux	Recharge	Pumping	Irrig.	OF	IF	BF
1996/ 1/ 1 - 1997/ 1/ 1	374.1	376.3	-0.6	1070.2	1775.5	611.1	0.0	75.2	0.0	0.0	286.1	20.7	69.4
1997/ 1/ 1 - 1998/ 1/ 1	217.4	215.5	0.9	1069.6	1670.5	800.1	0.0	14.6	0.0	0.0	191.9	4.3	19.3
1998/ 1/ 1 - 1999/ 1/ 1	184.2	178.1	3.3	947.0	1738.2	817.8	0.0	5.8	0.0	0.0	169.7	2.2	6.2
1999/ 1/ 1 - 2000/ 1/ 1	141.0	142.9	-1.4	985.2	1751.4	831.3	0.0	0.0	0.0	0.0	142.2	0.0	0.8
2000/ 1/ 1 - 2001/ 1/ 1	24.6	35.5	-43.9	557.4	1743.4	595.5	0.0	0.0	0.0	0.0	35.5	0.0	0.0
2001/ 1/ 1 - 2001/11/30	60.8	59.4	2.4	582.6	1535.9	501.2	0.0	0.0	0.0	0.0	59.4	0.0	0.0
1996/ 1/ 1 - 2001/11/30	1002.2	1007.6	-0.5	5212.0	10215.0	4157.0	0.0	95.7	0.0	0.0	884.7	27.3	95.7
Coefficient of determination: R2 = 0.720													

Table 3.3: Final calibrated model parameters value and range of the NAM Model

Parameter	Description	Parameter Range	Parameter Value
U_{max}	Maximum water content in surface storage	10 – 40	20
L_{max}	Maximum water content in lower zone/root storage	100 – 480	280
C_{QOF}	Overland flow coefficient	0.1 – 1.0	0.61
C_{KIF}	Interflow drainage constant	200 – 1000	827
C_{K1K2}	Time constant for overland flow and interflow	10 – 50	9.5
T_{OF}	overland flow threshold	0 – 0.99	0.004
T_{IF}	Interflow threshold	0 – 0.99	0.98
TG	Groundwater recharge threshold	0 – 0.99	0.984
C_{KBF}	Timing constant for base flow	300 – 4000	1200

The coefficient of determination (R^2) value during model calibration was observed as 0.72, indicating the good agreement between the simulated and observed catchment runoff in terms of the peak flows with respect to timing, rate and volume. The difference in Q-observed and Q-simulated was reasonable i.e. -0.5 %, which shown good match between the observed and simulated runoff values. The resultant graphs presenting comparison between observed and simulated discharge are shown in Figures 3.4 and 3.5 below which gives the idea and view of match obtained during the RR Model Calibration. The beginning and termination of observed and simulated flow events were matching well. In case of amplification i.e. peaks flows, the model seems to be not predicting well. The double mass curve during calibration period showing

comparison between accumulated observed and accumulated simulated runoff has been presented in Figure 3.6.

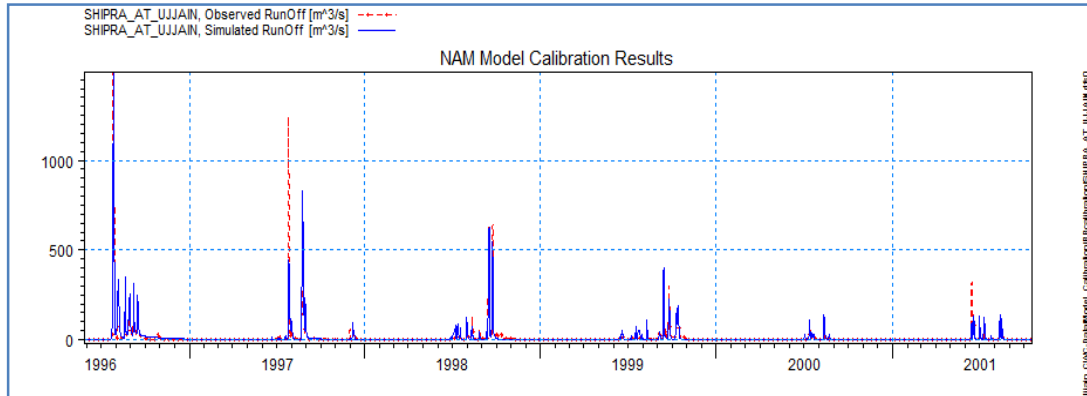


Figure 3.4: Comparison between observed and simulated discharge for calibration

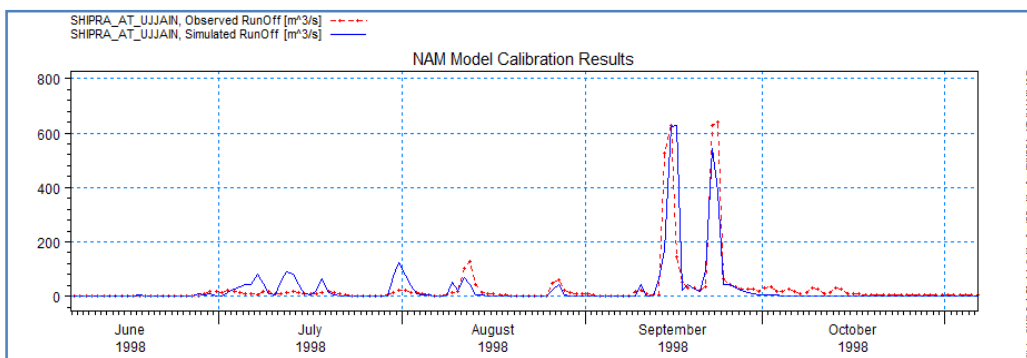


Figure 3.5: Comparison between observed and simulated discharge for calibration for 1998

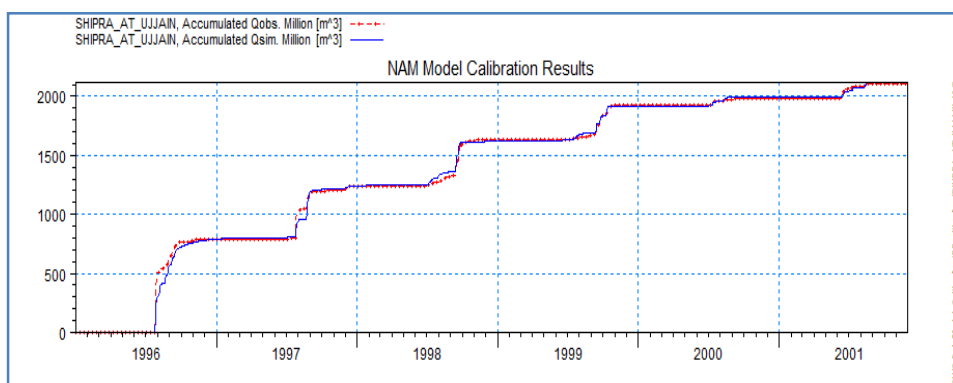


Figure 3.6: Double mass curve during calibration period

The graph showing comparison of the observed and simulated annual runoff depth during calibration is shown in Figure 3.7. It was observed that the observed and simulated annual runoff depths were matching perfectly.

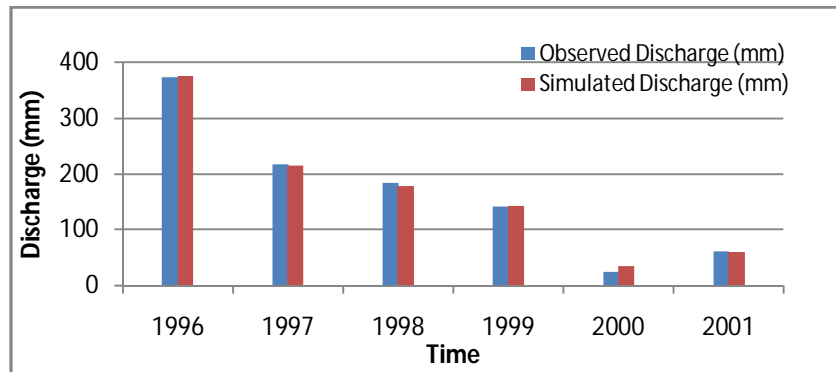


Figure 3.7: Comparison of the observed and simulated annual runoff during Calibration

Once the model was calibrated and set of model parameters were obtained, the model was validated to check its performance for the remaining period. The simulation statistics of hydrological components obtained during model validation is given in Table 3.4. Comparison between observed and simulated discharge for validation are shown in Figure 3.8 and 3.9.

