

Report no. ____

DECISION SUPPORT SYSTEM FOR WATER RESOURCES PLANNING IN UPPER
BHIMA BASIN, MAHARASHTRA

2017-18

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN, ROORKEE, UTTARAKHAND, INDIA

PREFACE

DSS essentially consists of an easy to use interface to various simulation models and tools needed for water resources planning. Availability of various tools in one platform makes it easy for decision maker to obtain information with regard to water resources in a basin for various planning scenarios. In World Bank assisted Hydrology Project- II, one of the projects was a development of a Decision Support System (DSS) for water resources planning. In this project, a DSS was developed by DHI, Denmark for Government of India. DSS was customized for pilot basins in nine participating states in India. The DSS consists of a platform, Mike Basin Hydro water allocation model and lumped and distributed rainfall- runoff modelling systems. Platform is a modular system and has various modules namely GIS, time series, spreadsheet, scenario, dashboard and scripting.

In customization of the DSS for pilot basins, models were developed in a close source Mike Basin software. For Maharashtra, Upper Bhima Basin up to Ujjaini was taken up for a pilot study. In the present study, development of applications were continued in this pilot basin of Maharashtra State. In the basin, two reservoir complexes namely Khadakwasla and Kukadi exist. The complexes have multi- purpose uses. In particular, Khadakwasla complex has large uses for both municipal and irrigation purposes. Due to presence of several reservoir in the western Ghat region in the basin, large command area exists. In particular, large area is irrigated by New Mutha Right Bank Canal Command area. Conjunctive use planning will be needed for the command area. Large part of the study area lies in rain shadow zone and is effected by drought. Meteorological drought is one of the drought types and the area is effected by meteorological drought. In the study investigations were done in multipurpose reservoir operation, meteorological drought, BOD and DO in Mula-Mutha and Bhima river and conjunctive use operation in a command. Various methods and modeling tools were used in the study. For reservoir operation and conjunctive use study, Mike Hydro Basin was used. BOD and DO simulation was carried out using spread sheet. Online available computer program executable was used for computing SPI from rainfall data.

This is a final report of the study entitled 'Decision support system for water resources planning in Upper Bhima basin, Maharashtra' and was carried out under the work programme of Water Resources Systems Division, National Institute of Hydrology, Roorkee. The study group comprises of D.S. Rathore, M.K. Goel, R.P. Pandey, Sanjay Kumar and Surjeet Singh.

(S. K. Jain)
Director

Contents

ABSTRACTS.....	ii
1.0 INTRODUCTION.....	1
2.0 REVIEW.....	3
3.0 STUDY AREA, DATA AND SOFTWARE.....	5
4.0 METHODOLOGY.....	9
5.0 RESULTS AND DISCUSSIONS.....	14
CONCLUSIONS.....	18
REFERENCES.....	19

LIST OF FIGURES

<i>Fig. 3.1 Upper Bhima basin up to Ujjani</i>	<i>8</i>
<i>Fig. 3.2 Urban centers, STP and water quality stations in Upper Bhima basin.....</i>	<i>8</i>
<i>Fig. 4.1 Basin schematic for water quality modeling.....</i>	<i>12</i>
<i>Fig. 4.2 Basin schematic for reservoir simulation</i>	<i>12</i>
<i>Fig. 4.3 Mike Hydro Basin Irrigation module setup for command BM51 (NMRBC).....</i>	<i>13</i>
<i>Fig. 4.4 Mike Hydro Basin setup for command BM51 (NMRBC).....</i>	<i>13</i>
<i>Fig. 5.1 River water quality in Mula- Bhima river reach for Scenario A, B and C.....</i>	<i>15</i>
<i>Fig. 5.2 DO and BOD for Scenario A- C and stations in Mula- Bhima river reach</i>	<i>15</i>
<i>Fig. 5.3 Change in supply for scenario A to B at different supply dependability.....</i>	<i>16</i>
<i>Fig. 5.4 Yearly Drought classes and percent rainfall deficit</i>	<i>16</i>
<i>Fig. 5.5 Comparison of total water supply in BM51 for different conjunctive use cases.....</i>	<i>17</i>
<i>Fig. 5.6 Comparison of groundwater supply in BM51 for different conjunctive use cases</i>	<i>17</i>
<i>Fig. 5.7 Comparison of groundwater depth in BM51 for different conjunctive use cases.....</i>	<i>18</i>