Table 3.4: Simulation statistics of hydrological components obtained during model validation

```

File Edit Format View Help
*****
*
*   RAINFALL RUNOFF SIMULATION
*   PARAMETER FILE       : Model.rr11
*   SIMULATION DATE      : 8-FEB-2016 13:16:16
*
*****

SIMULATED PERIOD : From: 2002/ 1/ 1 12:00 To: 2006/11/30 12:00
TIMESTEP       : 24.00 HOURS
(Accumulated values in mm)
Catchment: MODEL, Area= 2102.00 km2
-----
Period          | Q-obs  Q-sim  %diff  | RainFall  Potevap  ActEvap  CapFlux  Recharge  Pumping  Irrig.  OF  IF  BF
-----
2002/ 1/ 1 - 2003/ 1/ 1 | 90.8  109.9  -21.0  | 736.4  1717.2  580.7    0.0      0.0      0.0     0.0  109.9  0.0  0.0
2003/ 1/ 1 - 2004/ 1/ 1 | 168.8 357.6 -111.9 | 1100.1 1688.9  701.0    0.0     67.9    0.0     0.0  292.1  6.7  58.7
2004/ 1/ 1 - 2005/ 1/ 1 | 134.7 140.1  -4.0   | 813.5  1717.0  694.3    0.0      0.0     0.0     0.0  130.9  0.0  9.2
2005/ 1/ 1 - 2006/ 1/ 1 | 91.9  104.8  -14.0  | 676.3  1743.9  585.6    0.0      0.0     0.0     0.0  104.8  0.0  0.0
2006/ 1/ 1 - 2006/11/30 | 356.1 596.2 -67.4  | 1373.0 1633.0  698.4    0.0    176.0    0.0     0.0  434.0 12.7 149.5
-----
2002/ 1/ 1 - 2006/11/30 | 842.3 1308.6 -55.4 | 4699.3 8500.0 3260.0    0.0    243.9    0.0     0.0 1071.8 19.5 217.4
-----
Coefficient of determination: R2 = 0.502

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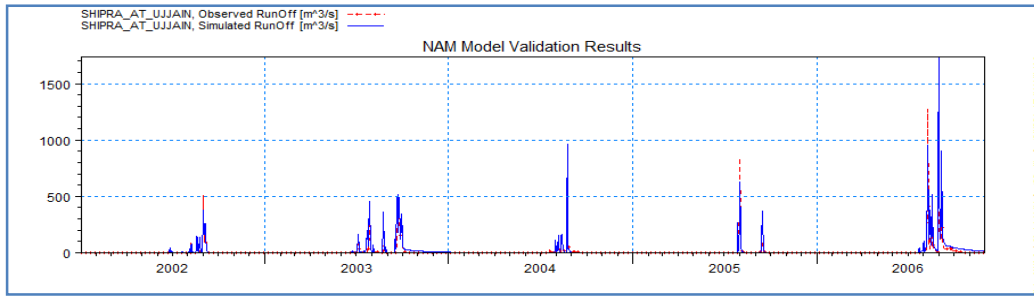


Figure 3.8: Comparison between observed and simulated discharge for validation

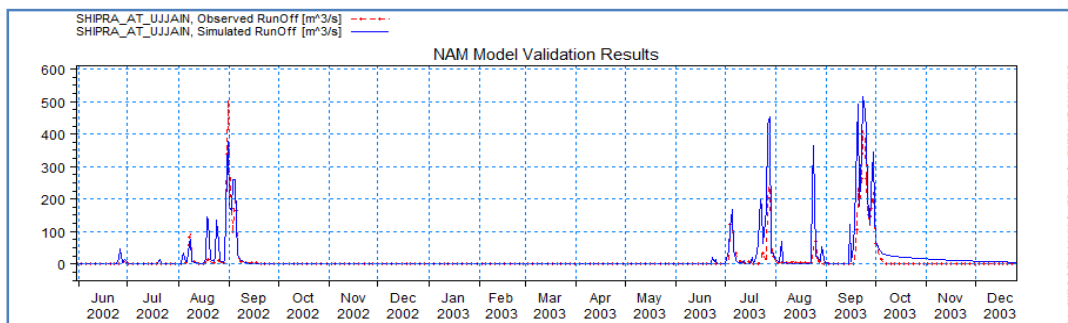


Figure 3.9: Comparison between observed and simulated discharge for validation for 2003

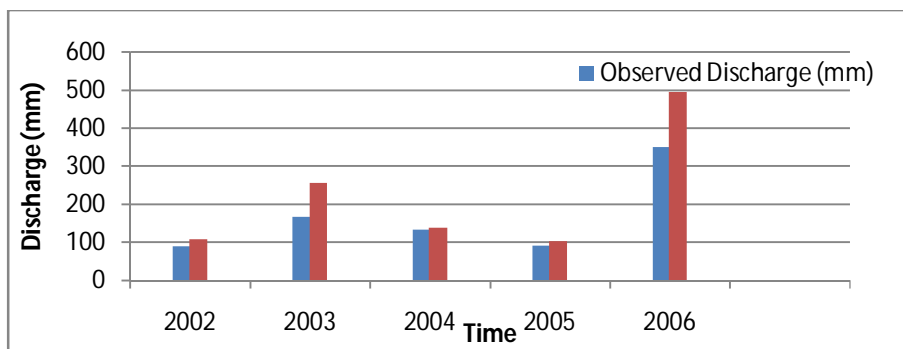


Figure 3.10: Comparison of the observed and simulated annual runoff during Calibration

The coefficient of determination for the validation process of the model was observed as 0.502, indicating moderate agreement between the simulated and observed catchment runoff. The difference in Q_{observed} and $Q_{\text{simulated}}$ seems to be reasonable indicating good match between the observed and simulated runoff. Figure 3.8 and 3.9 shows the good match between observed and simulated runoff during model validation. However on comparison on annual basis as shown in Figure 3.10 it was found matching well. Thus it could be seen that model is performing with reasonable accuracy and can be used in Shipra basin for water resources planning purpose such as simulation of long term runoff time series at the desired location in Shipra basin for assessment of water availability, low flow analysis, flood analysis etc.

CHAPTER 4

DEVELOPMENT OF SHIPRA RIVER BASIN MODEL IN MIKE BASIN AND DEVELOPMENT OF DSS APPLICATIONS

4.1 DSS Work Plan

The Shipra river has two main tributaries, Gambhir and Khan river. The increasing domestic and industrial demand in the Shipra basin is due to the growing modern cities like Indore, Ujjain and Dewas having huge potential for industrial growth causing enormous pressure to meet their water demands. The river experiences very high water demand especially during Kumbh mela organized periodically at Ujjain. To meet the increasing water demands in the basin, the state has planned to make step by step arrangement to supplement Shipra river through Narmada-Shipra link. The 77% surface water supply of Indore city is being fulfilled by water supply from Narmada river. The state has recently completed the Narmada-Shipra link and 2.5 to 5 m³/s water is being transferred to Shipra river. The Gambhir dam is located on Gambhir river to fulfill irrigation demand and for domestic water demand of Ujjain city. State has also planned to undertake Narmada-Gambhir link to improve the water availability in Gambhir river to fulfill its demands. Thus the hydrology of the Shipra river basin has become very complex due to various water transfer schemes and storage structures constructed on Shipra and its tributaries as shown in Figure 4.1. Under such circumstances the development of DSS applications would help to address supply and demand scenario and other hydrological issues of Shipra basin for water resources development, planning and management under changing hydrological and climatic conditions.

For development of DSS in Shipra basin, the approach of Integrated River Basin Management (IRBM), which is based on the idea of taking the river basin or watershed as a management unit has been accepted. To perform the holistic analysis with multi-criteria optimization task and assessment of effects of measures, integrated modeling techniques have been adopted. In this context, computer based hydrological modelling tools like MIKE 11, MIKE ZERO, MIKE BASIN, etc. capable to manage the huge amount of data, perform analysis, simulation, multi-objective evaluation of results and providing the essential information required in decision making were used for DSS development.

4.2 DSS framework

The DSS framework includes generation of data base using data collected from field and historical data, preparation of temporal and spatial data base, generation of GIS layers, application of appropriate hydrological model, optimization, model simulation, alternate

decisions. The generated information on analysis of alternate decisions can be used to make appropriate final decisions. The information and output can also be made available on web using the dashboard application of DSS. The framework for development of DSS in Shipra basin is shown in Figure 4.2.

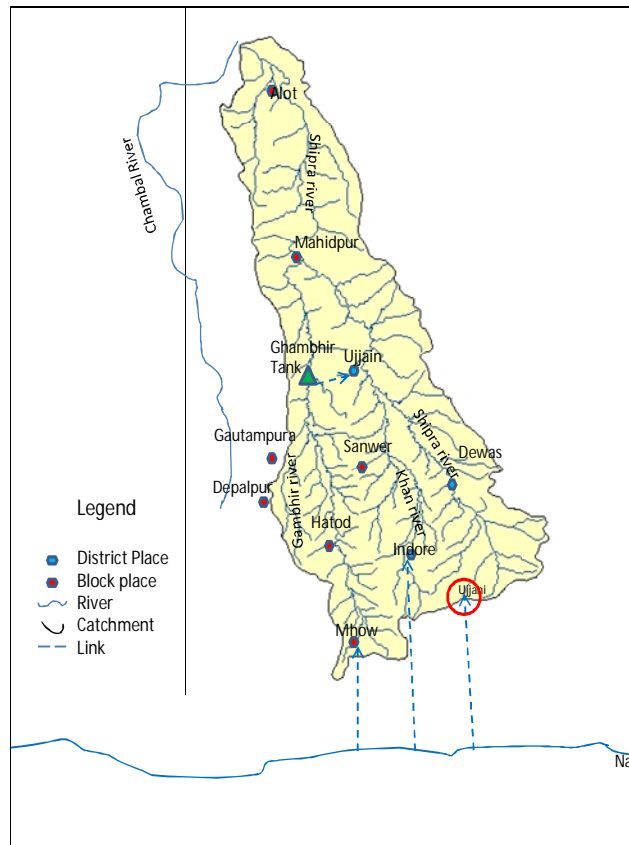


Figure 4.1: Water transfer arrangement in Shipra basin

4.3 DSS components

The DSS software, developed by the Danish Hydraulic Institute (DHI), Denmark for integrated water resources development and management of water resource systems in India under HP-II project is capable of addressing the following five components.

1. Surface water planning
2. Integrated operation of reservoirs
3. Conjunctive surface water and ground water planning
4. Drought monitoring, assessment and management
5. Management of both surface and ground water quality

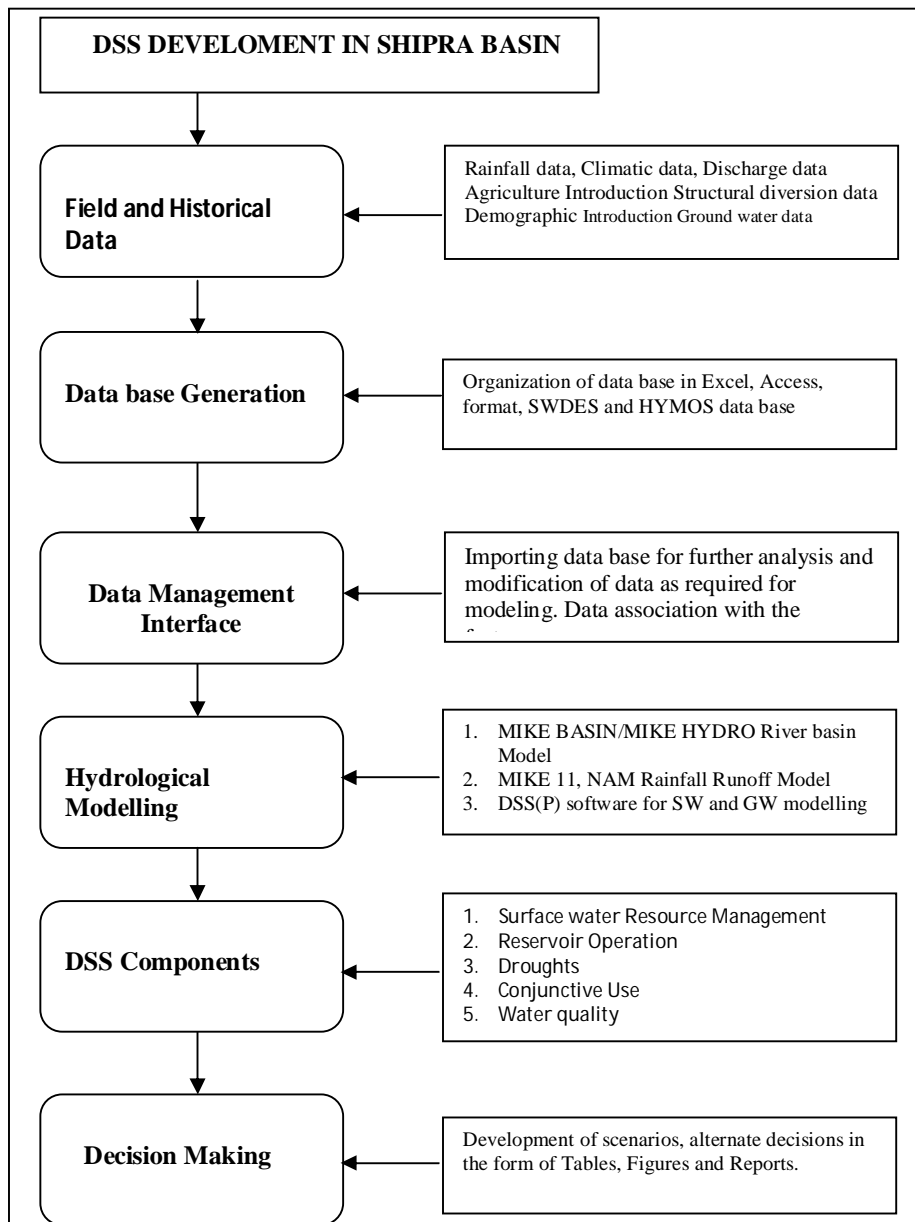


Figure 4.2: Outline and framework to carry out the DSS applications work

4.4 Shipra Mike Basin (MB) Model Description

The Shipra river basin is subjected to various water transfer operations associated with the river as discussed in earlier chapter. To assess the water availability status under different hydrological conditions and to develop various scenarios for assessment of surplus and deficit situation, the Shipra River Basin Model was developed in MIKE BASIN software. The GIS data base of catchment map, drainage map, confluence point locations, discharge gauging sites and influencing rain gauge locations, town location was used in MB model to develop Shipra River

Basin model. The process of development of Shipra River Basin model in MIKE BASIN is described in detail in this chapter. The complete hydrological information of Shipra basin was imported in the model and then used for development of various Decision Support System (DSS) applications and scenarios for water resources planning in the basin.

4.5 Arc GIS

The Shipra river basin has its geographical area 5679 sq km and it comes under Survey of India toposheet 46M, 46N, 55A and 55B. The base and other spatial information required to develop Mike basin model such as drainage network, stream flows, towns, catchments, Digital Elevation Model (DEM) were prepared in Arc GIS platform and are shown in Figures 4.3, 4.4, 4.5 4.6.

4.6 Development of Mike Basin model of Shipra Basin as a DSS

Mike Basin is a computer based model developed by DHI, Denmark where GIS is a part of it with which modelling can be done for water resource planning and management. In MIKE BASIN, the river basin is represented in a mathematical form which includes the configuration of the main rivers and their tributaries within the basin spatially and temporally. The rivers and their main tributaries are represented by a network of branches and nodes in the MIKE BASIN, so called as a network model. In the model branches represent individual stream sections while the nodes represent confluence points. There are also diversions where some water transfer activities may occur like industrial, reservoir, and hydropower water uses or some important locations where model results are to be obtained or required. The river system is represented in the model by a digitized river network that can be generated in Arc Map 9.3. By using MIKE 11 NAM rainfall-runoff model, catchment inflows can be simulated in the NAM model with rainfall and evaporation data as inputs which is then used in MIKE BASIN model for further DSS application.

MIKE BASIN has a large scale potential in reservoir modelling. For every individual reservoir operation rule curves are associated to check the performance of the reservoir in specified operating policies. According to demand and possible expected inflows, Rule Curves are used in MIKE BASIN to define the desired storage volume, water releases at any time according to water levels available in the reservoirs and the time of the year. The basic input data for the MB model is the time series data for catchment runoff, river node allocations etc. The user defined or RR module catchment runoff can be taken as specific runoff data. After allocating all the water usage data, model simulates the overall system by using water balance methods at each and every node. The simulation performance of the model can be viewed, checked and evaluated easily. The obtained results are represented or viewed as time series data, daily or monthly

summary in tabular forms or graphical forms. For a specific part of the model or for the entire model, a map of visualized groups of results is obtained by Arc Map Graphical User Interface. Thus MB model is capable of developing various hydrological scenarios and work as a DSS which enables the planners and policy makers to take appropriate decision.

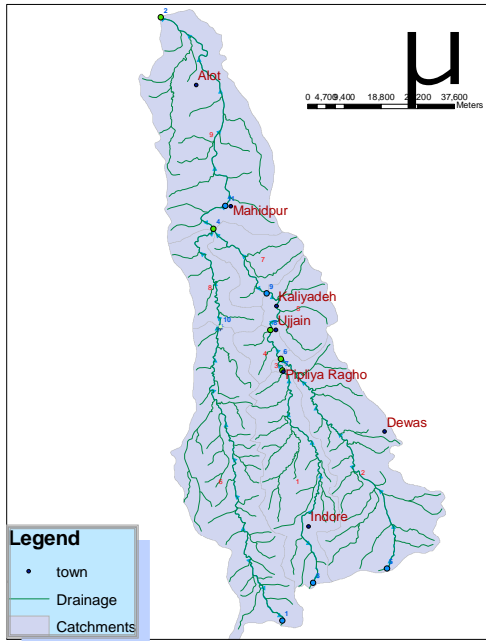


Figure 4.3: Shipra basin with drainage system

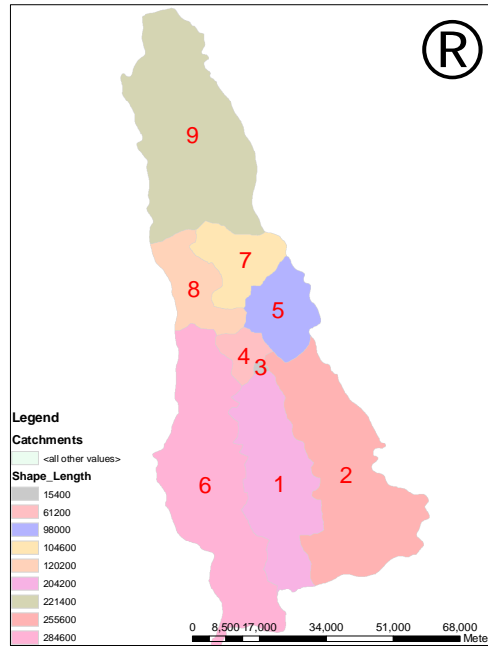


Figure 4.4: Shipra basin with sub watersheds

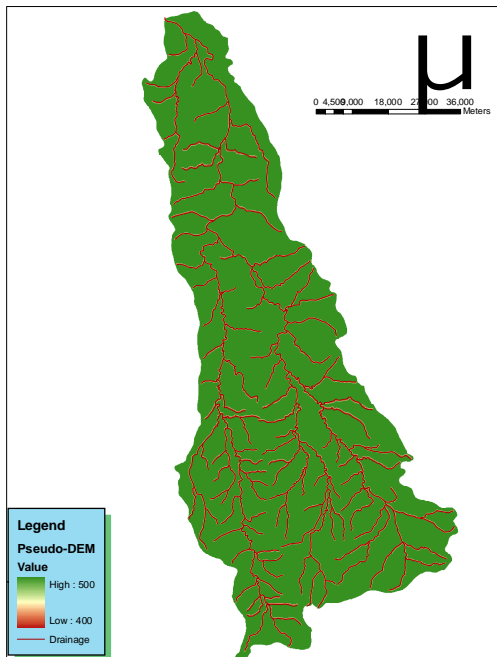


Figure 4.5: Shipra basin with Pseudo DEM

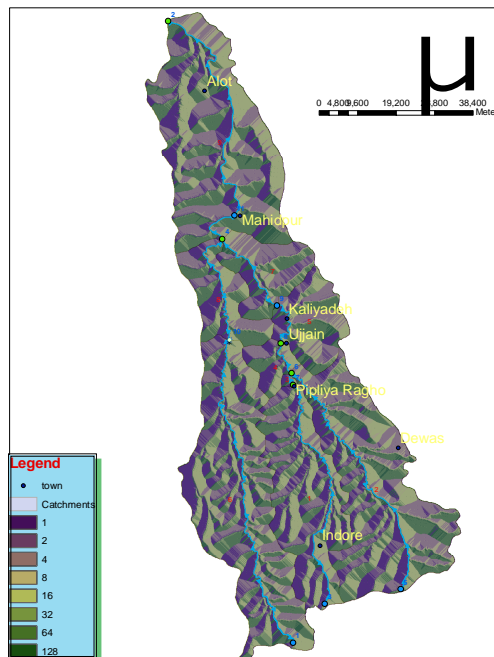


Figure 4.6: Shipra basin with Flow Directions

4.6.1 Drainage Network

The drainage network for Shipra river and its tributaries developed using Arc GIS was imported in Mike Basin platform for catchment delineation so as to demarcate sub-watershed boundaries and point of your interest from planning point of view as shown in Figure 4.7.

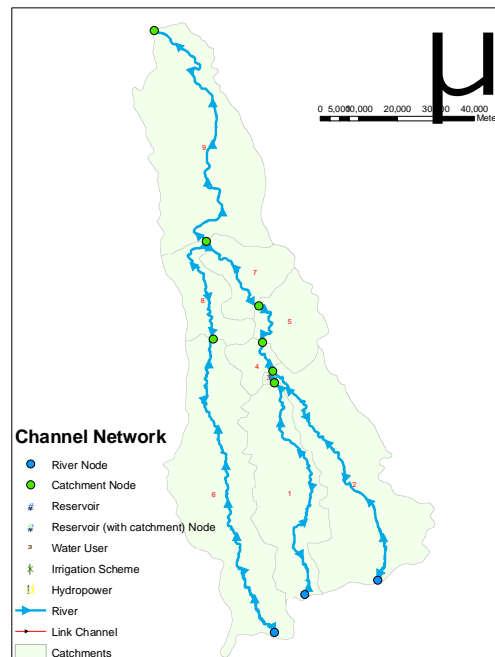


Figure 4.7: Channel Network and Locations of Nodes.

4.6.2 Catchments

Catchment runoff nodes represent locations in the model where water is introduced directly to the stream network system. After delineating the river network, required nodes are set and desired catchments are delineated for the Shipra Basin using Mike Basin catchment delineation tools. Figure 4.8 shows the catchment details. The numbers represent different sub watersheds in the catchment.

4.6.3 Water Users

In MIKE BASIN network model is constructed in which the rivers and their tributaries are represented by branches and nodes. In the model different types of water users can be used like Irrigation, Domestic, Waterworks, Industry, Wastewater treatment plants etc. The present model consists of two water users which are domestic user for Ujjain city and irrigation user for irrigation from Khan diversion. As explained above a specific runoff time series data assigned to

the catchments in river system for the simulation of discharge from the catchments. The Mike basin has a facility to associate time series data with the model features such as catchments, tributaries and water user's demand. A water user node could have multiple sources and multiple return flow points. Only one upstream river node has been used as a source and return flow channel was defined. The domestic user is the Ujjain City, which receives water from the Gambhir Reservoir and its return flow was added into the Shipra River. Return flow is considered as 10% of the total supply. The population of Ujjain City in the year 2015 was calculated from 2001 and 2011 population census data. Rate of increase of population was considered 19.69% as suggested in Ujjain municipal plan. The approximate population of Ujjain city in 2015 was calculated as 5.49 lakh. As per the norms given by National Building Code domestic supply should have provision of water supply of 135 l/day/person. Thus the water demand of Ujjain City was estimated as $0.86\text{m}^3/\text{s}$ throughout the year. With the given water demand and return flow for Ujjain city water user, a scenario was simulated for the period from 1/1/1988 to 31/12/2006 in Mike Basin to analyze the water supply status and water surplus deficit scenario of the Ujjain city. If city encounters water supply deficit, then discharge from the reservoir can be increased according to the total storage volume present in the reservoir to fulfill the demand.

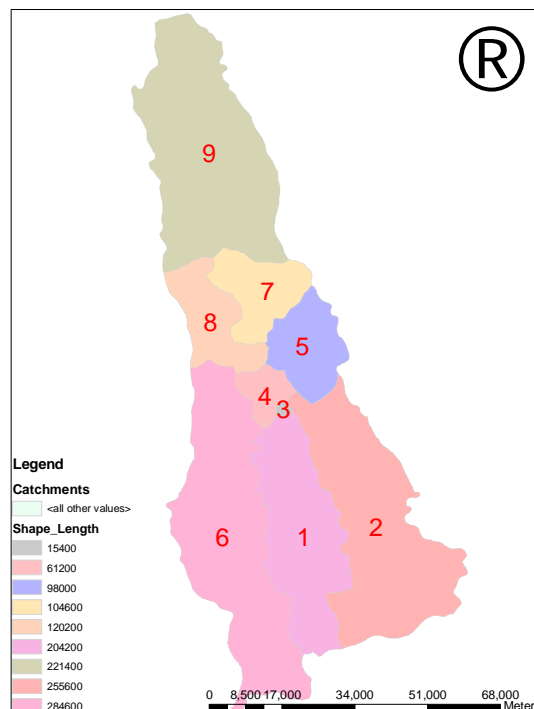


Figure 4.8: Delineated sub watersheds in Shipra basin

Second water user was Irrigation user which receives water from the Khan river diversion. A detailed note about Khan Diversion is given in the next section of this chapter. The amount of water diverted in lean period through Khan Diversion with maximum capacity of $5\text{m}^3/\text{s}$ has been planned to be utilized for irrigation purpose, thus the Irrigation user in the model uses the diverted water. The water is not to be diverted during monsoon season and that has been taken care in the model development. The Khan Diversion scenario was simulated in Mike Basin for the period from 1/1/1988 to 31/12/2006. The results of the simulation were analyzed to assess net flow to irrigation node, water demand deficit, water availability at Ujjain city, reduction in dependable flow due to Khan diversion etc. and attempts were made to identify possible remedial measures to be adopted to address the issue of assured water availability to meet water demand of Ujjain. The Mike Basin model interface with Khan Diversion, Ujjain city user, Gambhir dam and Irrigation user is shown in Figure 4.9.

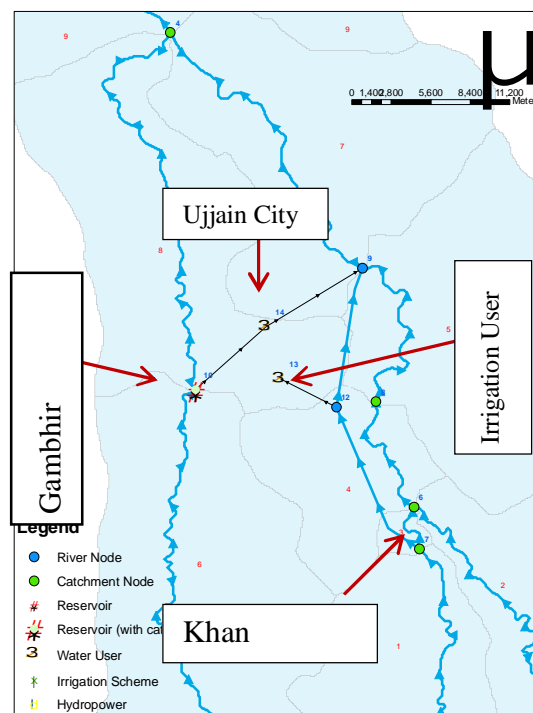


Figure 4.9: Shipra basin with Water Users, Gambhir Reservoir and Khan Diversion.

4.6.4 Reservoirs

For development of reservoir simulation in Mike Basin, the time series information required includes bottom level, crest, spillway, top of dead storage, and minimum operation pool elevations; minimum and maximum releases; precipitation data, seepage loss, and evaporation;

and flood control and operational rules levels has to be assigned to the reservoir for the various connected users.

In present study a Mike Basin scenarios were simulated for Gambhir reservoir located on Gambhir river. Gambhir river is a tributary of Shipra river. The reservoir is operated to provide domestic water supply to Ujjain city and limited irrigation supply during lean periods. To develop Gambhir reservoir model all the required information like its Area-Elevation-Capacity curve, various characteristic levels, evaporation and other losses time series were used as input information. To assess the reservoir performance and demand supply situation at user node Ujjain, physical characteristics and operational rules were assigned to the reservoir and various scenarios were generated. Gambhir reservoir is shown in Figure 4.9. The MB Model Interface of Shipra River Basin Model is shown in Figure 4.10.

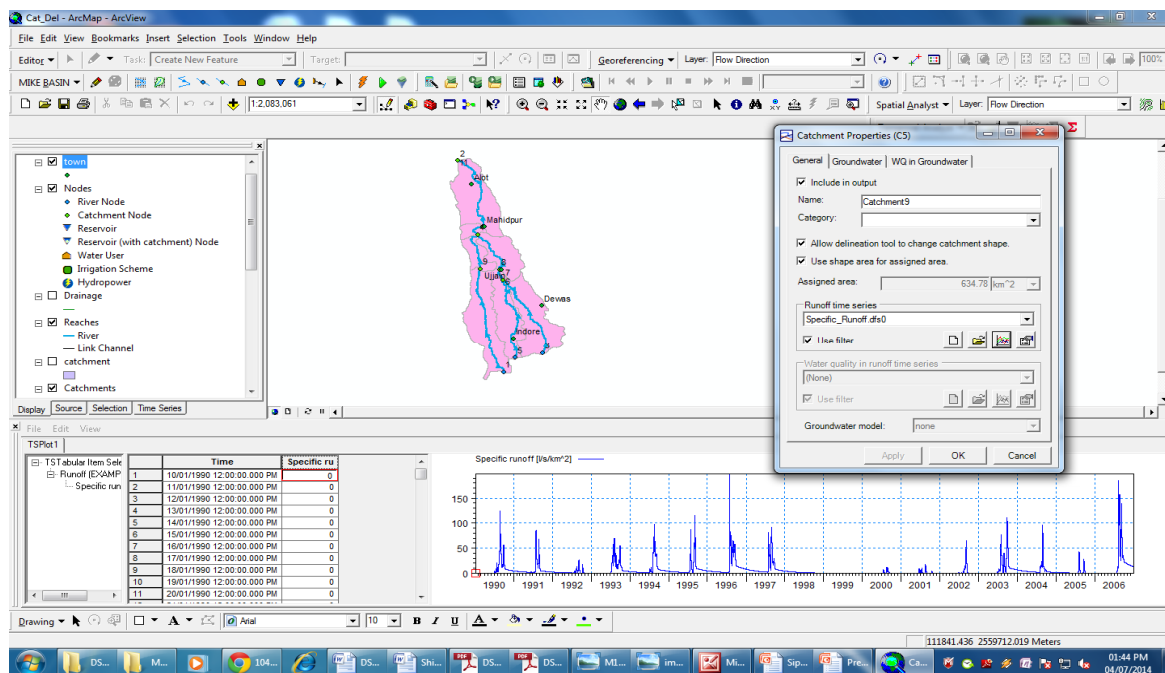


Figure 4.10: MIKE BASIN Model Interface of Shipra River Basin Model

4.7 DSS Applications

By using Mike Basin and Mike 11 NAM model, a well-equipped Shipra basin model was developed. The NAM Rainfall runoff model developed at Ujjain was taken as the reference input in the Mike Basin model. Once the Shipra basin model was developed, the hydrological developmental work taken up in the basin and features associated with that development such as Khan diversion and Narmada-Shipra link were also incorporated in the model and accounted for the analysis. Different scenarios under changing hydrological conditions were developed and

analyzed for water resource planning and management. The details of these two major projects and its hydrological aspects are discussed in detail in the sub-sections below.

4.7.1 Khan Diversion

The Khan River is a tributary of Shipra River. Khan river is originated near Indore city, which carries sewage and polluted water of Indore city and nearby industrial area. The confluence point of Khan river to Shipra river in the upstream of Ujjain city near Shani Mandir is well known for its religious, social and cultural importance. Every day thousands of pilgrims take holy bath at Ujjain Ghat. Simhastha (Kumbh Mela) is also organized after every 12 years at Ujjain where lakhs of pilgrims take holy bath on special days. The last Simhastha was held in April 2016. Looking to the historical and pilgrimage importance of Shipra river and Simhastha, it is planned and proposed to divert the Khan river to avoid pollution of Shipra by Khan river. The Khan river is proposed to be diverted from stop dam near Pipliya Ragho village and that diversion will join Shipra at downstream of Kaliyadhe Palace. Monsoon flow will pass through Khan river and non-monsoon flow will be bypassed through a Khan Diversion over a stretch of 19.25 km. The main purpose of this project is to divert polluted Khan river water from entering in to Shipra during non-monsoon period when the Simhastha has to be held at Ujjain. The diversion channel will carry non-monsoon flow under gravity. Good cultivation land is available on both the flanks of diversion channel which will be irrigated through the channel. A total area of 600 acres is proposed to be irrigated from this diversion. The photograph of field visit to gauging site of State Water Resources Department at Sanver is shown in Figure 4.11 however the discharge data of Sanver GD site has not been used in this study due to its inconsistency.



Figure 4.11: Gauging site on Khan river

4.7.2 Narmada-Shipra Simhastha Link Project

The main aim of Narmada-Shipra link project is to supplement Shipra with Narmada water so as improve water availability to meet various water demands and to maintain flow during Simhastha and other holy occasions in Shipra. The background of this link is that the Malwa region of M.P. had been experiencing acute water scarcity especially for drinking since about three decades due to drying up of rivers like Shipra, Gambhir and Kali Sindh. The ground water was plummeting at fast pace and if such conditions prevails, the whole Malwa region shall transform into a desert. Because of this situation, Narmada- Shipra Simhastha link project was chalked out for flowing Narmada water into Shipra river so that drinking water can be supplied to Dewas, Ujjain and villages on the banks of Shipra river and to make water available for holy dip in Shipra on special occasions. To study the changing hydrological condition due to Narmada-Shipra link and its impact on catchment hydrology, a link was added in Mike Basin model of Shipra River model which adds Narmada water to Shipra at Ujjaini Village from where the river Shipra originates. Salient features of Narmada-Shipra Simhastha link project are given in Table 4.1 and schematic view is shown in Figure 4.12.

Table 4.1: Salient features of Narmada-Shipra Simhastha link project

Sr. No.	Feature	Details
1	Water Quantity to be pumped or lifted	5 m ³
2	Total length of rising main	49 km
3	Length of rising main parallel to road	28 km
4	Total height of Pump-lifting	348 m
5	Diameter of rising main pipe	2 m
6	Electricity motor pumps (each)	3000 KW
7	Land acquirement - Forest areas - Private land	5 ha 70 ha



Figure 4.12: Narmada Shipra link

Narmada-Shipra link project involve lifting the water from Narmada which flow through the Satpura mountain range to the Shipra traversing in Malwa plateau which is about 400 m higher than the Narmada river valley. For this lift, pumps have been installed along its 49 km long course to lift the water to an altitude of 348 m. Under the Narmada- Shipra link project 5 cumec of Narmada reserved water which was earlier planned to be released to Sisliya reservoir has now been released to Shipra River near Ujjaini village in Indore district then flows through Shipra.

4.7.2.1 Benefits of the link project

When 2.5 to 5 cumecs of Narmada water is released into the starting point of Shipra river at village Ujjain, it will not only ensure available of water during Simhastha, but will also meet existing and future drinking water requirements of Ujjain and Dewas cities. It will also fulfill water requirements of Dewas-based industries, suburban drinking water requirements of Dewas-Indore Road and over 150 villages situated between the starting point of Shipra River and Ujjain city. Release of Narmada water into Shipra River will also recharge and increase groundwater table in the region. As a result, ample water will be available in wells, tube-wells and ponds. Power consumption on lifting water will come down when water level goes up. Water will be made available to a number of small and medium industries. One of the most remarkable benefits of the project will be that water requirements for holy bathing of lakhs of devotees will be fulfilled during Simhastha held at Ujjain after every 12 years. It will also helpful to meet other petty water requirements in the Shipra basin.

4.8 Development of Mike Basin Scenarios

Once the MB model was developed for a river basin with its associated feature, their properties, spatial information and temporal time series data, it was then used to develop number of alternate scenario which can help in decision making and future planning. Some of the scenarios developed considering the future hydrological changes in Shipra basin, its impact on water resources which may be helpful for future planning are discussed in this section.

4.8.1 Scenario 1: Model simulation without Khan Diversion and without Narmada-Shipra link.

In the first scenario MB model was simulated without any diversions and without Narmada-Shipra link as shown in Figure 4.13. As main focus of the study was the water availability and river flow at Ujjain in Shipra, results were analyzed to check the net flow in river at Ujjain. The model was setup and scenario was simulated and results obtained were analyzed on the basis of Flow Duration Curve at Ujjain and Mahidpur, runoff hydrographs at Ujjain and Mahidpur for

years 1994, 1995 and 1996 and runoff hydrographs for the whole simulation period from 1990 to 2006.

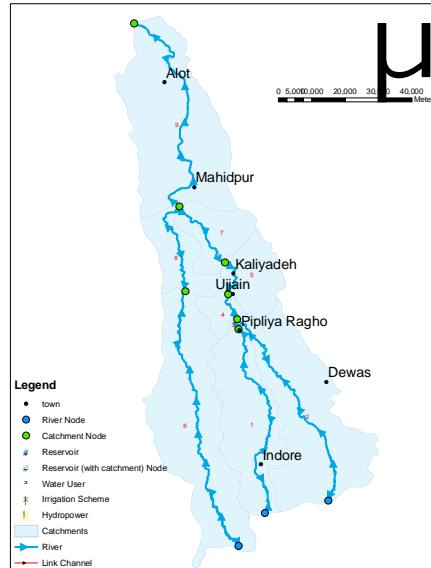


Figure 4.13: Model without Khan Diversion and without Narmada-Shipra link

4.8.2 Scenario 2: Model simulation with Khan Diversion and without Narmada-Shipra link

In the second scenario a Khan Diversion was incorporated in the MB model as shown in Figure 4.14. This arrangement will allow the Khan water to get diverted before it confluences with Shipra and it will bypass Ujjain Ghats and will again discharge in to Shipra at the downstream of Ujjain so as to avoid polluted water entering in to the Shipra at Ujjain. The diverted water is planned to be used for irrigation purpose hence an irrigation user was added to the diversion channel as shown in the figure. The diversion time series was set in such a way that it will divert Khan river water at a rate of $2.5 \text{ m}^3/\text{s}$ during non monsoon period only as the diversion is operative during non monsoon period only.

The return flow from the irrigation user on Khan Diversion was considered negligible. The MB model simulation results of Scenario-1 and Scenario-2 were compared with reference to the net flow at Ujjain. The Flow Duration Curves and runoff hydrographs at Ujjain were compared to assess the low flow situation occurred due to Khan Diversion. The analysis was carried out by comparing Flow Duration Curve at Ujjain for Scenario-1 (natural flow condition) and Scenario-2 (changed hydrological condition due to Khan Diversion). The runoff hydrographs simulated at Ujjain and Mahidpur for the individual wet and dry years 1994, 1995, 1996 and for whole simulation period 1990 to 2006 were analyzed.

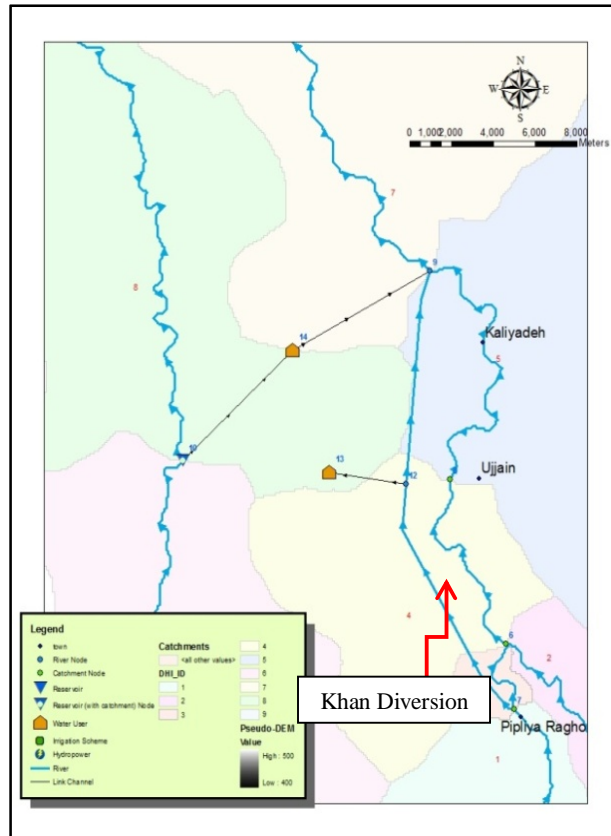


Figure 4.14: Scenario-2 Model with Khan Diversion but no Narmada-Shipra link

4.8.3 Scenario-3: Model simulation with Khan Diversion and Narmada-Shipra Link

In third scenario the Khan Diversion and Narmada-Shipra link both were added to the MB model to assess their impact on river flow. The Narmada channel was linked to Shipra at Ujjaini village as shown in Figure 4.15 and allowed a discharge $2.5 \text{ m}^3/\text{s}$ through this link during non-monsoon period. MB model simulation results were analyzed by comparing Flow Duration Curves and hydrographs at Ujjain for Scenario-1 (natural flow condition), Scenario-2 (with Khan Diversion) and Scenario-3 (with Khan Diversion and Narmada-Shipra link both).

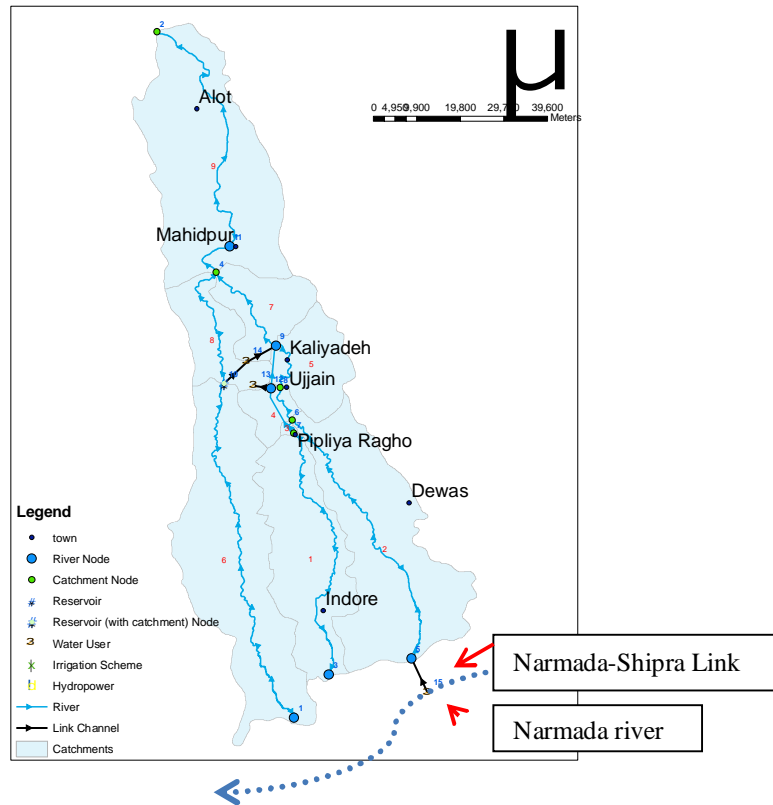


Figure 4.15: Scenario-3 Model with Khan Diversion and Narmada-Shipra Link

4.8.4 Scenario-4: Model simulation with Gambhir Dam for water supply to Ujjain

Gambhir reservoir located on Gambhir river is the main source of water supply to Ujjain city since long. The photograph showing Gambhir dam on Gambhir river is shown in Figure 4.16. To assess the demand supply scenario at Ujjain the reservoir model was developed in the Mike Basin. The details of the reservoir such as Area-Elevation-Capacity table, various operational levels, losses etc were collected from field agencies and the information was applied in the model. To estimate the water demand of the Ujjain city, the 2001 and 2011 census data was used to predict the present population. A supply of planned at the rate 135 lit/day/person for the Ujjain and same was incorporated in the model. The aim of this exercise was to plan a water supply from the reservoir to Ujjain city so that the available water can be used optimally to meet the demand. This exercise would assess the surplus deficit scenario under normal water supply condition and how deficit scenario changed if water supply is planned with few restrictions so as to meet partial water demands during summer season. It can be worked out by analyzing scenario for a specified reduction level of dam and for a particular reduction fraction for assessment of deficit if any experienced by the system. If there is any deficit in a particular period then, reduction fractions, reduction levels will be adjusted in such way that it will optimize the model

combination suggesting no deficit or minimum deficit water supply strategy for the period of water scarcity.



Figure 4.16: Gambhir dam on Gambhir river

4.9 Water Availability analysis under different scenarios

The MB model of Shipra basin was used to assess water availability Shipra river particularly at Ujjain for three different scenario. As the areas around Shipra river are developing domestically and industrially, it is facing problem of water availability to meet its demands. The water availability analysis in Ujjain is carried out by estimating dependable flow volumes at various probability levels using Flow Duration Curve technique. 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). The time periods usually considered in flow duration analyses are 1 day, 7 days, 10 days or 30 days. The present study was aimed to assess the availability of dependable flows volumes in the Shipra River on monthly basis within a year at 70, 75, 80, 85, 90 and 95% probability of exceedence for the period from 1990 to 2006. Monthly Flow Duration Curves (FDC) for different months and for different scenarios (scenario1, 2, 3) were developed and analyzed.

4.10 Results and Discussion

The various DSS scenarios were developed in Mike Basin platform through the Shipra basin model simulation under different hydrological conditions. The results obtained from various scenarios were analyzed and interpreted on the basis of their applications in water resources planning of the river basin and for decision making as discussed in the following sections.

4.11 Development of MB Model of Shipra basin for DSS

The spatial information layers of Shipra basin such as base map, drainage network, stream flows, towns, catchments, and Digital Elevation Model (DEM) were prepared in Arc GIS platform. This spatial information was then imported in Mike Basin module of Mike GIS for developing Shipra river MB model. Once the spatial information was imported, the properties like name, size, temporal time series, losses, rules, etc. were associated to the model features such as catchments, users, channels, dams, return flow channels, link channels. The temporal time series data such as rainfall, observed runoff, user demand, return flow, dam details, losses etc were imported in to the MB model using Excel Bridge or direct *dfs0* format time series. The NAM RR model parameters developed in the previous rainfall runoff modeling exercise were assigned to the appropriate catchment which would enables the model to simulate runoff from those catchments. The long term information on rainfall, runoff, evapotranspiration, diversions etc for the period from 1988 to 2006 was associated the various model features which were then used to simulate scenario of desired time and duration. A well-equipped DSS model of Shipra basin was developed using Mike Basin and Mike 11 NAM model which was then used to develop different scenarios under changing hydrological conditions due to Khan Diversion, Narmada-Shipra, and Gambhir reservoir supply. The various hydrological scenarios were developed using the MB model and discussed as below.

4.11.1 Scenario1: Model simulation without Khan diversion and without Narmada-Shipra link

In the first scenario, Mike Basin model was developed without Khan Diversion and without Narmada-Shipra link. The main aim of developing this scenario was to assess the water availability in Shipra river at Ujjain and Mahidpur under natural flow condition. The model simulation was carried out for the period from 1990 to 2006 using NAM RR model parameters obtained during rainfall runoff modeling. The net flow time series simulated during this scenario at Ujjain and Mahidpur were analyzed to assess water availability at Ujjain and Mahidpur. The comparison of simulated runoff hydrographs under normal flow condition at Ujjain and Mahidpur for the full simulation period and typical selected years are shown in Figure 4.17 and 4.18. From these figures, it was clearly seen that, Mahidpur being at the downstream of Ujjain experiences more runoff volume and high peaks.

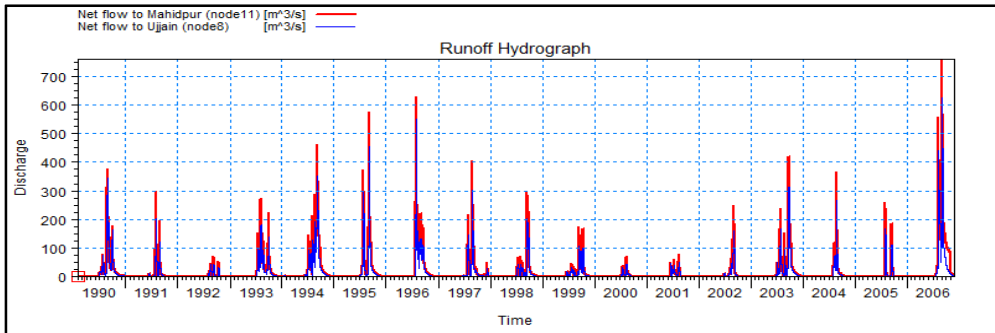


Figure 4.17: Runoff hydrograph at Ujjain and Mahidpur for whole simulation period

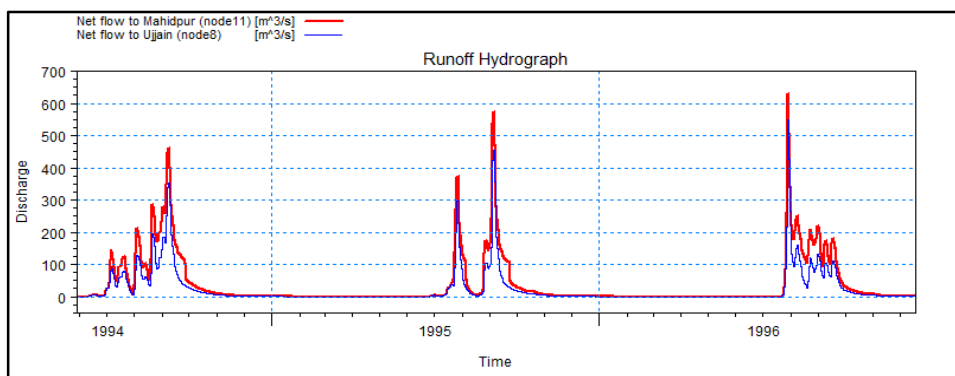


Figure 4.18: Runoff hydrograph at Ujjain and Mahidpur during 1994-96.

The Flow Duration Curve (FDC) for runoff simulated at Ujjain and Mahidpur were compared to assess water availability at these locations as shown in Figure 4.19. The FDC gives the idea of flow characteristics at the desired location and dependable flow at various probabilities. The comparison of dependable flow at various probabilities at Ujjain and Mahidpur is given in Table 4.2.

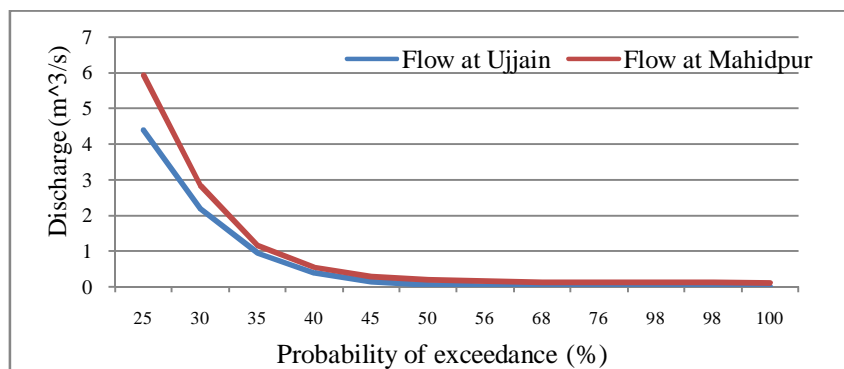


Figure 4.19: Flow Duration Curve at Ujjain and Mahidpur during non-monsoon month

The comparison of the FDC clearly indicated that the water availability situation at Ujjain has not been satisfactory. The dependable flow at 60% probability of exceedance and beyond that

was found zero. However at Mahidpur it was found having very low i.e. $0.1\text{m}^3/\text{s}$ even at 100%. The flow seen at Mahidpur was due to the Gambhir tributary joining Shipra at Mahidpur. It could broadly be concluded that water availability at both places Ujjain and Mahidpur in Shipra has seen to be the matter of concern from management point of view as the river is unable to meet its on-stream demand under the natural condition. It needs to be rejuvenated for augmentation of flow or it may be supplemented through some external sources to meet the demand and to maintain water availability ay Ujjain especially during special occasions and Simhastha.

Table 4.2: Dependable Flow at Ujjain and Mahidpur at different probabilities

Probability of Exceedance (%)	Dependable Flow at Ujjain (m ³ /s)	Dependable Flow at Mahidpur (m ³ /s)
1	624.61	760.16
25	4.39	5.92
50	0.05	0.19
60	0.01	0.16
70	0	0.14
80	0	0.13
90	0	0.12
100	0	0.11

4.11.2 Scenario2: Model simulation with Khan Diversion but no Narmada-Shipra link

In the second scenario, Khan Diversion was added on Khan river in the MB model for runoff simulation at desired locations. The purpose of this Khan diversion has already been explained in detail in the previous section. The main function of Khan Diversion is to divert water from Khan River during non-monsoon period only so as to avoid polluted Khan water from entering in to Shipra. As proposed in the plan, the irrigation user was added in the MB model and its demand had to be fulfilled from Khan diverted water. The irrigation water demand was considered $2.5\text{m}^3/\text{s}$ so that diverted water will be completely utilized for farming and there will be no return flow. Then simulation was carried out from 1990-2006 and results in the form of graphs and tables were analyzed to obtain desired information. The Flow duration curve at Ujjain after Khan Diversion is shown in Figure 4.20. From the graph it was clear that the dependable flow at higher probability say above 75% was zero which can be main concern from water availability and its management point of view.

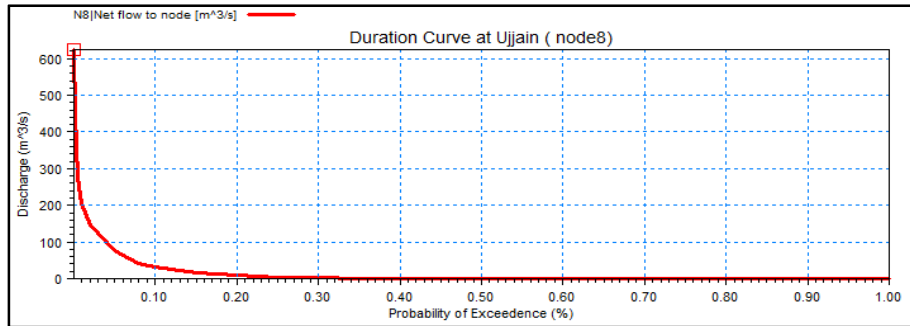


Figure 4.20: Flow Duration Curve at Ujjain after Khan Diversion

The simulation results showing comparison of runoff hydrographs at Ujjain with and without Khan Diversion (normal flow) for the whole simulation period and typical year 1991 are shown in Figure 4.21 and 4.22. The comparison of Flow Duration Curves at Ujjain under both conditions of scenario 1 and 2 are shown in Figure 4.23.

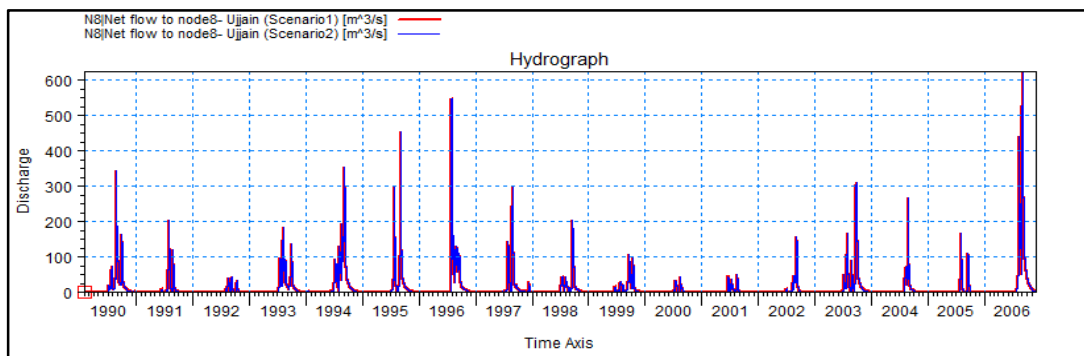


Figure 4.21: Runoff hydrograph at Ujjain with and without Khan Diversion (Scenario 1 & 2)

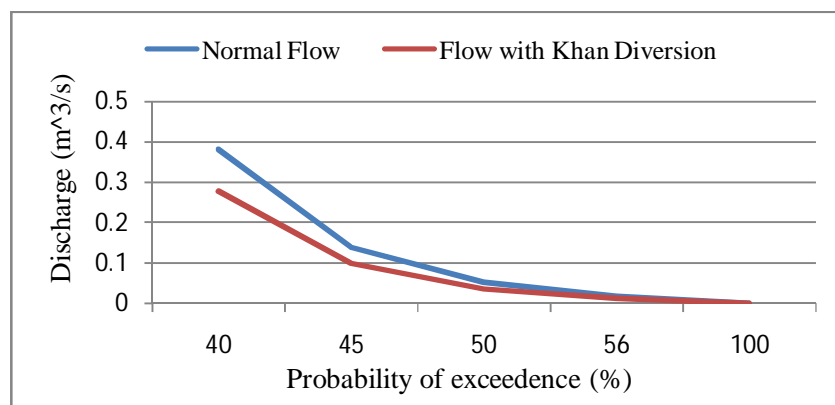


Figure 4.22: FDC of non-monsoon month at Ujjain with and without Khan Diversion.

From the figure comparison of runoff hydrograph and FDC obtained for scenario 1 and scenario 2 as shown in Figure 4.21 and 4.22 respectively it was revealed that the dependable flow at Ujjain has been found reduced due to Khan Diversion during non-monsoon period. This was because; the prevailing river flow of Khan was diverted by Khan Diversion. Moreover it was observed that the dependable flow of the river reduces with the increase in the probability of exceedance and tends to zero at 100% probability under both conditions.

4.11.3 Scenario 3: Model simulation with Khan Diversion and Narmada-Shipra link

In this scenario a Narmada-Shipra link was added to the MB model of Shipra and a discharge of 2.5 m³/s was pumped through this link into the Shipra river at its origin place Ujjaini. Then simulation was carried out and simulation results in the form of runoff hydrograph and FDC were compared with the previous scenario 1 (normal flow). The comparison of FDC at Ujjain between scenario 1 and scenario 3 i.e. with Narmada-Shipra link is shown in Figure 4.23 and dependable flows at various probability levels derived from FDCs are given in Table 4.3.

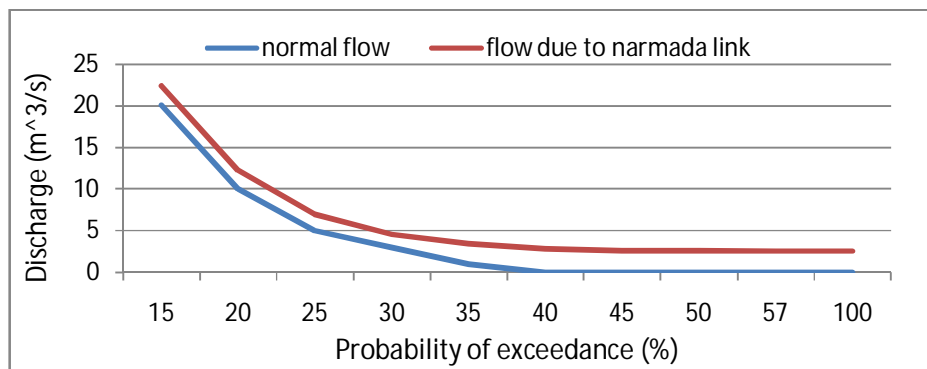


Figure 4.23: Comparison of FDC at Ujjain between normal flow and with Narmada-Shipra link.

Table 4.3: Flow values at different probabilities between normal flow and Flow due to N-S link

Probability of Exceedance	Dependable for Normal Flow (m ³ /s)	Dependable Flow due to Narmada-Shipra link(m ³ /s)
1	753	756
5	93	95
50	0	2.5
75	0	2.5
95	0	2.5
100	0	2.5

In normal flow condition as observed in Scenario 1, the river has no dependable flow at higher probabilities. When Narmada water added to the Shipra through Narmada-Shipra link, a

minimum dependable flow $2.5 \text{ m}^3/\text{s}$ was observed even at 100% probability. From this it could be concluded that the Narmada-Shipra link would help to maintain a regular dependable flow in Shipra at Ujjain during lean period and some special occasions. Further this model can be used to assess the water availability at Ujjain by accounting storage, seepage and evaporation losses of the river.

4.11.4 Scenario 4: Reservoir operations for Gambhir dam for demand supply analysis

Gambhir reservoir is the important source of water supply to the Ujjain city having domestic water demand $0.86 \text{ m}^3/\text{s}$. The Gambhir Reservoir was added in the Mike Basin model, reservoir properties such as FTL, dead storage level, other operating levels and losses information were assigned to the model. After incorporating the required details, the MB model was simulated and different scenarios were developed for reservoir operation to study how water supply to the Ujjain city can be managed without deficit or with allowable deficit under severe drought year. The simulation results would help to manage assured water supply to Ujjain under wet and dry year conditions by giving operational restrictions, user priorities and appropriate rule curves.

4.11.4.1 Simulation 4A: Reservoir without restrictions for water supply to Ujjain city

The Gambhir dam has a top level 545 m, dam crest 544 m and flood control level 542 m. For the first simulation, no restrictions were applied to water supply to Ujjain city. It would allow the reservoir to supply water to fulfill complete water demand of Ujjain city. The simulation result for the period 1996 – 2006 is shown in Figure 4.24. From figure it was observed that, throughout the simulation period, only year 2000 experienced the severe deficit even during drought year.