LIST OF TABLES

<i>Table 3.1 River system of Upper Bhima basin.....</i>	<i>7</i>
---	----------

ABSTRACTS

The Upper Bhima basin covers a geographical area of 14,712 sq. km. There are 14 major and medium dams in the Upper Bhima basin. Major dams in the basin include Pavana, Ghod, Mulshi (Tata), Khadakwasla, Chaskaman and Ujjani. The municipal corporations of Pune and Pimpri-Chinchwad, forming the Pune Metropolitan Region, constitute a part of this basin. The main tributaries of the river are Ghod and Mula-Mutha rivers. The places of origins of the tributaries of Bhima fall in comparatively heavy rainfall region. Length of Bhima up to Ujjani is 275 km. The basin is spread over three districts of Pune, Solapur and Ahmednagar in Maharashtra. BOD and DO were simulated in the river system from municipal corporation area of Pune and Pimpri-Chinchwad to Dhond GD site. The reaches simulated were Mula- Bhima, Mula-Pawna and Indravati-Bhima. Quartiles were computed from daily simulated BOD and DO of all stations and individual stations. Three scenarios A, B and C were historical flow, 20% reduced flow and STP capacity increased to 90% of the generated load respectively. For scenario C, at least 75% of the time the DO is better than critical value and for Khamgaon at least 25% of the time DO is critical. At Pargaon and Dhond, BOD is lower than two mg/l for 75% of the time. At Mula-Mutha confluence and Khamgaon BOD is lower than 11 mg/l and three mg/l 50% of the time respectively. Simulation of operation of Khadakwasla reservoir complex was done using conventional operating policy (rule curves) for irrigation and town water users for historic releases and 20% reduced releases scenario. For each scenario, changes in yield from the system were investigated. There is maximum 30% decrease in reservoir yield in reduced flow scenario. Drop in yield in the scenario increases at higher dependable supply. Both seasonal rainfall total and its monthly distribution are important for drought investigation. Drought magnitude and SPI values were grouped in to drought classes. A criteria was devised based on percentage of stations with different drought classes to arrive at basin wide drought class. For several consecutive years, namely 1971- 75, 1978- 79, 1982- 1988, 1993- 95 and 1999- 2003 drought/ dry weather conditions prevailed in the basin. Extreme, severe, moderate and mild drought condition occur in 11, 8, 5 and 19% of the years. In conjunctive use operation dynamic groundwater was simulated by assigning higher bottom level of the aquifer. Cases of 1 to 5% reduction in demand were simulated. Demand was also varied at two dependable supply levels. Maximum annual variation in groundwater supply between cases was 20%. At lower demand, 3.5 m fluctuation in water table was observed indicating carry over storage in the dynamic groundwater level.

1.0 INTRODUCTION

Integrated Water resources management (IWRM) involve multiple objectives, stakeholders and disciplines. With increasing demand, water disputes among competing user groups are increasing. This poses great challenge to water resources managers. IWRM practices will lead to satisfied water user groups and reduction in disputes. Decision support system may plays an important role in IWRM to overcome these challenges. A DSS is defined as technical tool that provide valid and sufficient information to IWRM decision maker. In DSS, IWRM policy options are developed and evaluated aided by current advances in science and technology. DSS may be utilized by government agencies, research organizations, industry etc. (Georgakakos 2004).

DSS Components

A typical DSS may have five components, namely data acquisition system, user- data- model interface, database, data analysis tools and interlinked models. Through data acquisition systems data area collected. These comprise of conventional sensors, remote sensors and manual data compilation through field surveys, interview, literature etc. User- data- model interface is a user interface for data transfer to DSS and access of data, tools and model to the user. Data are stored in to databases. Data may be those acquired by data acquisition systems, generated by data analysis tools and models etc. Data analysis tools are tools for visualization and analysis of data including GIS data. Models are used to quantify the response of water resources system to alternate scenario of basin development, hydrology, water use level and management policies (Georgakakos 2004).

River water pollution in India

Discharge of untreated or partially treated municipal waste water and industrial effluents is a major source of pollution. The estimated sewage generation from Class I cities and Class II towns (as per 2001 census) is 29129 MLD, which is expected to be 33212 MLD at present assuming 30% decadal growth in urban population. Existing STPs capacity is 6190 MLD (18.6% of the sewage generated) and another 1743 MLD (5.2% of the sewage generated) capacity is being added. Since actual capacity utilization of STPs is less (72.2%), total sewage treated is only 13.5 % of the sewage generated. Thus, large quantity of untreated municipal sewage is discharged in to river and water bodies rendering their water quality poor (<http://cpcb.nic.in/status-of-stps/>).

Drought in India

Nearly 68% of the country is prone to drought in varying degrees. Out of this, nearly 35% of the area with rainfall between 750 mm and 1,125 mm is considered drought-prone. Nearly 33% receiving less than 750 mm of rainfall is called chronically drought-prone. Since 2001, the country has experienced three major droughts, in the years 2002, 2004 and 2009. Due to varied physiographic and climatic conditions in India, drought of varying intensities are experienced almost every year in one or other part of the country. Nearly two thirds of the geographic area of India receives low rainfall (less than 1000 mm), which is also characterized by uneven and erratic

distributions. Out of net sown area of 140 million hectares, about 68% is reported to be vulnerable to drought conditions and about 50% of such vulnerable area is classified as 'severe', where frequency of drought is almost regular. Since only 45.0 per cent (2009-10) of the total cropped area is under irrigation, any shortfall in rainfall adversely impacts crop production (Rathore et al. 2014). During 1871–2002, there were 22 major drought years, defined as years with All India Summer Monsoon Rainfall (AISMR) less than one standard deviation below the mean (i.e. anomaly below –10 percent): 1873, 1877, 1899, 1901, 1904, 1905, 1911, 1918, 1920, 1941, 1951, 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1985, 1986, 1987, 2002. Droughts of years 1987 and 2002 were worst droughts at all India scale.