The details of that deficit year 2000 are shown in Figure 4.25. From this graph it was seen that the summer months April, May and June of year 2000 were the months of complete water deficit at Ujjain and dam became empty in the month of April, which was seen as a challenge to be resolved through appropriate operational and supply strategies. On examining the reason behind severe deficit, it was found that year 2000 was a severe drought year and received 557 mm rainfall thus the Gambhir reservoir might not have filled completely causing severe water scarcity that year. Thus to overcome this situation, in the next simulations the flood control level and restriction fractions were adjusted so that Ujjain city will get assured water may be with some continuous deficit.

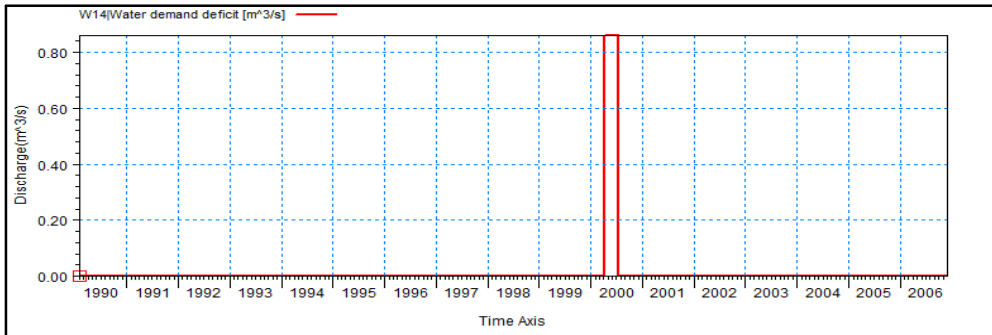


Figure 4.24: Hydrograph showing demand deficit at Ujjain (Simulation 4A)

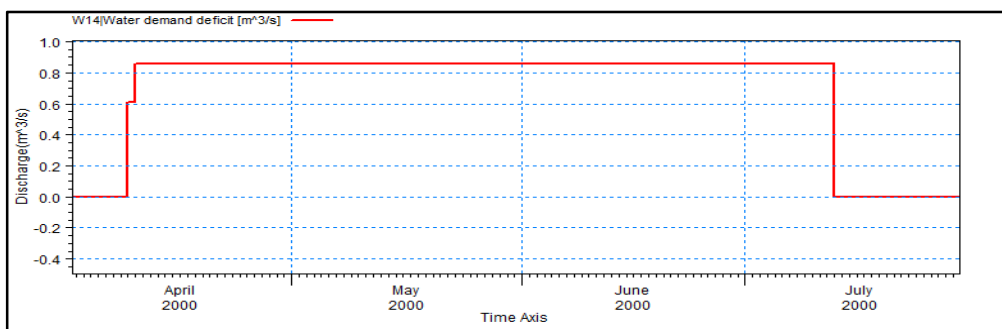


Figure 4.25: Hydrograph showing demand deficit at Ujjain in the year 2000 (Simulation 4A)

4.11.4.2 Simulation 4B: Reservoir designed with reduction level 542 m and reduction fraction of 0.86.

In the second simulation the restrictions are applied and reduction level was kept 542 m and reduction fraction was kept 0.86 of the demand of Ujjain city. As per this restriction, operation of reservoir will change and the water supply will be reduced to 0.86% of its demand immediately when reservoir level reaches at 542 m level. The resultant graph for whole simulation period 1996 – 2006 is shown in Figure 4.26. From graph of it was seen that, the deficit seen during April to June 2000 has been found reduced to great extent but June 2000 was found still under complete shortage of water with 100% deficit. The June 2000 water deficit situation can be seen clearly in Figure 4.27.

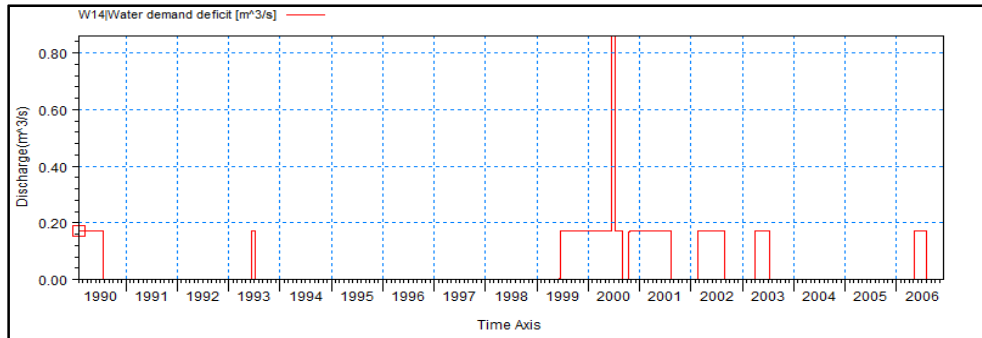


Figure 4.26: Hydrograph showing demand deficit at Ujjain 1990-2006 (Simulation 4B).

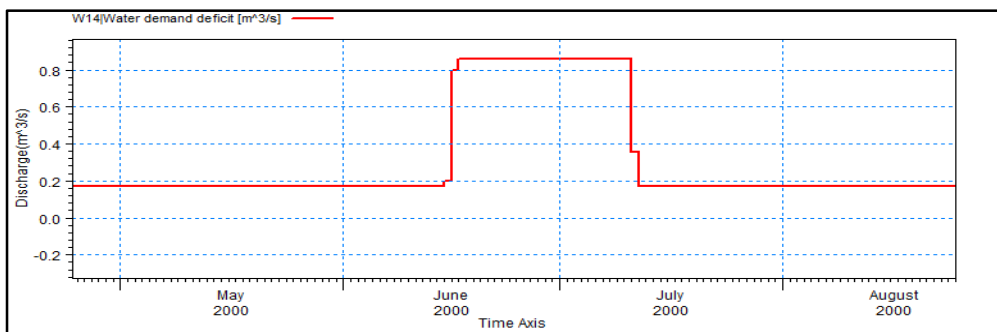


Figure 4.27: Hydrograph showing demand deficit at Ujjain in the year 2000 (Simulation 4B).

4.11.4.3 Simulation 4C: Reservoir operation with reduction level 542 m and reduction fraction of 0.65.

In the third scenario reduction level was kept same and reduction fraction was changed to 0.65 of demand, simulation was carried out. The Figure 4.28 shows the resultant graph, which indicated no improvement in the situation and still there was complete deficit during June 2000 when compared to the second simulation 4B. To overcome this again rule curves were changed and added more restriction on water supply with respect to the user demand.

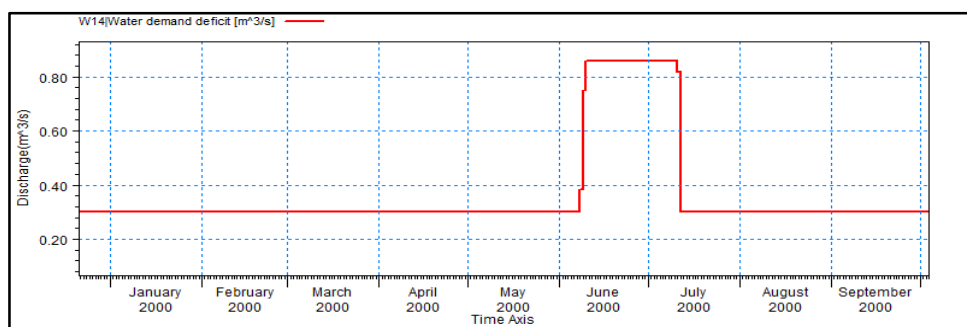


Figure 4.28: Hydrograph showing demand deficit at Ujjain in the year 2000 (Simulation 4C).

4.11.4.4 Simulation 4D: Reservoir operation with reduction level 545 m and reduction fraction maintained between 0.6 and 0.65

In this simulation the reduction level was fixed as FTL i.e. 545 m and reduction fraction was kept 0.65 of demand in the monsoon period and 0.6 in non-monsoon period. It means that restrictions were applied on water supply to Ujjain immediately after the withdrawal of monsoon when the reservoir was filled up to its FTL. Simulation was carried out and results are shown in Figure 4.29. From the graph it was clear that due to added restriction the water deficit of June 2000 has reduced significantly and Ujjain had a supply during June. However to manage the water supply during June 2000, the other non-monsoon months of the year November to April had a deficit of $0.35 \text{ m}^3/\text{s}$ and months May and June had deficit $0.45 \text{ m}^3/\text{s}$. The scenario 4D was found to be the better of others as there was water supply available with some deficit throughout the year under severe drought year. The remaining demand deficit of the city can be fulfilled through ground water supply or by some emergency action plan such as water supply from external sources.

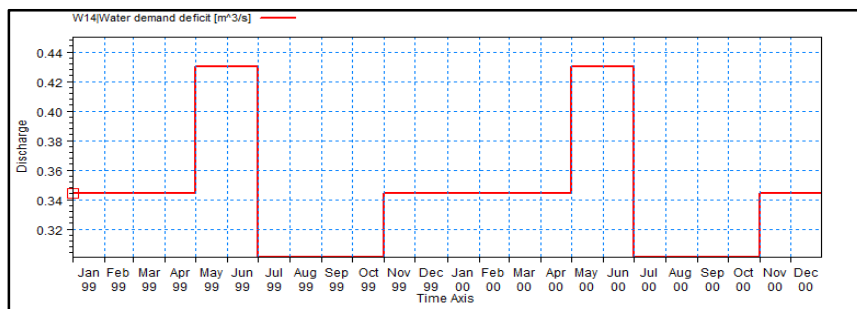


Figure 4.29: Hydrograph showing water deficit at Ujjain in the year 1999-2000 (Simulation 4D).

4.12 Water availability Analysis

Water availability analysis on the basis of dependable flow volumes at various probability levels was carried out in Shipra basin at Ujjain under different hydrological conditions as developed through MB model scenarios 1, 2 and 3. The water availability analysis was carried out using monthly FDC of MB model simulated flow for the period from 1996 to 2006. The dependable flows were calculated on monthly basis at 70, 75, 80, 85, 90, 95 and 100% probability of exceedance. The dependable flow (m^3/s) values for different scenarios at various probability levels were presented in Tables 4.4, 4.5 and 4.6.

Table 4.4: Dependable flow in Shipra river at Ujjain at various probability levels for Scenario 1
(Runoff simulation without Khan diversion and without Narmada-Shipra link)

Probability of exceedence (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
70	0.00	0.00	0.00	0.00	0.00	0.00	0.75	9.21	7.05	0.96	0.16	0.03
75	0.00	0.00	0.00	0.00	0.00	0.00	0.33	6.86	4.59	0.68	0.09	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.09	4.78	2.85	0.38	0.00	0.00
85	0.00	0.00	0.00	0.00	0.00	0.00	0.03	3.26	1.68	0.02	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.82	0.36	0.00	0.00	0.00
95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.01	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00

Table 4.5: Dependable flow in Shipra river at Ujjain at various probability levels for Scenario 2
(Runoff simulation with Khan diversion and without Narmada-Shipra link)

Probability of exceedence (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
70	0.00	0.00	0.00	0.00	0.00	0.00	0.75	9.21	7.05	0.96	0.11	0.02
75	0.00	0.00	0.00	0.00	0.00	0.00	0.35	6.86	4.59	0.68	0.06	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.09	4.78	2.85	0.38	0.00	0.00
85	0.00	0.00	0.00	0.00	0.00	0.00	0.03	3.30	1.68	0.03	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.82	0.29	0.00	0.00	0.00
95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.01	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00

Table 4.6: Dependable flow in Shipra river at Ujjain at various probability levels for Scenario 3
(Runoff simulation with Khan diversion and Narmada-Shipra link both)

Probability of exceedence (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
70	1.90	1.87	1.72	1.72	1.72	0.98	0.88	9.33	7.06	0.96	2.00	1.93
75	1.90	1.87	1.72	1.72	1.72	0.48	0.48	6.86	4.58	0.69	1.95	1.89
80	1.90	1.87	1.72	1.72	1.72	0.13	0.13	4.83	2.89	0.40	1.89	1.89
85	1.89	1.87	1.72	1.72	1.72	0.04	0.04	3.31	1.72	0.03	1.89	1.89
90	1.89	1.87	1.72	1.72	1.72	0.03	0.00	1.83	0.29	0.00	1.89	1.89
95	1.89	1.87	1.72	1.72	1.72	0.00	0.00	0.70	0.01	0.00	1.89	1.89
100	1.89	1.87	1.72	1.72	1.72	0.00	0.00	0.02	0.00	0.00	0.00	1.89

From Table 4.4 showing dependable flow at Ujjain for Scenario 1 when there was no Khan diversion and no Narmada-Shipra Link, it could be seen that the river was having flow in monsoon season only. A very little dependable flow was observed in the months of November and December. There was no dependable flow from January to June at even low probability. The river was having a highest flow of $9.21\text{m}^3/\text{s}$ at 70% probability and $0.02\text{m}^3/\text{s}$ at 100% probability in the month of August.

From Table 4.5 showing dependable flow at Ujjain for Scenario 2 when there was Khan diversion but no Narmada-Shipra Link, it could be seen that, because of diversion the Khan river water was seen diverted during non-monsoon season and river did not have flow during non-monsoon period. From Table 4.6 showing dependable flow at Ujjain for Scenario 3 when there was Khan diversion and Narmada-Shipra Link as well under operation, it could be seen that river had a assured flow throughout the year. The dependable flow was simulated with consideration of losses like evaporation, seepage and storage and was estimated in the range of 1.72 to 1.9 m³/s during lean period.

Comparison of Flow Duration Curves developed for June and December are shown in Figures 4.30 and 4.31. The comparison explain how the dependable flow in Shipra increased when Narmada Shipra link start operating. It can also be explained through Figure 4.32 showing dependable flow at 90% probability.

4.13 Conclusions

A GIS based MIKE BASIN model developed for Shipra river basin for water resource planning and management can be useful tool for development of various decisions supporting application in Shipra basin. The NAM rainfall runoff model was found suitable for Shipra basin and it was applied to the ungauged sub-basins of Shipra basin for simulation of runoff which was important for development of MB Model of Shipra.

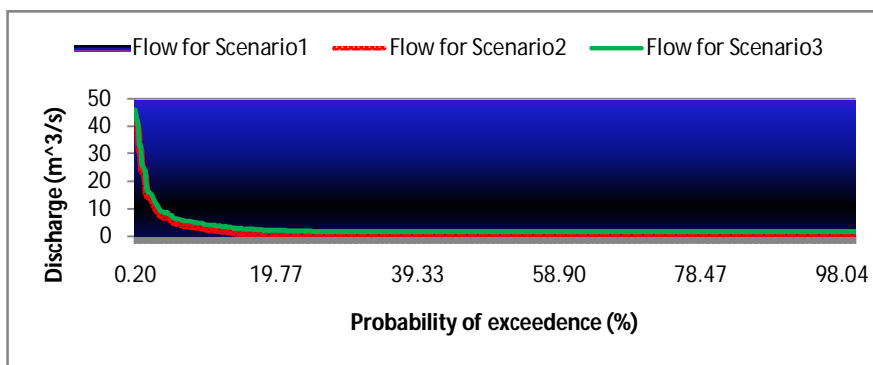


Figure 4.30: Flow Duration Curve for three Scenarios for June

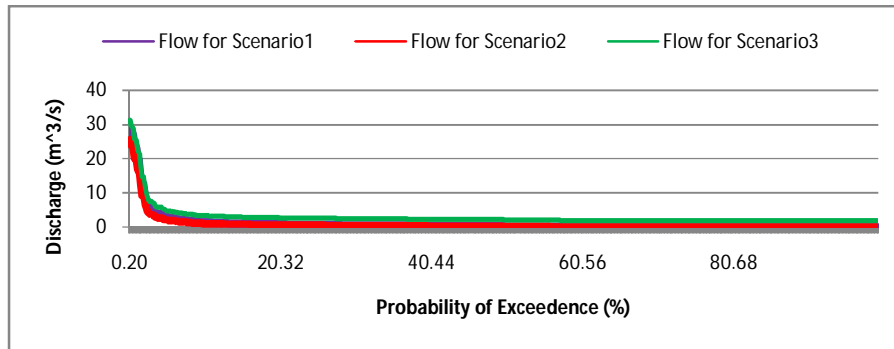


Figure 4.31: Flow Duration Curve for three Scenarios for December

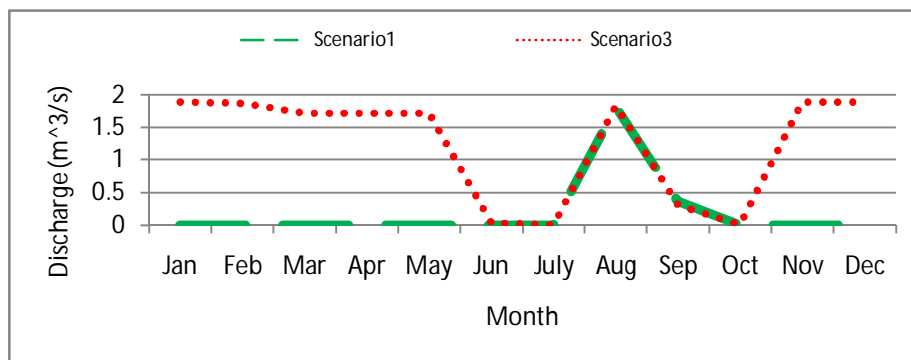


Figure 4.32: Water availability in Shipra under Scenario 1 and 3.

These combined models have been found very effective in simulating catchment runoff under changing hydrological conditions due to river diversion and river linking. Three different scenarios which are to be undertaken on Shipra to meet its water demand and maintain the water quality in the river, were developed in MB model for assessment of river flow at Ujjain in Shipra river under changing hydrological conditions. The Mike Basin model of Shipra was used for decision making and developing DSS application scenarios.

The first scenario was developed in MB model of Shipra without Khan Diversion and without Narmada-Shipra link. The results have shown that the Shipra at Ujjain is having flow only in monsoon season and river runs dry in non-monsoon season under natural conditions. In second scenario, to avoid polluted Khan water entering in to Shipra, a Khan diversion was added in the model and impact on water availability at Ujjain was assessed. The dependable lean period flow was found decreased due to Khan diversion at Ujjain and its magnitude can easily be analyzed graphically using hydrograph and flow duration curve and also using tabular information. Such information enables the planners or decision makers to have quick and comprehensive view of possible results. In the third scenario Narmada-Shipra link was added to the Shipra so that the Shipra can be supplemented from Narmada to meet its water demand and to make available

assured water for various occasions such as Kumbh on which holy bath is being taken by number of pilgrims on the Ghats of Shipra. This also helps to meet various water demands such as villages on the bank, on stream irrigation and industrial supply, etc. A flow of 2.5 m³/s was added through the link to Shipra which in turn have found improved the water availability at Ujjain and results have shown that a minimum of 1.7 m³/s dependable flow would be available even in non-monsoon months at very high probability.

In Scenario 4, the reservoir operation analysis was carried out for Gambhir reservoir which is the main source of water supply to Ujjain city. The supply demand analysis was carried out on long term basis considering the wet and dry years. In the year 2000, the region had experienced severe drought conditions and the reservoir storage in that year was not sufficient to meet annual demand of Ujjain city. From the simulation results it was observed that, if the reservoir supply had planned without any restriction, the reservoir would have been emptied by the month of March and no water to supply April 2000 onwards for summer months. The DSS scenarios were developed in Mike Basin model with restrictions of different operating rules to make supply to Ujjain city round the summer season with allowable deficit. The better scenario was obtained when the reduction level was fixed to the top level of the reservoir i.e. 545m; reduction fraction was kept 0.65 in the monsoon period and 0.6 in non-monsoon period. It means that restrictions were applied on water supply to Ujjain immediately after the withdrawal of monsoon when the reservoir was filled up to its FTL. Under this reservoir planning the available reservoir storage was utilized in such a way that Ujjain city got water supply throughout the year with some deficit even under severe drought situation.

The water availability analysis in Shipra at Ujjain under different hydrological conditions as mentioned in scenario 1, 2 and 3 was carried out using Mike Basin simulated flow time series during the period from 1990 to 2006. Monthly dependable flows were obtained from monthly FDC derived at Ujjain and it was concluded that there was no flow in non-monsoon period in Shipra under natural condition which further again critical due to Khan Diversion. The water availability at Ujjain has been found improved significantly during non-monsoon period due to Narmada-Shipra link. The Mike Basin model has been found capable of simulating catchment runoff under different hydrological conditions such river diversion, interlinking, losses, etc.

CHAPTER 5

ASSESSMENT OF CLIMATE CHANGE IN SHIPRA RIVER BASIN

5.1 Introduction

Climate change is a change in the statistical distribution of weather patterns when that change lasts for an extended period of time i.e., decades to millions of years. Climate change may refer to a change in average weather conditions, or in the time variation of weather around longer-term average conditions i.e., more or fewer extreme weather events. Climate change is caused by factors such as biotic processes, variations in solar radiation received by earth, plate tectonics, and volcanic eruptions. The global and local climate has been changing as evidenced by increase of temperature and rainfall intensity. Certain human activities have also been identified as significant causes of recent climate change, often referred to as "global warming" which may have highly extensive, complicated and uncertain impact on environment. Studies have demonstrated that global surface warming is occurring at a rate of 0.74 ± 0.18 °C over 1906-2005. Impact of climate change in future is quite severe as given by IPCC reports which signify that there will be reduction in the freshwater availability because of climate change. This has also been revealed that by the middle of 21st century, decrease in annual average runoff and availability of water will project up to 10–30% (IPCC, 2007).

The rainfall received in an area is an important factor in determining the amount of water available to meet various demands, such as agricultural, industrial, domestic water supply and for hydroelectric power generation. Global climate changes may influence long term rainfall pattern impacting the availability of water, along with the danger of increasing occurrences of droughts and floods. In India, the southwest monsoon, which brings about 80% of the total precipitation over the country, is critical for the availability of freshwater for drinking and irrigation. Changes in climate over the Indian region, particularly the southwest monsoon, would have a significant impact on agricultural production, water resources management and overall economy of the country. Water resources are important to both society and ecosystems. In many areas, climate change is likely to increase water demand while shrinking water supplies. This shifting balance would challenge water managers to simultaneously meet the needs of growing communities, sensitive ecosystems, farmers, ranchers, energy producers, and manufacturers.

In the process of decision making for water resources and management, the information of climate change impacts on catchment hydrology can be of great help to the planners to manage future water demands likely to be affected. In view of this, the present study envisages the assessment of climate change in Shipra river basin using trend analysis of rainfall, temperature data and simulated runoff data. The Shipra river basin come under the region of sizeable water

scars area with increasing water demand due to agricultural, domestic and industrial growth. Thus the climate change effect in this region may have adverse impact on natural resources and ultimately on its economy of the region. In this context, attempts have been made to assess the impact of possible climate change on catchment hydrology and water availability in the Shipra basin. Climate change indication can be accessed through statistical methods of trend analysis of climatic variables such as rainfall and temperature.

5.2 Materials and Methodology

5.2.1 Assessment of Climate Change

The effects of climate change can be assessed by detection of trend in climatic and hydrological variables over the long time period by number of statistical methods. A trend is a significant change over time exhibited by a random variable, detectable by statistical parametric and non-parametric procedures at different level of significance. Simple way to indentify trend is plotting straight line graph for the rainfall or temperature anomaly. Trend can also be identified using 3-year or 5-year moving average method. Generally, such tests are conducted for annual, seasonal, monthly time scale.

5.2.2 Trend Detection

Trend analysis of hydro climatic variables is one way to assess how the climate has evolved over time. Trend detection refers to methods used to extract an underlying behavioral pattern in a time series. Trend is defined as the general movement of a series over an extended period of time or it is the long term change in the dependent variable over a long period of time. Trend is determined by the relationship between two variables as temperature and time, rainfall and time, and rainy days and time. Trend in the rainfall time series can be detected by plotting simple straight line or by moving average method. Trend can also be detected by analysis of anomaly or residual time series. In the present study, trend analysis of all the independent weather parameters like annual rainfall, seasonal rainfalls, seasonal monthly rainfall, rainy days and temperature in Shipra basin were examined using straight line method, moving average method and by using statistical non parametric Mann-Kendall test

5.2.3 Trend Analysis for Climate Change

In order to understand the climate variability of rainfall and temperature in Shipra basin, long term rainfall and temperature data from 1961 to 2012 was analyzed to recognize the recent trend of variation in climatic data. In present study, rainfall trend analysis was carried out for the long term time series of 53 years time period from 1961 to 2013. Moreover, to quantify whether trend

appear particularly severe during a particular time period, time series were divided into two parts i.e. from 1961 to 1985 and 1986 to 2013 and results were analyzed separately for all time series. Monthly data obtained were converted to seasonal and annual averages for each station. Trends were identified for rainfall data using information like annual rainfall, maximum rainfall and rainy days by plotting straight line and 5-year moving average method. Trend was also detected by analysis of anomaly or residual time series. However, these methods only give information about rising or falling trend of the time series. To acquire the more information on trend such as its significance, statistical tests have to be conducted. To understand the climate change scenario in Shipra basin non-parametric Mann-Kendall test was conducted. It has a capability to identify positive (rising) or negative (falling) trend and demonstrate its significance. The rainfall trends over study area were analyzed for each rain gauge station on annual basis, quarterly basis, pre-monsoon period and monsoon period. Four quarters of the year were classified as 1st Quarter December to February, 2nd Quarter March to May, 3rd Quarter June to August and 4th Quarter September to November. The trend analysis of temperature data was carried out for monthly mean maximum, mean minimum, highest maximum and lowest minimum values.

5.2.4 Parametric and Non-parametric Statistical Tests

Both parametric and non-parametric statistical tests can be used in trend detection in order to quantify the significance of trends in a time series (Durdu, 2010). These may include tests such as linear regression, ordinary least squares (OLS), regression autoregressive integrated moving average (ARIMA) models, the Spearman partial rank correlation test (SPRC), and the Mann Kendall trend test, among others. The use of statistical tests involves testing of the null hypothesis which assumes that the data are random and are not correlated i.e., no trend will be observed against the alternative hypothesis that there will be a significant trend detected, either positive or negative. Although parametric tests are more powerful in nature, they have to satisfy the assumption of normal distribution, and independent observation (Önöz and Bayazit, 2003). If the assumptions made are not met, then the tests will yield unreliable results and interpretations, because the estimates of the significance level will not be correct (Kundzewicz and Robson, 2004).

Non-parametric tests are used when the assumptions of the parametric tests cannot be fully met. Non-parametric tests have less strict assumptions and have a higher tolerance with respect to missing values and non-normal distribution (Cunderlik and Burn, 2004). Since earth-based scientific phenomena including hydrological processes tend to have non-stationary characteristics and non-normal distributions, non-parametric tests are usually preferred over parametric tests in conducting a trend analysis (Hirsch and Slack, 1984; Lattenmaier, 1988). Furthermore, hydrological data normally exhibit autocorrelation; therefore, data values are not

independent. They may also show seasonality, which violates the assumption of constant distribution (Kundzewicz and Robson, 2004). In this study non parametric Mann-Kendall test was used for annual rainfall and temperature data to check whether the trend was significant or not at 95% level of significance i.e., $Z > +1.96$ or $Z < -1.96$.

5.2.5 Calculation of the Mann-Kendall Statistic

Mann (1945) presented a non-parametric test for randomness against time, which constitutes a particular application of Kendall's test for correlation, commonly known as the 'Mann-Kendall. The Mann-Kendall test is a non-parametric test for identifying trends in time series data. The test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987). One benefit of this test is that the data need not conform to any particular distribution. Moreover, data reported as non-detects can be included by assigning them a common value that is smaller than the smallest measured value in the data set. The procedure that will be described in the subsequent paragraphs assumes that there exists only one data value per time period. When multiple data points exist for a single time period, the median value is used.

The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, S , is assumed to be 0 (e.g., no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S .

Let X_1, X_2, \dots, X_n represents n data points where X_j represents the data point at time j . Then the Mann-Kendall statistic (S) is given by following equation.

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

Where

$$\text{sgn}(\theta) = \begin{cases} +1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases}$$

when $n > 10$ the S statistic is approximately normally distributed with zero mean and variance as follows:

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18}$$

The standard normal deviation (Z Value) is computed as

$$Z = \begin{cases} \frac{s-1}{\sigma} & \text{if } s > 0 \\ 0 & \text{if } s = 0 \\ \frac{s+1}{\sigma} & \text{if } s < 0 \end{cases}$$

A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. When $Z > +1.96$ or $Z < -1.96$ then null hypothesis (H_0) is rejected at 95% level of significance level. Significance of positive and negative trend is found by the Z values at 95% level of significance. If Z value is greater than +1.96 it shows significant rising trend and if Z value is less than -1.96 it shows significant falling trend.

5.3 Assessment of Impact of climate change on catchment hydrology

Hydrologic response of the river basin is dependent on meteorological, environmental, physiological, geological, anthropological and many other parameters. Climate change certainly has its impact on fresh water availability such as stream flow, reservoir, lakes or ground water. Adverse effects of climate change on freshwater systems aggravate the impacts of other stresses, such as population growth, changing economic activity, land-use change and urbanization. Globally, water demand will grow in the coming decades, primarily due to population growth and increasing affluence; regionally, large changes in irrigation water demand as a result of climate change are expected. Thus it is important to detect the impact of climate change on the yield and water availability in the river. This information could be of important to planners and decision makers to take appropriate decisions to meet the challenges of excess or deficit water situation due to climate change. Similarly, Climate change may also have its impact on groundwater regime of the river basin.

In the present study attempt has been made to study the impact of climate change on hydrological behavior of the basin. It involves the analysis of observed runoff data and modified runoff data for climate change condition. The NAM rainfall runoff model developed for Shipra basin was used for simulation of modified runoff or using the rainfall data which has been subjected to significant trend. The observed runoff data exhibits the hydrological response of the river under the given rainfall condition. Thus observed runoff was considered as the reference scenario runoff and the NAM model simulated runoff was considered as a climate change scenario runoff. Once the reference and climate change scenario time series obtained, they were analyzed and compared on the basis of water availability in the river, peak flows and annual yield to study the impact of climate change on the catchment hydrology. The water availability was assessed by comparing dependable flow at Ujjain at various probability levels. To estimate the dependable flow at various probability levels, the Flow Duration Curve technique was used.

5.4 Results and Discussion

For assessment of climate change and its impact on catchment hydrology in Shipra basin the rainfall data of stations falling in Shipra basin, temperature data of Indore IMD observatory and observed runoff and NAM model simulated discharge at Ujjain have been analyzed and results are discussed in this section.

5.4.1 Trend Analysis

To understand the trends in climatic variables, the simple straight line plot and 5-year moving average methods were used for long term information like annual rainfall, maximum rainfall and rainy days. Trends were also detected by analysis of anomaly time series of monsoon and non-monsoon rainfall. The seasonal (monsoon) anomalies of rainfall amount for each station were computed with reference to the mean of the respective variable for the available record. The graphs of regression plot and five year moving average for different rainfall data like annual rainfall, seasonal rainfall, rainy days and anomalies for Dewas, Indore and Ujjain stations were analyzed for presence of any trend which can be assessed visually as shown in Figures from 5.1 to 5.9. From figure 5.1, showing graphical representation of annual, seasonal rainfall, moving average of annual rainfall and rainy days time series of Dewas station, it can be seen that there was decreasing trend in annual rainfall, seasonal rainfall and rainy days and non-monsoon rainfall. The same decreasing trend can also be seen evident in monsoon and non-monsoon anomalies as shown in Figure 5.2 and 5.3.

Almost same rainfall pattern was observed at Indore station as shown in Figure 5.4. The annual rainfall and monsoon rainfall graphs were not showing any trend while decreasing trend can be seen in non-monsoon and rainy days time series at Indore. From the graphs of monsoon and non-monsoon anomalies as shown in Figure 5.5 and 5.6 respectively, it was observed that, the monsoon anomalies did not exhibit any trend while non-monsoon anomalies have shown decreasing trend.

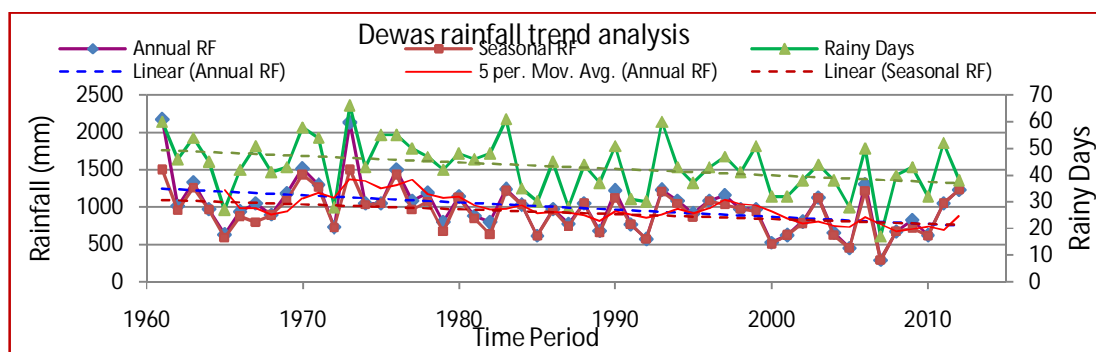


Figure 5.1: Trend analysis of rainfall and rainy days at Dewas station

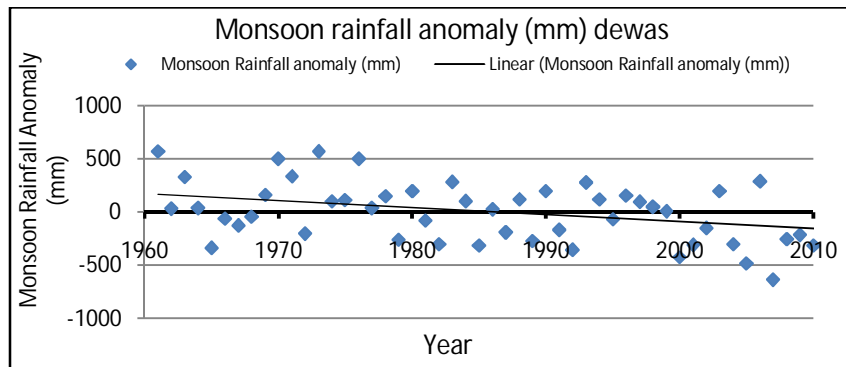


Figure 5.2: Trend analysis of Dewas monsoon rainfall anomaly

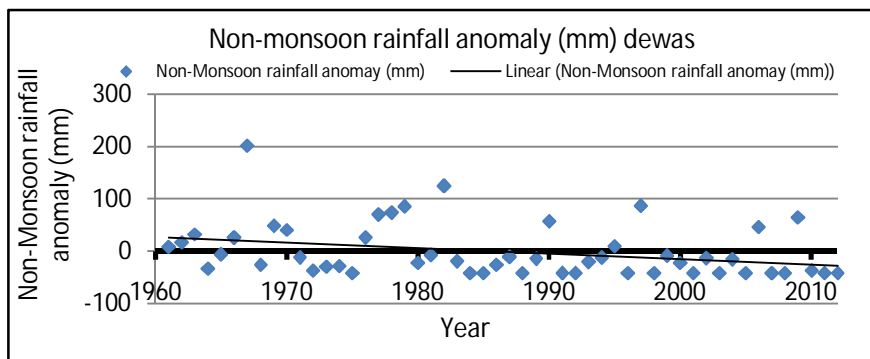


Figure 5.3: Trend analysis of Dewas non-monsoon rainfall anomaly

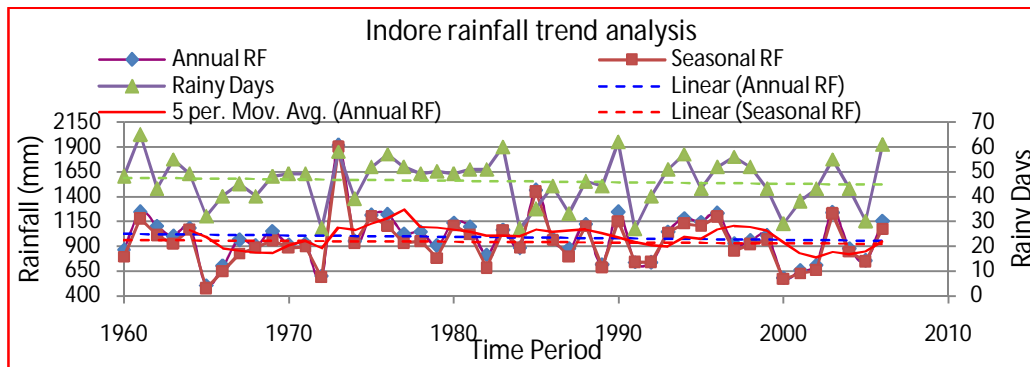


Figure 5.4: Trend analysis of rainfall and rainy days at Indore

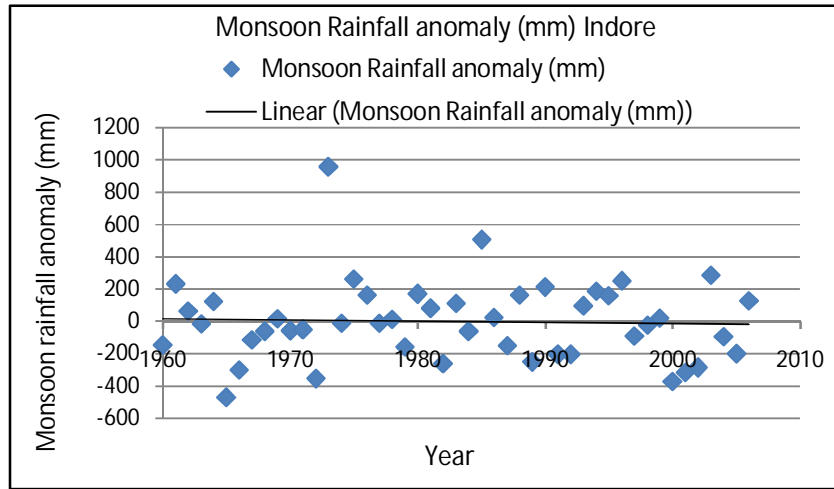


Figure 5.5: Trend analysis of monsoon rainfall at Indore

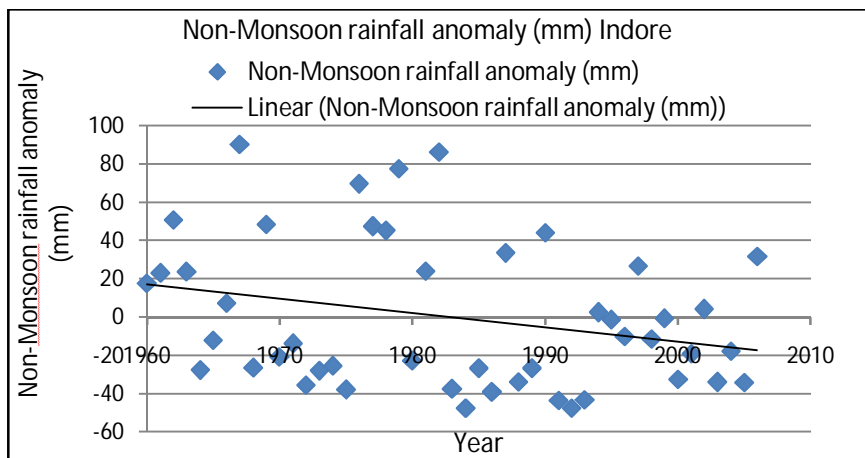


Figure 5.6: Trend analysis of non-monsoon rainfall at Indore

The trend analysis was also carried out for Ujjain station as shown in Figure 5.7. From the analysis of graphs, it was seen that the monsoon, non-monsoon rainfall and 5 year moving average graph did not show any trend while very slight falling trend was observed for number of rainy days. On comparison of anomaly graphs for monsoon and non-monsoon rainfall at Ujjain as shown in Figure 5.8 and 5.9 respectively, it was observed that monsoon anomaly did not show any trend while non-monsoon rainfall anomaly has shown very mild rising trend.

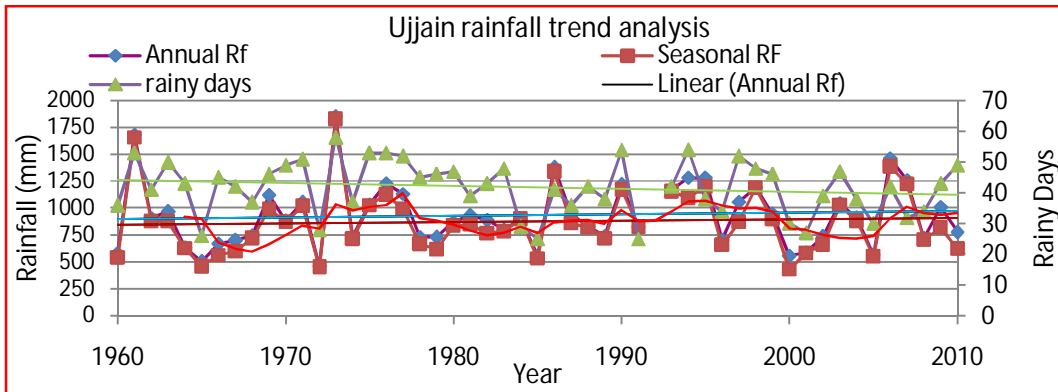


Figure 5.7: Trend analysis of rainfall and rainy days at Ujjain

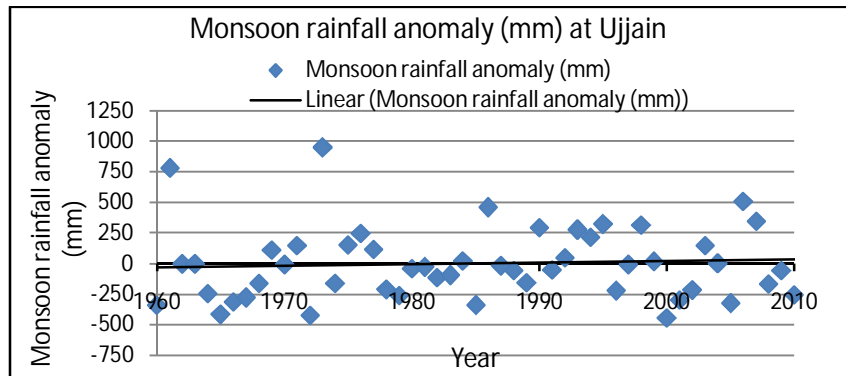


Figure 5.8: Trend analysis of monsoon rainfall anomaly at Ujjain

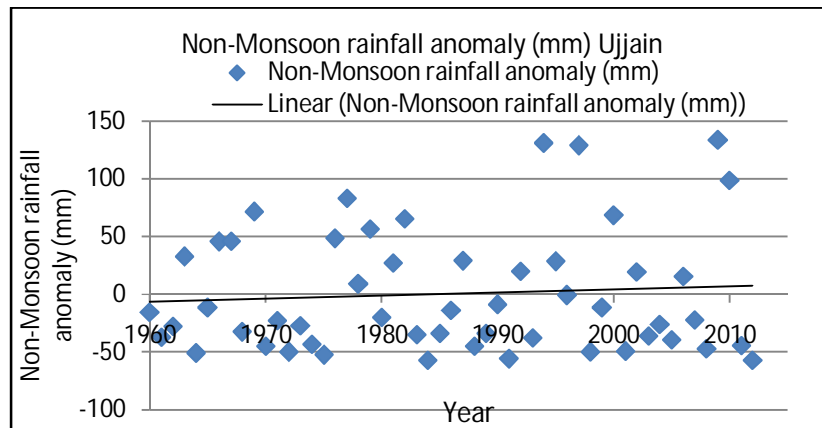


Figure 5.9: Trend analysis of non-monsoon rainfall anomaly at Ujjain

These straight line and moving averages graph plotted for rainfall data certainly show the presence of trend or no trend in the time series however it do not indicate the significance of rising or falling trend. Therefore, to assess and quantify the significance of the rising or falling

trend, a statistical non-parametric Mann-Kendall test was carried out using long term rainfall data of eight raingauge stations in Shipra basin.

5.4.2 Mann-Kendall Test

To understand the climate change scenario and to detect the presence of any trend in rainfall and temperature time series in Shipra basin non-parametric Mann-Kendall test was conducted. This test has a capability to identify positive (rising) or negative (falling) trend and demonstrate its significance. In present study, the rainfall trends over the study area were analyzed for of eight raingauge stations located in Shipra river basin on annual basis, quarterly basis, pre-monsoon period, monsoon period and rainy days. The trend analysis of temperature data was carried out for monthly mean maximum, mean minimum, highest maximum and lowest minimum values. Rainfall trend analysis was carried out for the long term time series of complete 55 years time period from 1958 to 2012. Moreover, to quantify whether trend appear particularly sever during a particular time period, time series were divided in to two parts i.e. from 1958 to 1985 and 1986 to 2012 and results were analyzed separately for all time series. The Mann-Kendall test was carried out using annual rainfall and temperature data to check whether the tread is significant or not at 95% level of significance i.e., $Z > +1.96$ or $Z < -1.96$.

The Mann-Kendall test results showing Z values at 95% level of significance for annual rainfall time series data from 1958-2012, 1958-1985 and 1986-2012 are given in Table no. 5.1, 5.2 and 5.3 respectively. The test results showing Z values at 95% level of significance for temperature data is given in Table 5.4.

Table 5.1: Mann-Kendall tests statistics Z values for rainfall from year 1958-2012

Station	Annua l	Monsoon	Non- Monsoon	June	July	Aug	Septr	Oct	Rainy days	Max. Rainfall
Dewas	-2.41	-1.77	-2.87	-1.04	-1.09	-1.62	-1.02	-0.97	-2.32	-1.34
Ujjain	1.07	0.93	-0.17	-0.77	0.00	0.93	1.01	2.42	-1.24	2.67
Indore	-0.55	-0.08	-1.35	0.80	0.08	0.17	-0.79	-0.79	0.02	0.99
Mahidpur	0.02	0.04	-0.95	0.90	0.02	0.37	0.26	-0.18	0.68	-1.37
Tarana	-0.33	-0.44	0.11	-0.54	1.38	0.18	0.00	0.16	-0.53	-0.67
Badnagar	0.60	-0.06	-0.09	1.47	0.68	0.10	0.06	-0.05	1.11	0.00
Khachrod	-1.19	-1.43	-2.04	0.41	-0.68	-0.15	-0.43	0.01	0.96	0.99
Sanver	0.54	0.67	-1.60	-0.71	1.04	-0.81	-0.13	0.36	-0.44	1.96

From the Table 5.1, showing Z values of long term annual rainfall time series from year 1958 to 2012 it was observed that in Shipra basin around 50% stations are experience falling trend in

annual rainfall and 60% stations are experiences falling trend in monsoon rainfall i.e. Dewas, Mahidpur, Tarana, Badnagar, Khachrod, Sanver. On comparing trend for number of rainy days, around 50% stations in Shipra basin like Dewas, Ujjain, Tarana and Sanver have experienced falling trend. Though the data indicated falling trend at many places, the trend was not found significant at 95% of significance level. Exceptionally Dewas station was observed as a critical station showing significant falling trend for the annual rainfall, non monsoon rainfall and for the rainy days at 95% level of significance with Z values -2.41, -2.87 and -2.32 respectively. Some stations in Shipra basin like Ujjain, Mahidpur, Badnagar and Sanver experienced rising trend too for annual rainfall time series but they were not found significant. However significant rising trend was observed at Ujjain for rainy days and maximum rainfall.

Table 5.2: Mann-Kendall tests statistics Z values for rainfall from year from 1958-1985

Stations	Annual	Monsoon	Non-Monsoon	June	July	Aug	Sept	Oct	Rainy days	Max. Rainfall
Dewas	-1.00	-0.82	-0.61	0.35	-2.13	0.86	-1.52	0.07	-0.44	-1.04
Ujjain	0.40	0.26	0.18	0.00	-0.53	2.16	-0.71	0.8	-0.11	0.88
Indore	0.71	1.10	-0.97	0.18	-0.18	1.45	-0.66	0.66	0.51	1.85
Mahidpur	-1.69	-1.81	-0.46	-0.31	-2.94	0.73	-1.81	0.3	-1.17	-1.25
Tarana	0.29	-0.15	-1.65	1.43	-1.35	1.48	-0.51	0.74	1.04	1.10
Badnagar	0.36	-0.26	0.28	1.98	-1.68	2.28	-2.32	0.08	0.2	-0.46
Khachrod	-1.50	-0.15	0.17	0.63	-2.17	1.55	-2.24	-0.09	1.12	-0.73
Sanver	-1.32	-1.32	-1.15	-1.50	-2.07	1.90	-1.94	2.22	-1.06	-0.29

From the Table 5.2, showing Z values of annual rainfall time series from year 1958 to 1985 it was observed that in Shipra basin around 50% of stations had a falling trend for annual rainfall and 75% stations had falling trend for monsoon rainfall i.e. Dewas, Mahidpur, Tarana, Badnagar, Khachrod, Sanver. On comparing trend for number of rainy days, around 63% stations had shown falling trend i.e. Dewas, Mahidpur, Badnagar, Khachrod and Sanver. Though there was falling trends at many stations but the trends were not significant at 95% of significance level. Exceptionally for July month few stations like Dewas, Mahidpur, Khachrod and Sanver had shown significant falling trend at 95% level of significance with Z value -2.13, -2.94, -2.17 and -2.07 respectively. When trend was compared on monthly rainfall times series basis, some stations like Ujjain, Indore, Tarana, Badnagar and Khachrod had experienced rising trend too however significant rising trend was observed only at two stations Badnagar and Sanver.

Table 5.3: Mann-Kendall test statistic Z values of rainfall from year 1986-2012

Stations	Annual	Monsoon	Non-Monsoon	June	July	Aug	Sept	Oct	Rainy days	Max. Rainfall
Dewas	-0.43	-0.06	-1.15	-2.13	0.00	-0.73	0.97	-0.98	0.02	0.91
Ujjain	-0.42	-0.29	-0.10	-2.59	-2.19	0.33	2.15	1.90	0.21	0.83
Indore	-0.31	-0.27	0.75	-1.48	-0.27	-0.02	1.61	-1.09	0.69	1.36
Mahidpur	1.48	1.40	1.28	0.32	0.57	0.40	1.64	-0.92	2.81	-1.13
Tarana	-1.13	-1.25	1.12	1.46	-1.06	-1.04	1.29	0.15	0.96	-2.08
Badnagar	-0.63	-1.21	-0.33	-1.50	0.42	-1.10	0.93	-0.25	-0.04	0.24
Khachrod	0.33	-0.13	-1.96	-0.10	-0.69	0.00	1.08	-1.14	0.15	-0.08
Sanver	0.31	-0.02	0.17	-1.06	-0.69	-0.1	1.25	0.09	0.42	1.65

From the Table 5.3, showing Z values of annual rainfall time series from year 1986 to 2012 it was observed that in Shipra basin around 63% of stations had observed falling trend for annual rainfall and 88% stations had observed falling trend for monsoon rainfall i.e. Dewas, Ujjain, Indore, Tarana, Badnagar, Khachrod, Sanver. On comparing trend for number of rainy days only one station Badnagar has shown falling trend. Though falling trend was observed at many stations, trend was not found significant at 95% of significance level. Exceptionally for June month, two stations Dewas and Ujjain had shown significant falling trend at 95% level of significance with Z value -2.13 and -2.59 respectively. The station Badnagar had shown significant falling trend for non monsoon rainfall. Some stations had experienced rising trend too, Dewas Ujjain, Mahidpur, Tarana, Badnagar, Khachrod and Sanver but significant rising trend was observed at Ujjain and Mahidpur for month of September and number of rainy days respectively.

Table 5.4: Mann-Kendall test statistic Z values for temperature

S.No	Month	M _{max}	H _{max}	M _{min}	L _{min}
1	January	0.89	2.74	1.41	1.33
2	February	0.36	1.95	2.93	3.18
3	March	2.36	1.55	2.45	2.81
4	April	2.39	1.84	0.69	0.15
5	May	1.95	1.78	0.81	1.38
6	June	0.74	2.34	1.31	1.97
7	July	0.93	0.34	2.10	-0.86
8	August	1.20	0.58	0.90	-0.22
9	September	1.92	1.60	1.49	1.76
10	October	2.37	2.46	0.88	0.95
11	November	3.57	3.10	1.76	1.94
12	December	3.35	2.78	1.82	2.90

It was very interesting to test the temperature data for detection of trend. From the Table 5.4 showing Z value of temperature of Indore from year 1956 to 2012 it was observed that overall temperature throughout the year was found increasing and most of the months have experienced significant rising trend at 95% significance level. From the analysis it can be seen that March, April, October, November and December had shown significant rising trend for mean maximum temperature (M_{max}) with Z value 2.36, 2.39, 2.37, 3.57 and 3.35 respectively. For highest maximum temperature (H_{max}), January, June, October, November and December months had shown significant rising trend. For Mean minimum temperature (M_{min}), February, March and July months had shown significant rising trend. For lowest minimum temperature (L_{min}), February, March, June and December months had shown significant rising trend i.e. with Z value 3.18, 2.81, 1.97 and 2.9 respectively. However July and August experienced non-significant falling trend with Z value -0.86 and -0.22 respectively. Thus from the above trend analysis of long term temperature data at Indore, it was observed that almost each month of the year is subjected to significant rising trend either it was M_{max} , H_{max} , M_{min} or L_{min} . The constant rise in temperature is the matter of concern for climate change, livelihood, especially water resources, agricultural production and other aspects of human life in the region.

5.4.3 Assessment of Impact of Climate Change on Catchment Hydrology

Assessment of impact of climate change on hydrological behavior of the basin involves the analysis of observed runoff data and modified runoff data for climate change condition using suitable tool like rainfall runoff model. In this analysis the observed data is considered as a reference scenario runoff whereas climate change scenario runoff was simulated using NAM rainfall runoff model with modified rainfall time series with significant falling trend as an input. The runoff data of Shipra basin at Ujjain G/d site for the period from 1988 to 2006 was used for this analysis. From the trend analysis of rainfall data as discussed in Section 5.3, it was observed that the Dewas station had shown significant falling trend having Z value -2.41 at 95% significance level. For the purpose of impact assessment of climate change on catchment hydrology it was assumed that the weighted rainfall of the Shipra basin up to Ujjain site is subjected to the significant falling trend as observed in case of Dewas station with Z value -2.41. However this is a hypothetical scenario generated to test and assess the impact of severe climate change condition. Therefore, for simulation of runoff data for climate change scenario, rainfall data was altered manually by manipulating the original rainfall data in such a way that on applying Mann-Kendall test, it would have significant falling trend at 95% level of significance with Z value -2.41. This modified rainfall data was then used as an input in NAM rainfall runoff model for generation of climate change scenario runoff and compared with reference scenario runoff on the basis of dependable flow at various probabilities, annual yield, peak flows and its correlation with rainfall.

The comparison of dependable flow at 75, 80, 85, 90 and 95% probability levels during monsoon runoff and individual months July, August and September for reference and climate change scenario are given in Table 5.5, 5.6, 5.7 and 5.8 respectively. From the analysis of these tables it was observed that climate change can have significant impact on stream flow in Shipra basin. The dependable flows at various probability levels were found decreased during monsoon season and all monsoon months individually due to significant decline of rainfall in Shipra basin.

Table 5.5: Dependable Flow in Monsoon Season for Reference and Climate Change Scenario

Month	Probability of Exceedance (%)	Dependable Flow (m ³ /s)	
		Reference Scenario	Climate Change Scenario
Monsoon Season (June-Sept)	70	0.90	0.17
	75	0.27	0.05
	80	0.02	0
	85	0	0
	90	0	0
	95	0	0

During monsoon season, dependable flow at 70% and 75% probability of exceedance for reference scenario was observed 0.9 m³/s and 0.27 m³/s and it was found decreased to 0.17 m³/s and 0.05 m³/s for climate change scenario respectively. The similar results were found for monthly rainfall also. For month of August dependable flow at 75% and 90% probability of exceedance was observed 9.7 m³/s and 2.21 m³/s for reference scenario and it was found decreased to 3.25 m³/s and 0.39 m³/s respectively for climate change scenario. The reduction in dependable flow during August and whole monsoon under climate change condition can be seen prominently from Figure 5.10 and 5.11.

Table 5.6: Dependable Flow in July for Reference and Climate Change Scenario

Month	Probability of Exceedance (%)	Dependable Flow (m ³ /s)	
		Reference Scenario	Climate Change Scenario
July	70	1.25	0.20
	75	0.65	0.08
	80	0.37	0.01
	85	0.16	0
	90	0.02	0
	95	0	0

Table 5.7: Dependable Flow in August for Reference and Climate Change Scenario

Month	Probability of Exceedance (%)	Dependable Flow (m ³ /s)	
		Reference Scenario	Climate Change Scenario
August	70	12.92	4.63
	75	9.70	3.25
	80	6.81	1.88
	85	4.36	0.98
	90	2.21	0.39
	95	0.83	0.13

Table 5.8: Dependable Flow in September for Reference and Climate Change Scenario

Month	Probability of Exceedance (%)	Dependable Flow (m ³ /s)	
		Reference Scenario	Climate Change Scenario
September	70	8.5	2.28
	75	5.57	1.27
	80	3.7	0.36
	85	2.39	0.12
	90	0.79	0.03
	95	0.01	0

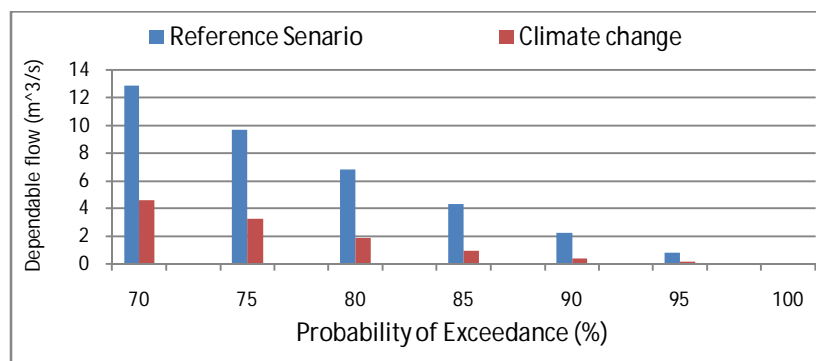


Figure 5.10: Comparison between dependable flow of reference and climate change scenario during August

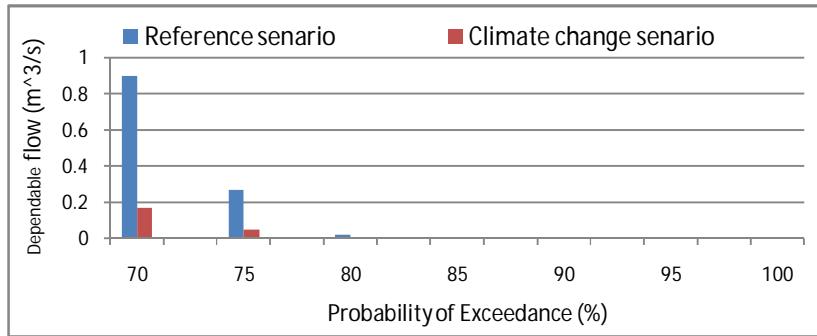


Figure 5.11: Comparison between dependable flow of reference and climate change scenario during monsoon

Similarly impact of impact of climate change on peak runoff and total runoff volume or annual yield was analyzed during the period from 1988 to 2006 as given in Table 5.9 and 5.10. From Table 5.9, it was observed that the climate change would have very significant impact on the peak flows in the river. In year 1988, peak flow under reference scenario was observed 202.38 m³/s and it was found decreased to 186.56 m³/s under climate change scenario, thus reduction in peak runoff due to climate change was 7.8%. Similarly, highest reduction was seen during 2003 where peak flow was observed decreased by 60.9% i.e. from 361.44 to 141.22 m³/s. Overall peak flow was found decreased by almost 8 to 61 % during all the years due to impact of climate change. Figure 5.12 shows comparison between Peak runoff of reference and climate change scenario.

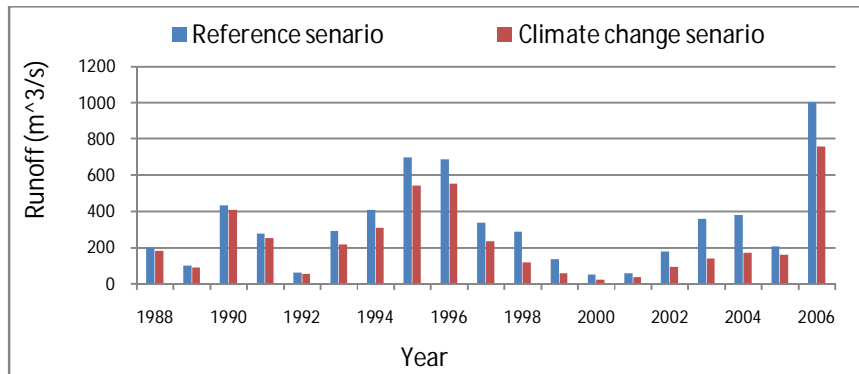


Figure 5.12: Comparison between Peak runoff of reference and climate change scenario

Table 5.9: Peak runoff (m³/s) for Reference and Climate change scenario

Year	Reference Scenario	Climate change Scenario	Difference (%)
1988	202.38	186.56	7.8
1989	104.66	94.06	10.1
1990	435.88	407.64	6.5
1991	277.59	254.10	8.5
1992	65.32	58.14	11.0
1993	296.25	220.94	25.4
1994	410.29	312.51	23.8
1995	702.99	543.63	22.7
1996	692.17	557.27	19.5
1997	340.06	238.37	29.9
1998	288.78	121.53	57.9
1999	136.70	62.68	54.2
2000	55.26	23.43	57.6
2001	63.54	42.74	32.7
2002	183.65	96.03	47.7
2003	361.44	141.22	60.9
2004	381.55	176.34	53.8
2005	210.50	160.02	24.0
2006	1004.77	759.58	24.4

On comparison of annual runoff volume under reference scenario and climate change scenario as given in Table 5.10, it was observed that the annual runoff volume of the river at Ujjain was seen decreased to great extent under climate change scenario. From table it was observed that, total runoff volume was decreased from 386.6 MCM to 331.17 MCM i.e. 14% decreased in the runoff volume from reference scenario to climate change scenario. This trend was seen during all the years. The decrease in annual runoff volume due to climate change can also be seen evident from Figure 5.13.

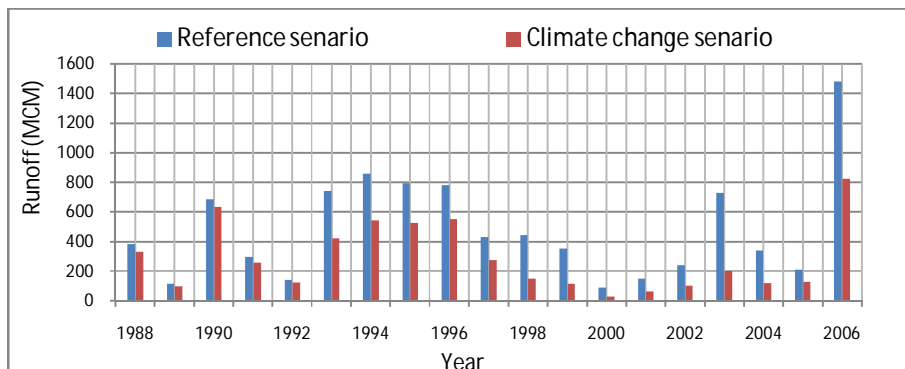


Figure 5.13: Comparison between annual runoff volume of reference and climate change scenario

Table 5.10: Annual runoff volume (MCM) for reference and climate change scenario

Year	Reference scenario	Climate change Scenario	Percentage change
1988	386.46	331.17	14.3
1989	117.54	102.06	13.2
1990	687.77	636.12	7.5
1991	297.10	260.90	12.2
1992	144.80	126.53	12.6
1993	743.90	425.09	42.9
1994	861.60	544.39	36.8
1995	791.68	527.06	33.4
1996	781.26	554.64	29.0
1997	434.48	277.47	36.1
1998	443.76	151.56	65.8
1999	354.82	116.94	67.0
2000	92.09	27.30	70.4
2001	150.18	68.40	54.5
2002	245.57	104.20	57.6
2003	731.96	200.51	72.6
2004	340.57	123.18	63.8
2005	212.93	129.22	39.3
2006	1483.66	821.88	44.6

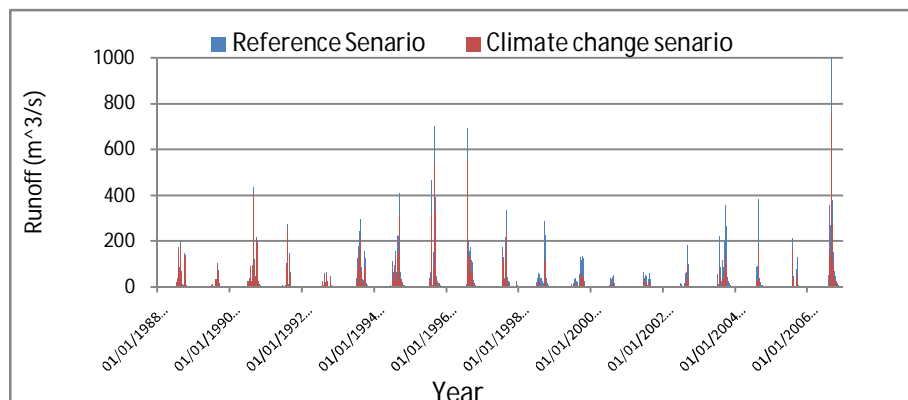


Figure 5.14: Comparison between runoff hydrograph of reference and climate change scenario

On comparison of dependable yield under reference scenario and climate change scenario as given in Table 5.11, it was observed that the dependable yield of the river at Ujjain was seen decreased to great extent under climate scenario. The dependable river yields at 75% and 90% probability of exceedance were 212.9 and 117.54 MCM for reference scenario which were found decreased to 116.9 and 68.3 MCM for climate change scenario respectively. Comparison between runoff hydrograph of reference and climate change scenario is shown in Figure 5.14.

Table 5.11: Dependable river yield for reference and climate change scenario

Probability of Exceedance (%)	Total volume (MCM)	
	Reference Scenario	Climate Change Scenario
70	245.57	123.18
75	212.93	166.94
80	150.18	104.19
85	144.8	102.05
90	117.54	68.39
95	92.09	27.3

5.5 Conclusions

The present study envisages the assessment of climate change impact of significant decline of rainfall in Shipra basin on runoff using long term hydro-meteorological data of Shipra river basin. The Shipra river basin come under the region of sizeable water scares area with increasing water demand due to agricultural, domestic and industrial growth. Under the circumstance, the climate change effect in this region may have adverse impact on natural resources and ultimately on its economy of the region. Thus the analysis was carried out to identify the trends of annual and seasonal rainfall at eight different stations in Shipra river basin as well as maximum and minimum temperatures at Indore. For identification of trend, straight line methods, moving average methods were used and to test the level of significance of trend, non parametric Mann-Kendall test was used.

From the trend analysis of rainfall data by straight line method it was observed that there was decrease in rainfall at some stations like Dewas, Indore however station like Ujjain has shown rising trend. According to Mann-Kendall test result, it was observed that over the period from 1956 to 2012, 50% stations of the basin have observed falling trend for annual rainfall time series and 60% station have observed falling trend for monsoon rainfall time series but trend was not found significant. Exceptionally Dewas was observed as a critical station showing significant falling trend for the annual rainfall, non monsoon rainfall and for the rainy days as well at 95% level of significance. When data was analyzed in two different time periods from year 1956 to 1985 and 1986 to 2012, Mann-Kendall test results shown that 50% of stations observed falling trend for annual rainfall and 75% stations observed falling trend for monsoon rainfall during 1956 to 2012. During this period significant falling trend was observed in the July rainfall at Dewas, Mahidpur, Khachrod and Sanver. During 1985 to 2012 Mann-Kendall test results shown that 63% of stations have observed falling trend for annual rainfall and 88% stations have observed falling trend for monsoon rainfall. During this period significant falling trend was observed in June rainfall at Dewas and Ujjain. Thus it could be concluded that significant falling

trend had been detected at Dewas during the long term time period and short term period as well. This may be due to rapid population growth in the city, fast urbanization and industrialization in nearby area which might have affected the local climate of the area. From the analysis it was also observed that some stations have shown rising trend too for particular months. The trend analysis of long term monthly temperature data indicated significant rising trend for mean maximum temperature (M_{max}), highest maximum temperature (H_{max}), mean minimum temperature (M_{min}) and lowest minimum temperature (L_{min}). The trend was observed significant during most of the months indicating overall temperature rise in the Shipra basin.

To assess the impact of climate change on catchment hydrology, the observed runoff time series was considered as a 'reference scenario runoff' and runoff simulated with the help of NAM rainfall runoff model using input rainfall time series with significantly falling trend was considered as 'climate change scenario runoff'. On comparison of runoff for reference and climate change scenario from 1988 to 2006, it was observed that dependable flows at various probability levels were found decreased for 'climate change scenario'. Similarly comparison between peak runoff and total volume was carried out and it was seen that peak flows and total volumes during 'climate change scenario' were found decreased significantly. Thus it could be concluded that if rainfall in Shipra basin been subjected to adverse impact of climate change such as significant falling trend, it would definitely affect the runoff yield of the river. Climate change will have severe impact on catchment hydrology and falling rainfall trend will not only reduce the runoff yield but also reduce the peak flows, low flows and it would have adverse impacts on the total water resource scenario of the basin. The basin may face huge water scarcity and reduction in dependable flow in river which may ultimately increases the demand deficit and may alter the economical activity of the region. However this scenario was purely hypothetical and aim of this exercise to highlight the impact of climate change more clearly.

Shipra river is one of the sacred river in Hinduism and Simhastha (Kumbh) is being held after every 12 years at Ujjain. Moreover Shipra water is being used to meet domestic, agricultural and industrial water demand in the region. The present climate change analysis offers remarkable insight and new prospective for policy makers, decision makers, water resource managers, agriculturist and planners in helping them to take proactive measures for water resources development and planning in context of climate change for regional level planning. Timely measures can help in reducing irreparable damages that can be caused by climate change.

CHAPTER 6

ASSESSMENT OF DECLINING FLOW IN SHIPRA RIVER

6.1 Introduction

In Central India most of the rivers are of intermittent nature having huge yield during monsoon which is drained down without being trapped and rivers becomes dry during non-monsoon or lean period. Those rivers which were of perennial nature are either becoming intermittent or facing the problem of reduction of lean period flow. The reasons behind this are over exploitation of surface and ground water resources to meet increasing domestic, irrigation and industrial water demands. The ground water contribution in the form of base flow to the river and return flows either of irrigation or other sources are responsible for the river flow during lean period. Thus decrease of base flow is one of the major reasons behind decline of during lean period. In case of Shipra river, it is reported that, the river was perennial up to mid seventies. Now the Shipra river flow has been seen reduced during monsoon and lean period as well and the nature of the river has been changed to intermittent where river has its flow during monsoon season and 2-3 months thereafter only. This intern has reduced the water availability and dependable flow of the river which is causing problem to fulfil various water demands of the people.

Number of researchers has worked on the aspects of declining of river flow all over the world. Szilagyi (2001) carried out study to identify causes of declining flows in the Republican river in the central great plains of North America. Based on the average annual water balance of the basin he concluded that decline in runoff values over two 20-year periods was accompanied by a similar reduction in the runoff ratio values. He used the formula given by Wigley and Jones (1985) to determine the relative change in runoff. He also concluded that the observed decline in runoff cannot be explained by changes in climatic variables over the area; rather, it is also the result of the combined effects of the following human activities: crop irrigation, change in vegetative cover, water conservation practices, and construction of reservoirs and artificial ponds in the basin. These human-induced changes increase the amount of water being evaporated over the basin, thereby reducing the amount of water available to runoff. Vyas (2008) in his draft for National River Policy described hydro geological approach to restore the depleting river. He listed out main factors responsible for decline of water table in the catchment of a river basin and also explained the possible causes of depletion of river flow during non monsoon season. He suggested various measures of river rejuvenation so that river water can meet drinking water needs of nearby locality and support agricultural activities.

In present study, an attempt has been made to address this issue scientifically through assessment of declining monsoon and lean period river flow and its quantification. The long term observed runoff data of Ujjain and Mahidpur station was analyzed for the assessment of trend in dependable flow and its quantification. The NAM RR model was used to simulate runoff at outlet of the Shipra for further analysis. The study aimed to identify the presence of trend in the flow of the river and its impact on water availability and dependable flow in the river using non parametric Mann-Kendall test. In the study Wigley and Jones Index (1985) was also used for identification of relative runoff change in the Shipra river basin. This index highlights the changes in the trend of runoff. The ground water data was analyzed and attempts were made to find the relation between ground water regime in Shipra basin and declining river flow in river. Possible remedial measures were proposed for sustainable Shipra river basin development and management.

6.2 Methodology

Assessment of declining flow in Shipra was carried out on the basis of analysis of dependable flow using observed runoff data and simulated runoff data at selected locations on Shipra as discussed below. Ground water data of the observations wells falling in the various reaches of the river basin were also analyzed and attempts were made to find the relation between ground water regime in Shipra basin and declining river flow in river. Possible remedial measures were proposed which may be useful for sustainable Shipra river basin rejuvenation.

6.2.1 Analysis of Dependable Flow

Dependable flow at Ujjain and Mahidpur gauge discharge sites and at Shipra outlet on 10 daily bases were analyzed to assess the flow variability in the Shipra river basin over the period of time. In this exercise the dependable flows at various probability levels i.e. at 70, 75, 80, 85, 90 and 95 percent probability of exceedance were evaluated using Flow Duration Curve technique using daily discharge data of 28 years period from 1985 to 2013. Runoff data of 28 years was grouped into 10-three years period like 1985-1987, 1988-1990, 1991-1993, 1994-1996, 1997-1999, 2000-2002, 2003-2005, 2006-2008, 2009-2011, 2012-2013. Daily discharge data of all 10-three years period was arranged on 10-daily bases as 1st 10-daily, 2nd 10-daily and 3rd 10-daily and so on up to 36th 10-daily from January to December.

6.2.2 Identification of Trend in River Flow

Natural changes in hydrologic variables are usually gradual and are caused by several reasons. Trend analysis of the hydrological time series is done to identify the nature of the hydrologic

process represented by the sequence of observations and occurrence of changes over the long time period.

In this study dependable flow estimated for 10 three years period using daily runoff time series of 28 years from 1985 to 2013 were used for the trend analysis at Ujjain, Mahidpur and Shipra river outlet. The observed discharge data of Ujjain and Mahidpur gauge discharge sites was used for the analysis. The discharge data of Shipra outlet point was not available due to unavailability of gauging site at that location hence the discharge data at its outlet was simulated using the NAM rainfall runoff model as discussed in chapter - - - Assessment of trend using linear graphical method and Mann- Kendall test has been discussed in detail in chapter **** of this report.

6.2.2.1 Wigley and Jones Index

Wigley and Jones (1985) suggested an index to determine the relative change in runoff using runoff time series data, precipitation, evapotranspiration information and runoff ratio. Runoff ratio is the percent of precipitation that emerges as runoff. Wigley and Jones index helps to determine the relative changes in runoff over a period of time which helps to judge the rising or declining of river flow. Wigley and Jones (1985) gave the following formula.

$$r_o = \frac{P - (1 - rr)et}{rr}$$

Where r_o = relative change (i.e., the ratio between the disturbed and undisturbed values) in runoff as a function of relative changes in precipitation p and evapotranspiration et ; and rr = runoff ratio.

To assess the relative change occurred in Shipra river flow over the period of time the Wigley and Jones applied to the observed runoff data at Ujjain having catchment area 2102 km² and Mahidpur having catchment area 4350 km². The annual weighted rainfall, runoff and evaporation data of Ujjain and Mahidpur sites from 1985 to 2012 was used in the index for the analysis of relative change in runoff. This index is one of the simplest and easiest methods to determine the trend in the runoff. Wigley and Jones also indicated that decline in runoff cannot only be explained by changes in climatic variables but it is the combined effect of all the human related activities such as crop irrigation, change in vegetative cover, water conservation practices, and construction of reservoirs and artificial ponds in the basin.

6.3 Results and Discussion

6.3.1 Dependable Flow and its Trend Analysis at Ujjain

6.3.1.1 Graphical trend analysis

The Ujjain site is located in the upstream of Shipra river covering 2012 km² area of Shipra basin. The dependable flow analysis of observed runoff data at Ujjain was carried out on 10-daily basis and the sample output of estimated dependable flow values at 75% probability of exceedance on 10 daily basis for 10 three years period are given in the Table 6.1.

Table 6.1: Dependable Flow in Shipra River at Ujjain G/D site at 75% probability

MONTH	10 Daily	1985-1987	1988-1990	1991-1993	1994-1996	1997-1999	2000-2002	2003-2005	2006-2008	2009-2011	2012-2013
JAN	1 st 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 nd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 rd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FEB	1 st 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 nd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 rd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAR	1 st 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 nd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 rd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
APR	1 st 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 nd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 rd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAY	1 st 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 nd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 rd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JUN	1 st 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 nd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 rd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JUL	1 st 10-Daily	0.00	0.00	0.00	0.00	1.76	0.00	0.00	0.00	0.00	0.00
	2 nd 10-Daily	0.00	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00	0.00
	3 rd 10-Daily	0.00	0.00	1.73	6.35	1.94	0.00	0.58	0.00	0.00	0.00
AUG	1 st 10-Daily	0.00	0.00	3.42	6.95	2.40	0.37	5.28	5.82	4.72	0.00
	2 nd 10-Daily	0.00	0.00	2.05	3.20	3.01	2.20	0.00	5.00	4.23	0.00
	3 rd 10-Daily	0.00	2.34	0.84	12.43	2.52	1.52	1.11	3.46	6.72	17.80
SEPT	1 st 10-Daily	0.00	1.96	2.89	38.52	3.05	0.45	0.00	3.29	14.75	26.00
	2 nd 10-Daily	0.00	0.00	0.00	3.97	4.25	0.00	0.00	3.27	0.00	11.55
	3 rd 10-Daily	0.00	0.00	0.00	2.07	3.98	0.00	0.00	0.00	0.00	0.00
OCT	1 st 10-Daily	0.00	0.00	0.00	1.61	2.89	0.00	0.00	0.00	0.00	0.00
	2 nd 10-Daily	0.00	0.00	0.00	1.88	3.24	0.00	0.00	0.00	0.00	0.00
	3 rd 10-Daily	0.00	0.00	0.00	0.00	2.76	0.00	0.00	0.00	0.00	0.00
NOV	1 st 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 nd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 rd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DEC	1 st 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 nd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 rd 10-Daily	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The sample graph showing linear trend for 1st 10 daily of monsoon months at 75% probability at Ujjain are shown in Figure 6.1. These graphs indicated that the dependable flow in 1st 10 daily period in the month of July and October has shown falling trend whereas for in 1st 10 daily period of August and September shown rising trend.

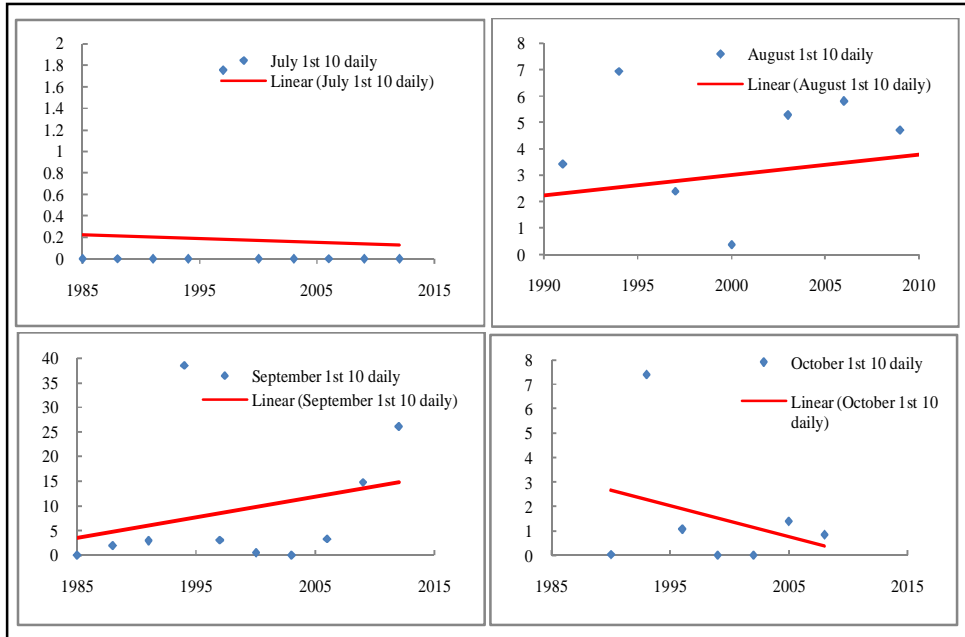


Figure 6.1: Linear Trend for 10 Daily data of Monsoon Months at Ujjain (1985-2013)

The results of the graphical linear trend analysis whether rising trend (*RT*), falling trend (*FT*), or no trend (*NT*) were summarized at all the probability levels and are given in Table 6.2.

From Table 6.2, showing results of simple linear trend analysis, it can be seen that the river at Ujjain show No trend (*NT*) during non monsoon or lean period. This was observed due to no flow situation during non monsoon season for most of the three years period at 70% probability and above. From the analysis of trend, July 2nd and 3rd 10 daily period of has been found experiencing falling trend. The period from August 1st 10 daily to September 2nd 10 daily has been found experiencing rising trend for dependable flow at Ujjain. However, the remaining period of monsoon from September 2nd 10 daily onwards has been found with falling trend for dependable flow at all probabilities. Thus from linear trend analysis it could be broadly be seen that the Shipra at Ujjain do not have flow at 70% and higher probability during lean period. Hence it has indicated no trend during non monsoon or lean period. At Ujjain, the dependable flow of Shipra has shown falling trend in the beginning of monsoon period. It was found experiencing rising trend during middle of the monsoon i.e. August and was found falling trend thereafter.

Table 6.2: Trend chart of 10 daily data of Ujjain at various probability levels
(Rising trend-RT, Falling trend-FT, No trend-NT)

MONTH	10 DAILY	70%	75%	80%	85%	90%	95%
JAN	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
FEB	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
MAR	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
APR	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
MAY	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
JUN	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
JUL	1 st 10-Daily	FT	FT	FT	NT	NT	NT
	2 nd 10-Daily	FT	FT	FT	FT	NT	NT
	3 rd 10-Daily	RT	FT	FT	FT	FT	NT
AUG	1 st 10-Daily	RT	RT	RT	RT	RT	RT
	2 nd 10-Daily	RT	RT	RT	RT	RT	RT
	3 rd 10-Daily	RT	RT	RT	RT	RT	RT
SEPT	1 st 10-Daily	RT	RT	RT	RT	RT	RT
	2 nd 10-Daily	RT	RT	RT	RT	FT	FT
	3 rd 10-Daily	FT	FT	FT	FT	FT	FT
OCT	1 st 10-Daily	FT	FT	FT	FT	FT	FT
	2 nd 10-Daily	FT	FT	FT	FT	FT	FT
	3 rd 10-Daily	FT	FT	FT	FT	NT	NT
NOV	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
DEC	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT

6.3.2 Mann-Kendall Test Analysis

Though the dependable flow in the river indicate mixed trend i.e. rising or falling trend during the monsoon, it was considered necessary to be judged on the basis of its significance. To assess whether the trend was significant or not, a trend analysis was carried out using non-parametric

Mann-Kendall (MK) test. The Z value showing MK statistics at 95% confidence level for dependable flow values at various probability levels are given in Table 6.3.

Table 6.3: Z Statistic of 10 daily data of Ujjain at various probability levels

MONTH	10 DAILY	70%	75%	80%	85%	90%	95%
JAN	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
FEB	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
MAR	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
APR	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
MAY	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
JUN	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
JUL	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	-0.78	0	0	0	0	0
	3 rd 10-Daily	0.37	-0.71	-0.78	-0.56	-0.78	0
AUG	1 st 10-Daily	2.07	0.64	1.3	1.11	1.48	1.3
	2 nd 10-Daily	0.93	0.93	1.11	0.93	1.15	0.96
	3 rd 10-Daily	1.61	1.97	1.71	1.53	1.54	1.92
SEPT	1 st 10-Daily	0.63	1.53	1.53	1.54	1.92	1.73
	2 nd 10-Daily	0.92	1.12	0.92	0.31	-0.11	-0.11
	3 rd 10-Daily	0	-0.26	-0.26	-0.26	-0.26	0
OCT	1 st 10-Daily	-0.26	-0.26	-0.26	0	0	0
	2 nd 10-Daily	-0.26	-0.26	-0.26	-0.26	-0.52	-0.35
	3 rd 10-Daily	0	0	0	0	0	0
NOV	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
DEC	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0

From the analysis of Table 6.3 it was observed that the MK test has also exhibited the result as obtained through graphical method. The dependable flow for non monsoon period shows no trend with Z value zero up to July 1st 10 daily. The July 2nd to 3rd 10 daily period was found

experiencing falling trend but it was not found significant. The August 1st 10 daily to September 1st 10 daily rising trend was found. The rising trend was found significant only during August 3rd 10 daily at 75% probability i.e. Z value 1.97 at 95% confidence level. The September 2nd 10 daily onwards the dependable flow has shown falling trend as Z value was found negative but was not found significant as all z values were found higher than -1.96.

6.3.3 Wigley and Jones Index

Wigley and Jones index applied to determine the relative changes in runoff over a period of time which helps to judge the rising or declining of river flow at Ujjain. To perform this analysis, weighted annual Rainfall, Runoff and Evapotranspiration of Shipra up to Ujjain catchment area was considered. These parameters were applied for the period from 1985 to 2012 in Two Distinct 14 and 13 Year Periods i.e. 1985 to 1998 and 1999 to 2012 respectively and results in the graphical form are shown in Figure 6.2 to 6.5.

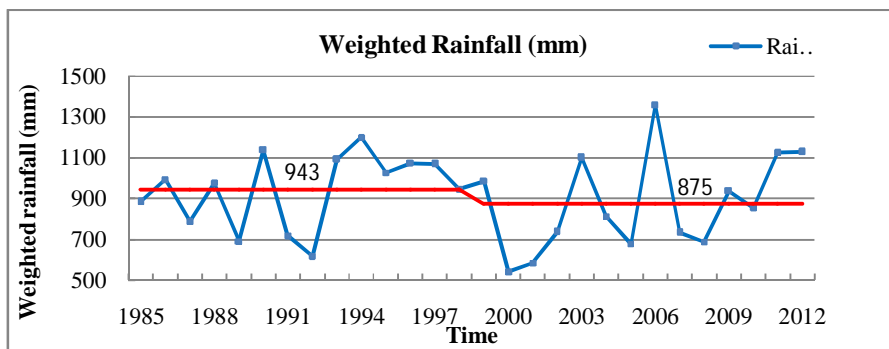


Figure 6.2 : Weighted annual precipitation (mm) at Ujjain in two distinct periods 1985-1998 and 1999-2012

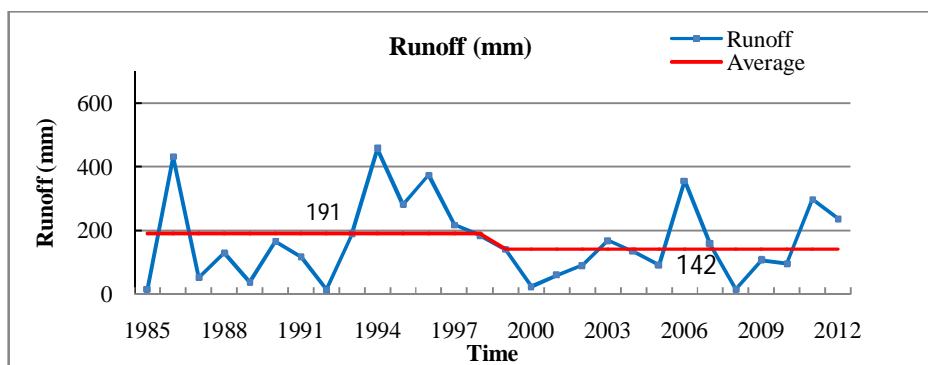


Figure 6.3: Annual discharge (mm) at Ujjain in two distinct periods 1985-1998 and 1999-2012

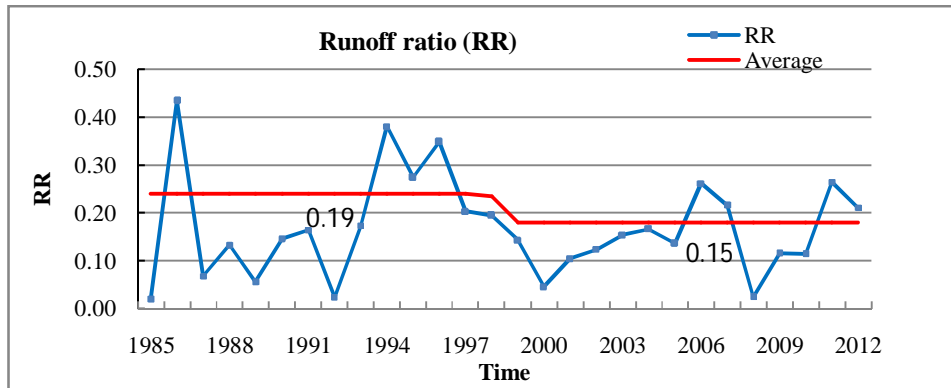


Figure 6.4: Annual runoff ratios (%) at Ujjain in two distinct periods 1985-1998 and 1999-2012

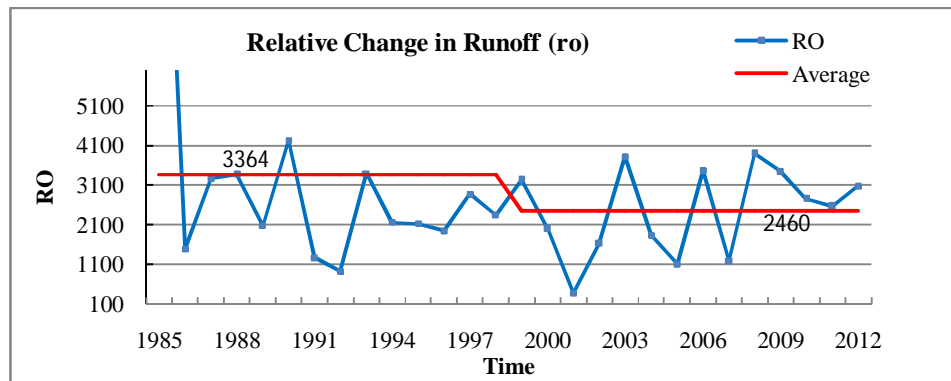


Figure 6.5: Relative change in runoff at Ujjain in two distinct periods 1985-1998 and 1999-2012

From Figure 6.2 it is clearly observed that at Ujjain, the weighted average annual rainfall has been found decreased during the recent period from 1999 to 2012 as compared to old period from 1985 to 1998. The weighted average annual rainfall value has been found decreased from 943 to 875 mm. Similarly, average annual runoff shown in Figure 6.3, Runoff ratio shown in Figure 6.4 and Relative change in runoff (r_0) shown in Figure 6.5 have shown significant decrease during the recent period 1999 to 2012 as compared to old period 1985 to 1998. Thus from the entire three tests it can broadly be observed that at Ujjain, over the period of time, the rainfall and runoff has decreased to great extent.

6.3.4 Dependable Flow and Its Trend Analysis at Mahidpur

6.3.4.1 Simple graphical methods

The Mahidpur G/d site is located at the downstream of Shipra river covering 4350 km² area of Shipra basin. To assess the trend in runoff data at Mahidpur, dependable flow analysis was

carried out using simple graphical methods. The graphs showing linear trend for 1st 10 daily of monsoon months at 75% probability at Mahidpur are shown in Figure 6.3.

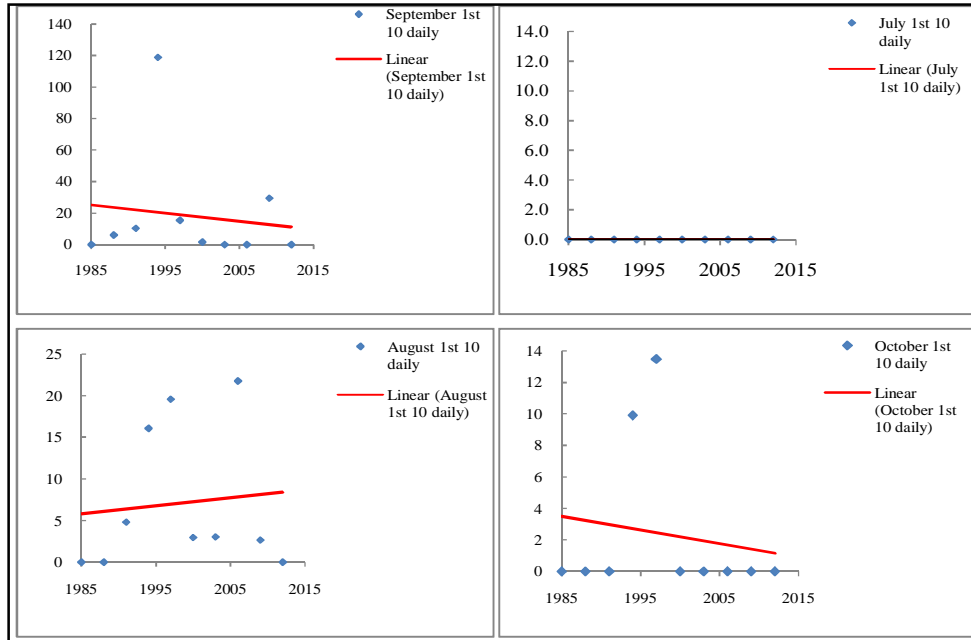


Figure 6.6: Linear Trend for 10 Daily data of Monsoon Months at Mahidpur (1985-2013)

The results of the graphical linear trend analysis whether rising trend (*RT*), falling trend (*FT*), or no trend (*NT*) of Mahidpur were summarized at all the probability levels and are given in Table 6.4.

From Table 6.4 showing simple linear trend analysis, it can be seen that the river has no flow during non monsoon season at 70% probability and above. Thus, showing no trend (*NT*) during non-monsoon period at Mahidpur. The July 2nd and 3rd 10 daily period has been found experiencing falling trend. The August 1st 10 daily at all probability and August 2nd 10 daily at 75 and 80% probability has been found experiencing rising trend for dependable flow at Mahidpur. The remaining period of monsoon from August 2nd 10 daily to November 1st 10 daily has been found with falling trend for dependable flow at all probabilities. From November 2nd 10 daily onwards no trend was observed in non monsoon season.

From the analysis of above Table 6.4 showing linear trend analysis it could be broadly be seen that the Shipra river at Mahidpur do not have flow at 70% and higher probability during lean period. Then its trend cannot be assessed for non monsoon or lean period. At Mahidpur, the dependable flow of Shipra has shown falling trend in the beginning of monsoon period. It was

found experiencing rising trend during middle of the monsoon i.e. August and was found falling trend thereafter.

Table 6.4: Trend chart of 10 daily data of Mahidpur at various probability levels
(Rising trend-RT, Falling trend-FT, No trend-NT)

MONTH	10 DAILY	70%	75%	80%	85%	90%	95%
JAN	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
FEB	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
MAR	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
APR	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
MAY	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
JUN	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
JUL	1 st 10-Daily	FT	NT	NT	NT	NT	NT
	2 nd 10-Daily	FT	FT	FT	FT	FT	FT
	3 rd 10-Daily	FT	FT	FT	FT	FT	FT
AUG	1 st 10-Daily	RT	RT	RT	RT	RT	NT
	2 nd 10-Daily	NT	RT	RT	NT	FT	FT
	3 rd 10-Daily	FT	FT	FT	FT	FT	FT
SEPT	1 st 10-Daily	FT	FT	FT	FT	FT	FT
	2 nd 10-Daily	FT	FT	FT	FT	FT	FT
	3 rd 10-Daily	FT	FT	FT	FT	FT	FT
OCT	1 st 10-Daily	FT	FT	FT	FT	FT	FT
	2 nd 10-Daily	FT	FT	FT	FT	FT	FT
	3 rd 10-Daily	FT	FT	FT	FT	FT	FT
NOV	1 st 10-Daily	FT	FT	FT	FT	FT	FT
	2 nd 10-Daily	FT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT
DEC	1 st 10-Daily	NT	NT	NT	NT	NT	NT
	2 nd 10-Daily	NT	NT	NT	NT	NT	NT
	3 rd 10-Daily	NT	NT	NT	NT	NT	NT

6.3.5 Mann-Kendall (MK) Test

Though the river experienced mixed type of trend rising or falling trend during the monsoon, it was needed to be judged on the basis of its significance. To assess the trend was significant or not a trend analysis was carried out using non-parametric Mann-Kendall (MK) test. The Z value showing MK statistics at 95% confidence level for dependable flow values at various probability levels are given in Table 6.5.

Table 6.5: Z statistic of 10 daily data of Mahidpur

MONTH	10 DAILY	70%	75%	80%	85%	90%	95%
JAN	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
FEB	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
MAR	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
APR	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
MAY	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
JUN	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
JUL	1 st 10-Daily	-1.04	0	0	0	0	0
	2 nd 10-Daily	-0.58	-0.1	-0.56	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
AUG	1 st 10-Daily	0.64	0.27	0.27	0.45	0.37	0.19
	2 nd 10-Daily	-0.09	0.09	0	-0.19	-0.19	-0.58
	3 rd 10-Daily	-1.17	-1.17	-1.36	-1.72	-1.54	-1.54
SEPT	1 st 10-Daily	-0.09	-0.37	-0.37	-0.93	-0.74	-1.12
	2 nd 10-Daily	-1.15	-1.15	-1.32	-1.32	-1.32	-1.32
	3 rd 10-Daily	-0.78	-0.78	0.78	0	0	0
OCT	1 st 10-Daily	-0.26	-0.26	-0.26	-0.26	-0.26	-0.52
	2 nd 10-Daily	-0.26	-0.26	-0.26	-0.26	-0.26	-0.26
	3 rd 10-Daily	-0.26	-0.26	-0.26	-0.26	-0.26	-0.26
NOV	1 st 10-Daily	-0.26	-0.26	-0.26	-0.35	-0.35	-0.35
	2 nd 10-Daily	-0.35	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0
DEC	1 st 10-Daily	0	0	0	0	0	0
	2 nd 10-Daily	0	0	0	0	0	0
	3 rd 10-Daily	0	0	0	0	0	0

From the analysis of Table 6.5 it was observed that the MK test also exhibited the result as obtained through graphical method. The non monsoon period shows no trend with Z value zero up to June 3rd 10 daily. The July 2nd 10 daily periods was found experiencing falling trend but it was not found significant. No trend was found in July 3rd 10 daily periods. The August 1st 10 daily at all probability was found rising trend but was not significant. The August 2nd 10 daily to November 1st 10 daily showed falling trend as Z value was found negative but was not found significant as all z values were found higher than -1.96.

6.3.6 Wigley and Jones Index

Wigley and Jones Index is also one of the methods to analyze the trend of runoff. This index helps to determine the relative change in runoff over a period of time. To perform this Index weighted annual Rainfall, Runoff and Evapotranspiration (ET) of Mahidpur area was required as discussed in section 3.3.2.3 earlier. When these parameters were applied in formula for Mahidpur area from period 1985 to 2012, following results were obtained in graphical form shown in Figure 6.7 to 6.10.

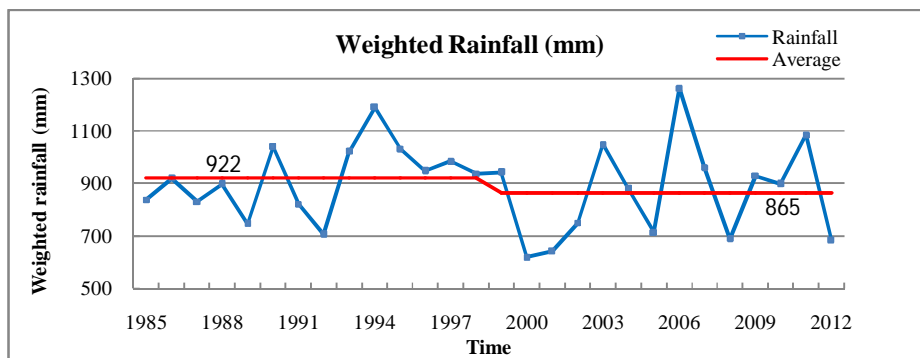


Figure 6.7: Weighted annual precipitation (mm) at Mahidpur for periods 1985-1998 and 1999-2012

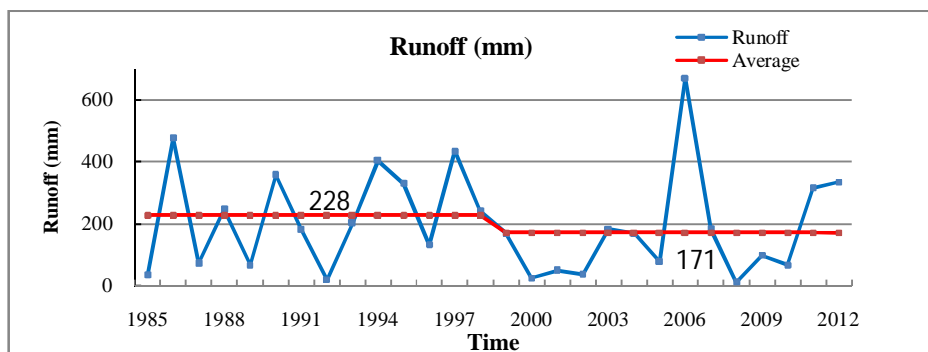


Figure 6.8: Annual discharge (mm) at Mahidpur in two distinct periods: 1985-1998 and 1999-2012)

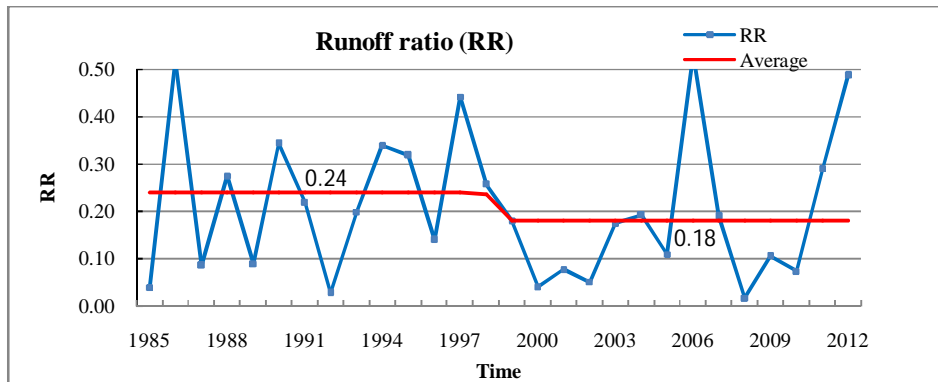


Figure 6.9: Annual runoff ratios (%) at Mahidpur in two distinct periods: 1985-1998 and 1999-2012)

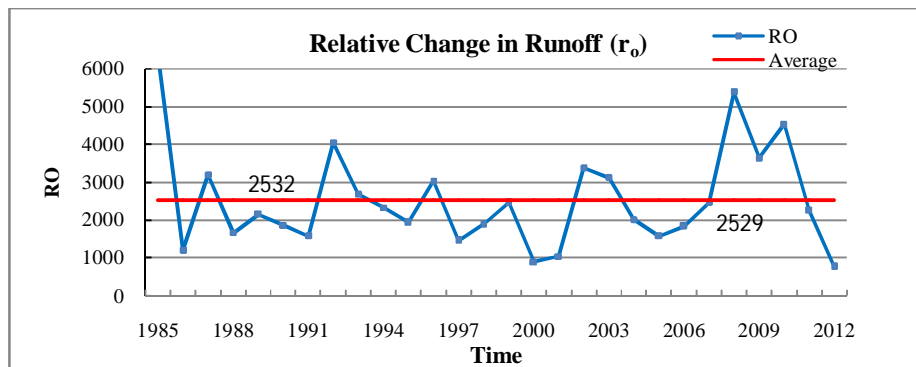


Fig. 6.10: Relative changes in runoff at Mahidpur in two distinct periods: 1985-1998 and 1999-2012)

From Figure 6.7 it is clearly observed that at Mahidpur, the weighted average annual rainfall has been found decreased during the recent period from 1999 to 2012 as compared to old period from 1985 to 1998. The weighted average annual rainfall value has been found decreased from 922 to 865 mm. From Average annual runoff shown in Figure 6.8 and Runoff ratio shown in Figure 6.9 shown significant decrease during recent period whereas relative change in runoff (r_o)_h shown in Figure 6.10 have little change in average value during 1985 to 2012. Thus from these four tests it can be broadly observed that in Mahidpur also over the period of time river flow has decreased significantly in monsoon as well as non monsoon period in Shipra river.

6.4 Dependable Flow and Its Trend Analysis at Outlet of Shipra basin.

Shipra river after flowing through the Ujjain and Mahidpur reaches and confluence with Chambal river. Since there was no G/d site at the outlet, the runoff was simulated at this location

where Shipra joins river Chambal. To simulate runoff at outlet of the Shipra, the NAM Rainfall-Runoff model was used. The NAM simulated runoff time series of the period from 1990 to 2010 was analyzed to assess the river flow characteristics at the outlet point of Shipra as analyzed in case of Ujjain and Mahidpur.

6.4.1 Graphical trend analysis

The analysis of simulated runoff and dependable flow 70% probability of exceedance shown that the river has flow even during non monsoon months as well. To assess the trend in runoff over the long time period, a simple graphical technique was used. The sample graph showing linear trend for 1st 10 daily of monsoon months at 75% probability of exceedance at outlet of Shipra are shown in Figure 6.11. The dependable flow thus obtained on 10-daily basis for seven 3 years period from 1990 to 2010 at 70, 75, 80, 85, 90, 95% probability levels were analyzed graphically for identification of trend, if any, and are summarized in Table 6.7

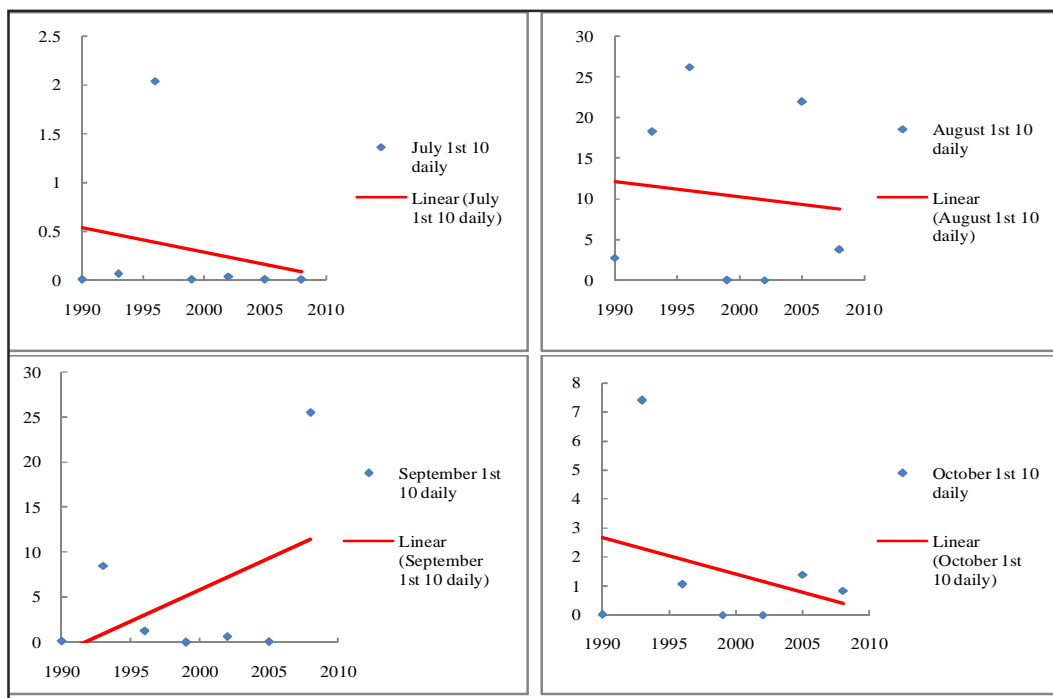


Figure 6.11: Linear Trend for 10 Daily data of Monsoon Months at outlet of Shipra River (1990-2010)

From the analysis of results it was observed that the Shipra river has flow during monsoon and non-monsoon season as well. Thus it can be said that the Shipra at its outlet has perennial flow. From Table 6.7, it was observed that the dependable flow during the lean period exhibits falling trend at all probability levels above 70%. The August 2nd 10 daily to October 1st 10 daily has

been found experiencing rising trend. The period from October 2nd 10 daily to December 3rd 10 daily was found to experience falling trend for dependable flow at outlet of river basin.

Table 6.6: Dependable Flow in Shipra River at outlet at 75% probability.

MONTH	10 Daily	1990-1992	1993-1995	1996-1998	1999-2001	2002-2004	2005-2007	2008-2010
JAN	1 st 10-Daily	0	0	1.21	0	0	0.02	0.04
	2 nd 10-Daily	0	0	1.13	0	0	0.02	0.04
	3 rd 10-Daily	0	0	1.05	0	0	0.02	0.03
FEB	1 st 10-Daily	0	0	0.98	0	0	0.02	0.03
	2 nd 10-Daily	0	0	0.91	0	0	0.02	0.03
	3 rd 10-Daily	0	0	0.86	0	0.02	0.02	0.03
MAR	1 st 10-Daily	0	0	0.81	0	0	0.01	0.03
	2 nd 10-Daily	0	0	0.75	0	0	0.01	0.02
	3 rd 10-Daily	0	0	0.7	0	0	0.01	0.02
APR	1 st 10-Daily	0	0	0.65	0	0	0.01	0.02
	2 nd 10-Daily	0	0	0.61	0	0	0.01	0.02
	3 rd 10-Daily	0	0	0.57	0	0	0.01	0.02
MAY	1 st 10-Daily	0	0	0.53	0	0	0.01	0.02
	2 nd 10-Daily	0	0	0.5	0	0	0.01	0.02
	3 rd 10-Daily	0	0	0.46	0	0	0.01	0.01
JUN	1 st 10-Daily	0.01	0	0.43	0	0	0.01	0.01
	2 nd 10-Daily	0.01	0.01	0.4	0.01	0	0.01	0.01
	3 rd 10-Daily	0.01	0.41	0.38	0.01	0.71	0.01	0.01
JUL	1 st 10-Daily	0.01	3.73	2.13	0.01	0.79	0.08	0.01
	2 nd 10-Daily	0.13	138.30	1.99	0.98	0.01	0.07	0.01
	3 rd 10-Daily	4.56	62.69	21.76	18.37	0	15.01	0.01
AUG	1 st 10-Daily	10.29	175.42	91.7	0.26	26.65	114.05	14.39
	2 nd 10-Daily	5.60	4.96	6.52	5.85	19.3	59.69	21.47
	3 rd 10-Daily	43.42	33.74	20.14	1.97	62.2	13.43	35.05
SEPT	1 st 10-Daily	3.53	11.55	20.8	0.01	15.71	0.23	46.61
	2 nd 10-Daily	0.08	17.16	5.98	0	17.02	41.54	22.34
	3 rd 10-Daily	0.04	14.82	17.03	0	0.53	11.28	17.85
OCT	1 st 10-Daily	0.01	13.46	2.2	0	0	10.53	3.76
	2 nd 10-Daily	0.06	6.78	2.05	0	0	0.08	0.37
	3 rd 10-Daily	0.05	6.27	0.71	0	0	0.04	0.01
NOV	1 st 10-Daily	0	5.83	0.66	0	0	0.03	0.09
	2 nd 10-Daily	0	5.45	0.61	0	0	0.03	0
	3 rd 10-Daily	0	5.09	0.57	0	0	0.03	0
DEC	1 st 10-Daily	0	4.75	0.54	0	0	0.03	0
	2 nd 10-Daily	0	4.44	0.5	0	0	0.03	0
	3 rd 10-Daily	0	4.14	0.47	0	0	0.02	0

Table 6.7: Trend analysis of 10-Daily flow of Shipra at outlet at various probability levels

MONTH	10 DAILY	70%	75%	80%	85%	90%	95%
JAN	1 st 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	2 nd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	3 rd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
FEB	1 st 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	2 nd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	3 rd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
MAR	1 st 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	2 nd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	3 rd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
APR	1 st 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	2 nd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	3 rd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
MAY	1 st 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	2 nd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	3 rd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
JUN	1 st 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	2 nd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	3 rd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
JUL	1 st 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	2 nd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	3 rd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
AUG	1 st 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	2 nd 10-Daily	<i>RT</i>	<i>RT</i>	<i>RT</i>	<i>RT</i>	<i>RT</i>	<i>RT</i>
	3 rd 10-Daily	<i>FT</i>	<i>FT</i>	<i>RT</i>	<i>RT</i>	<i>RT</i>	<i>RT</i>
SEPT	1 st 10-Daily	<i>RT</i>	<i>RT</i>	<i>RT</i>	<i>RT</i>	<i>RT</i>	<i>RT</i>
	2 nd 10-Daily	<i>RT</i>	<i>RT</i>	<i>RT</i>	<i>RT</i>	<i>RT</i>	<i>RT</i>
	3 rd 10-Daily	<i>RT</i>	<i>RT</i>	<i>RT</i>	<i>RT</i>	<i>RT</i>	<i>FT</i>
OCT	1 st 10-Daily	<i>RT</i>	<i>NT</i>	<i>NT</i>	<i>FT</i>	<i>NT</i>	<i>FT</i>
	2 nd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	3 rd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
NOV	1 st 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	2 nd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	3 rd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
DEC	1 st 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	2 nd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>
	3 rd 10-Daily	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>	<i>FT</i>

At the outlet, the dependable flow of Shipra has shown decreasing trend in the beginning of non-monsoon or lean period. However, the rising trend was observed for dependable flow at various probability levels during August 2nd 10 daily and September of monsoon period. Shipra river was found experiencing rising trend during middle of the monsoon i.e. August and September and was found falling trend thereafter.

6.4.2 Mann-Kendall test

For further investigation and to check the significance of rising or falling trend in dependable flow, non-parametric Mann-Kendall test was used for trend analysis. The Z value showing MK statistics at 95% confidence level for dependable flow values at various probability levels are given in Table 6.8

Table 6.8: z statistic of 10 Daily data at outlet of Shipra River at Kalu-Kher Village

MONTH	10 DAILY	70%	75%	80%	85%	90%	95%
JAN	1 st 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
	2 nd 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
	3 rd 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
FEB	1 st 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
	2 nd 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
	3 rd 10-Daily	1.20	1.20	1.20	1.20	1.20	1.20
MAR	1 st 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
	2 nd 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
	3 rd 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
APR	1 st 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
	2 nd 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
	3 rd 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
MAY	1 st 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
	2 nd 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
	3 rd 10-Daily	0.90	0.90	0.90	0.90	0.90	0.90
JUN	1 st 10-Daily	0.00	0.90	0.00	0.00	0.90	0.90
	2 nd 10-Daily	-0.90	-0.30	0.00	0.00	0.00	0.00
	3 rd 10-Daily	0.00	-0.30	-0.60	-0.60	-0.60	-0.60
JUL	1 st 10-Daily	-0.75	-0.75	-0.75	-0.75	-0.45	-0.60
	2 nd 10-Daily	-1.35	-1.65	-1.50	-1.50	-1.20	-1.05
	3 rd 10-Daily	-0.90	-1.20	-0.90	-0.90	-1.20	-1.05
AUG	1 st 10-Daily	-0.30	0.00	0.00	-0.30	0.00	0.00
	2 nd 10-Daily	1.50	2.10	1.80	2.40	2.10	0.00
	3 rd 10-Daily	-0.30	-0.30	0.00	0.00	0.30	0.30
SEPT	1 st 10-Daily	0.60	0.60	0.30	0.00	0.00	0.00
	2 nd 10-Daily	1.50	1.20	0.60	0.30	0.30	0.00
	3 rd 10-Daily	0.90	0.90	0.90	0.60	0.30	0.15
OCT	1 st 10-Daily	0.00	0.00	-0.15	-0.15	0.00	-0.15
	2 nd 10-Daily	-0.15	-0.15	-0.45	-0.45	-1.05	-1.05
	3 rd 10-Daily	-1.05	-1.05	-1.05	-1.05	-0.75	-0.60
NOV	1 st 10-Daily	-0.15	0.00	-0.15	-0.60	-0.60	-0.60
	2 nd 10-Daily	-0.15	-0.60	-0.60	-0.60	-0.60	-0.60
	3 rd 10-Daily	-0.15	-0.60	-0.60	-0.60	-0.60	-0.60
DEC	1 st 10-Daily	-0.15	-0.60	-0.60	-0.60	-0.60	-0.60
	2 nd 10-Daily	-0.15	-0.60	-0.60	-0.60	-0.60	-0.60
	3 rd 10-Daily	-0.15	-0.60	-0.60	-0.60	-0.60	-0.60

From the analysis of Table 6.8, it was observed that the MK test also exhibited the similar results as obtained through graphical method. The non monsoon period from January 1st 10 daily shows falling trend but was not significant up to June 1st 10 daily. The June 2nd 10 daily periods to August 1st 10 daily was found experiencing falling trend but it was not found significant. During August 2nd 10 daily significant rising trend was found at 75, 85 and 90% probability with Z value 2.103, 2.403 and 2.103 respectively. The August 3rd 10 daily to September 3rd 10 daily rising trends was observed but was not significant. Then after October 1st 10 daily to December 3rd 10 daily non significant falling trend was observed.

6.5 Ground water data analysis

To compare the results of declining river flow in Shipra with the ground water status of the area in basin a trend analysis of ground water levels data was carried out. For this purpose the observation wells falling in 5 km distance from the river course in upstream area, middle area and downstream area were identified. The pre-monsoon and post-monsoon groundwater level data of such 15 wells from 1984 to 2014 was analysed graphically to assess the general trend at selected wells in the basin. The location of observation wells falling in Shipra basin is shown in Figure 6.12

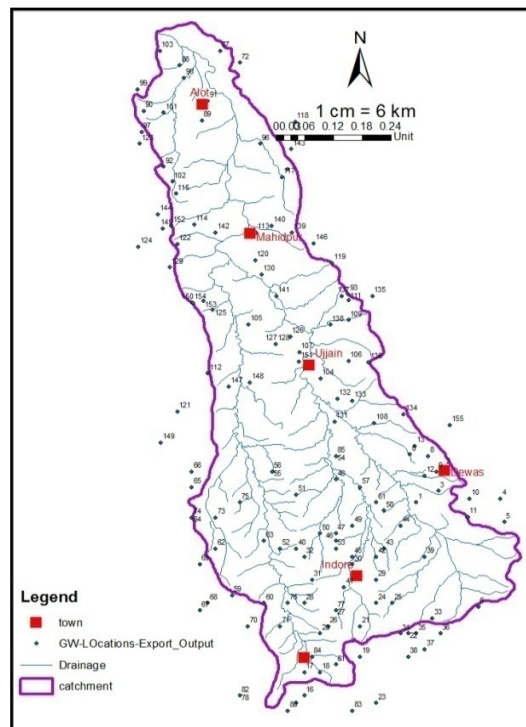


Figure 6.12: Location of observation wells falling in Shipra basin

The graphs showing groundwater table trend in upstream of the Shipra basin covering stations, Lohar pipliya, Buran khedi, Barlai, Narwar, Nonora and average groundwater levels are shown in Figure 6.13. The graphs showing groundwater table trend in middle area of the Shipra basin covering stations, Panth pipliya, Kheda khajuria, Lohona, Narayana, Kaluheda and average groundwater levels are shown in Figure 6.14. The graphs showing groundwater table trend in the downstream area of the Shipra basin covering stations, Barakhedokalan, Khajuri deora, Shisha kheri, Tal and Alot area are shown in Figure 6.15.

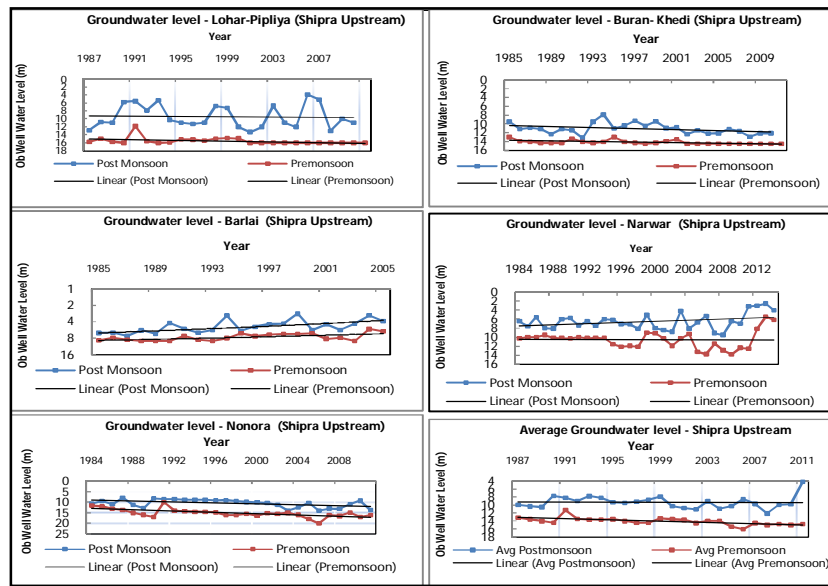


Figure 6.13: Ground water table in upstream area of the Shipra basin

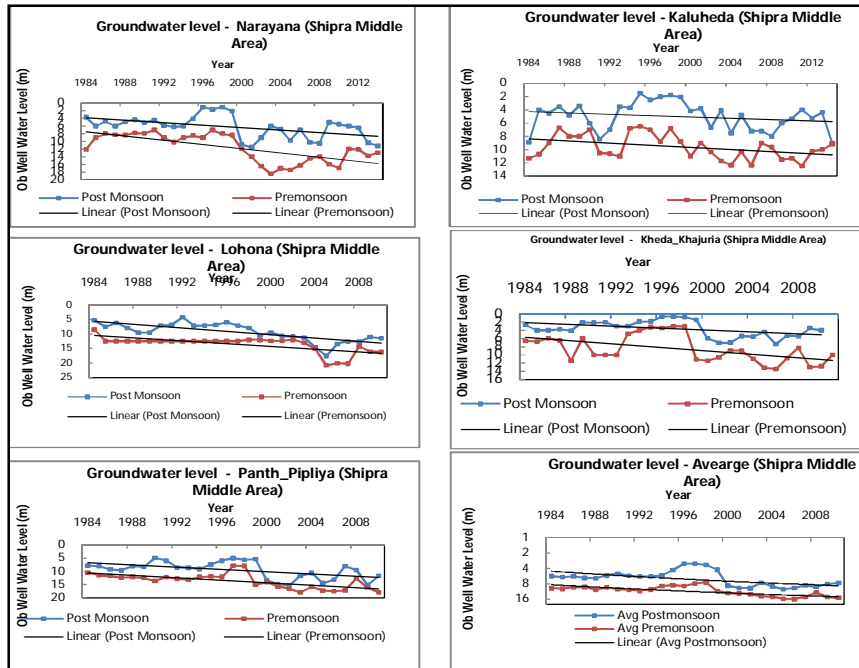


Figure 6.14: Ground water table trend in middle area of the Shipra basin .

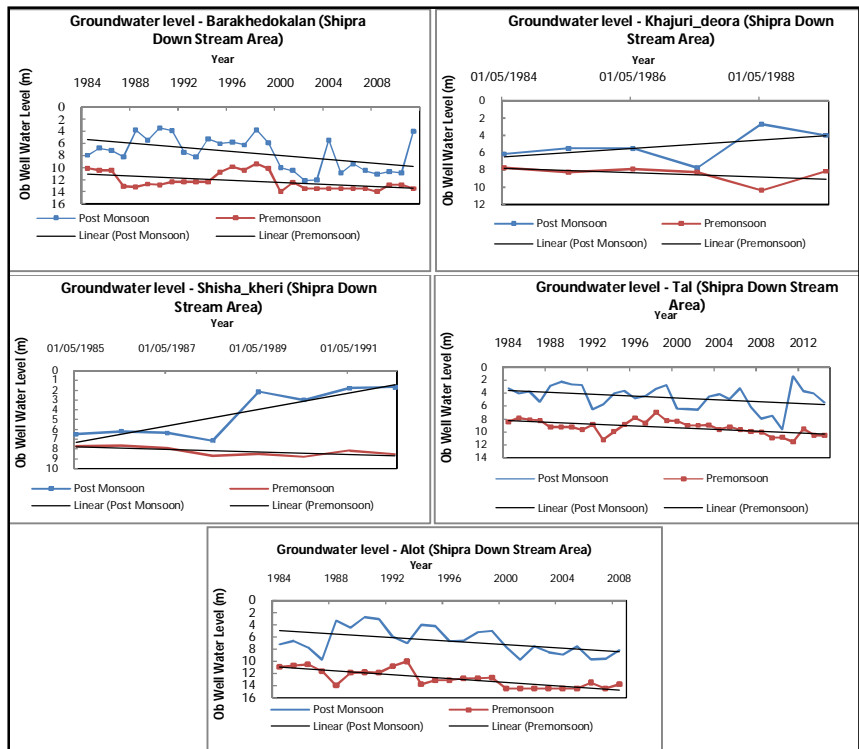


Figure 6.15: Ground water table trend in the downstream area of Shipra basin

The results indicated that the ground water levels in the Shipra basin upstream has shown falling trend at all the individual well locations and even when regionalized, the falling trend was observed at upstream area, middle area and downstream area in the basin. Declining of ground water levels was found higher in middle area of the basin where important cities like Indore and Ujjain are located. Thus it may be concluded that the declining of ground water levels causing reduction of base flow is the main reason for reduction of lean period flow in the river.

6.6 Conclusions

The analysis of Shipra river flow data indicated an intermittent nature at Ujjain and Mahidpur however it became perennial at its outlet near Kalu-Kher village confluencing Chambal river. To identify the existence of trend in the dependable flow, trend analysis was carried out using graphical and Mann-Kendall test. The relative change in runoff was assessed and analyzed using Wigley and Jones Index. From the trend analysis of dependable flow it could broadly be concluded that at Ujjain and Mahidpur, Shipra river has no flow during lean period hence judging the trend during lean period was intricate. However the dependable flow in Shipra river during monsoon season exhibited rising and falling trend both. During the beginning and end of monsoon months at Ujjain and Mahidpur Shipra river was found experiencing falling trend whereas during mid monsoon (august, September) rising trend was observed. Mann-Kendall test was also found supporting the trend exhibited through linear or graphical method. From the analysis using NAM simulated discharge data at outlet of Shipra, it was concluded that Shipra river has become perennial however the flow during monsoon and non monsoon was found declining in the same fashion as at Ujjain and Mahidpur. Thus the overall runoff data analysis at different locations in Shipra river indicated the declining flow situation during lean period in Shipra basin which may cause threat for water resources management in the basin and need of urgent attention for its revival.

The falling trend in the Shipra runoff in beginning and at the end of monsoon may be indicative of impact of land use practices adopted in the basin. However the rising of river runoff in the middle of the monsoon may be due to insufficient or incapable land use practices to handle high runoff during principle rainy months. Thus it shows the need of adaptation proper land treatment in the basin to handle peak and high runoff so that it may augment groundwater recharge and will be helpful to manage prolonged lean period flow in the river.

From the analysis ground water table data of upstream, middle reach and downstream area of the Shipra basin it may be concluded that the declining of ground water levels causing reduction of base flow is the main reason for reduction of lean period flow in the river.

6.7 Possible reasons for reduced lean period flow in Shipra

The Shipra river water of the Shipra is used for drinking, industrial use and lift irrigation purposes and to take holy dip during various occasions at Ujjain Ghats. It is reported that there is a normal practice of pumping water from the river for providing irrigation to surrounding agricultural fields. Earlier the Shipra river was perennial but now, the river flow has been reduced during monsoon and non monsoon (lean) period as well and the nature of the river has been changed to intermittent where river flow only during monsoon and 2-3 months thereafter. Major portion of the Shipra basin uses ground water to meet its irrigation demand. The river basin has generally shallow aquifers with poor storage capacity and the natural discharge generally dewater the ground water aquifers immediately after monsoon. Moreover due to increasing of ground water exploitation, the water table goes down and aquifers are emptied fast and therefore their contribution to the river system as base flow gets reduced. This situation reduces ground water contribution to Shipra river during non-monsoon season i.e. ultimately reducing the quantity and duration of flow in the entire river. Beside this, possible causes of base flow reduction in the Shipra river may be the very high spatial and temporal variability of rainfall, reduction in rainfall or change in rainfall pattern, recurrent droughts, climatic changes affecting rainfall pattern, rapid urbanization and increasing water demands, river diversions and changes in hydrological conditions of the watershed. Another reason may be the deforestation, which has caused the depletion of water retaining capacity of the river catchment.

6.8 Possible remedial measures for sustainable Shipra river basin revival

- Main reason behind declining of river flow is the reduction of base flow in Shipra river. Hence it is important to identify causes and formulate of strategies based on scientific input for base flow augmentation in Shipra.
- Base flow augmentation can be achieved through the temporary storage of subsurface water in floodplains, stream banks or stream bottoms during the wet season, either by natural or artificial means, for later release during the dry season to increase the magnitude and duration of low flows. Base flow augmentation strategies may includes:
 - ✓ range management
 - ✓ upland vegetation management
 - ✓ riparian vegetation management
 - ✓ upland runoff detention and retention
 - ✓ use of in-stream structures on main Shipra river and its tributaries: identification of potential sites which can provide maximum capacity with in-stream submergence only.
- Implementation of integrated watershed management programs through IWMP and other government schemes in sub-watersheds.

- Water conservation practices in sub-watersheds, construction of small dams on joining streams.
- Ground water recharging by natural and artificial methods
- Water harvesting and water management strategies in the basin
- Selection of priority watersheds for soil and water conservation measures, water harvesting and water management strategies.
- Improving irrigation practices to make judicious use of ground water with conjunctive use of surface and ground water
- Demand management in the Shipra basin, reduction of losses and prioritization of water for various uses such as drinking water needs of nearby locality, industrial use, holy purposes and irrigation use for sustainability of flow.
- Immediate action needed to improve water quality in Shipra and its tributaries, specially Khan river which is carrying municipal sewage load of Indore city and industrial waste in to Shipra
- Rejuvenation of traditional water bodies and small dams.
- Micro irrigation, small surface water schemes, farm tanks, catchment management, conjunctive use of surface and groundwater resources, adopting different techniques of irrigating fields (drip and sprinkler)
- Plantation of local indigenous native species along the river bank which may help to absorb water, recharge local water bodies and then release it slowly to maintain a minimum flow in the river.
 - ✓ For forested catchment area: Babool, Neem, Salai, Khair, Seja, Tendu, etc
 - ✓ On river bank: Babool, Neem, Salai, Palas, Chhind, Jamun, etc
- Plantation of grass, shrubs of local indigenous species in the catchment.
- Coordination between various Govt. organization, trainings, mass awareness, peoples participation.

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