Drought is classified as meteorological, agricultural and hydrological. Meteorological drought is defined based on departure of rainfall from its normal value. Meteorological drought is said to have occurred when rainfall departure is less than -25% of the rainfall normal. The drought is further classified as moderate and severe based on departure between -25 and -50% and <-50% of the normal rainfall respectively. Agriculture drought (Kharif season) is defined as departure less than -50% from normal rainfall for four consecutive weeks or less than 5 cm weekly rainfall. For agriculture drought in other period of the year, the criteria is applied for six consecutive weeks.

Reservoir operation

Due to temporal variability in availability of water in a river system and its demand, surface storages are created. Water resources managers need to operate these storages to meet various demands effectively as well as manage inflows in to these storages. Reservoirs are operated by managing spills in to the river system and releases for water uses. Operation of reservoirs is dependent on both its purposes and storage volumes created. As per capacity of reservoir compared to inflow, the reservoirs may be classified as pondage type, within- year, carry- over storages and reservoir systems. Pondage type reservoirs are operated to meet the water requirements in periods with low rainfall in monsoon season. In Rabi season, these reservoirs support small irrigated area. Within- year storage reservoirs have definite filling and depletion periods. These are completely emptied at the start of monsoon season. Carry- over storage reservoirs have large storages to cater to deficit rainfall over multiple years. System of reservoirs are operated in integrated manner to meet the demand for the complete system.

The reservoirs are planned for single or multiple purposes e.g. conservation, flood control, navigation, hydropower and recreation etc. The objective for flood moderation is achieved by reducing to moderate level. In general, flood control reservoirs are multipurpose reservoirs and they have conservation purposes in addition to flood control. The reservoirs are normally maintained at the top of conservation level. Based on forecast of flows, the level in the reservoir is lowered below the conservation level to create additional flood control storage. For operation of conservation reservoirs, long-term or seasonal forecast is useful. In case of forecast of lower flow, the releases from the reservoirs are restricted. In case of high flow forecasts, the available water is fully utilized.

Rule curve is the target level planned to be achieved in a reservoir under different conditions of probabilities of inflows and / or demands during various time periods in an year. Rule curves are obtained through reservoir operation studies for historic and generated long term inflows. Rule curves are simply plot of reservoir water level verses Julian day. A reservoir manager strive to maintain reservoir water level as close as possible to these rule curves. This is achieved through curtailing the releases or allowing spill in to the river channel in case of low or high flow respectively.

Conservation storage: operation schedule for the reservoirs consists of two parts, namely filling and depletion periods. Reservoirs meant for meeting demands in non- monsoon periods should be filled as early as possible. Excess inflows after meeting the monsoon period demand should be stored in the reservoir. In years with low inflows, releases in monsoon periods should be reduced by appropriate amount. During non- monsoon period or depletion period, water is released from reservoir to meet demand for that period. For system of reservoirs, the releases from the reservoirs are apportioned based on storages or other criteria (CWC 2005).

2.0 REVIEW

Water quality

Al-Dulaimi (2017) applied QUAL2K model for CBOD and DO modeling for a 251 km reach of Diyala River, a tributary of Tigris in Iraq. The river is main water resource of Iraq and drains an area of 32600 sq. km. CBOD, DO and discharge in the river at upstream of the reach is 3, 6 mg/l and 150 cumec respectively. BOD and DO of effluent of WTP range between 3- 5.2 and 3.2- 5.6 mg/l. BOD and DO for drains range between 50- 220 and 1- 4 mg/l. Discharge for drains and WTP range between 0.01- 4.37 cumec. Calibrated values of CBOD oxidation and hydrolysis rates were 4 and 2 day⁻¹ respectively. Relative error of CBOD and DO simulation varied between 4- 23% and 10- 15%. Modelled DO ranges between 10 and 4 mg/l. Modelled CBOD ranges between 3- 7 mg/l. Simulation was also done with constant BOD load of 70 mg/l from effluent. This reduced CBOD to range of 2- 6 mg/l. It was recommended that BOD should be limited to 50 mg/l for effluent.

DO-BOD modeling at monthly scale was done for Yamuna river between Wazirabad and Okhla for a river stretch of 22 km using MATLAB for year 2011. Nearly 25% BOD load is report to be settled in the reach. It is assumed that the settled load is compensated by unaccounted BOD load from non point sources. Thus, settling rate is assumed to be zero. Small part of settled load is degraded anaerobically due to low DO level in the reach. Thus, SOD is assumed to be zero. High turbidity prevent penetration of light, thereby preventing phytoplankton grown. Hence, photosynthesis oxygenation was assumed to be zero. Thirteen drains join the river in the studies stretch. Monthly observed data were available for two sites namely Nizamuddin and Agra canal 15 and 24 km downstream from Wazirabad. Large variation in simulated and observed BOD load was seen except for April and June months. Observed DO was zero except for months of July,

August and September. Simulated DO for December to June was either zero or close to zero for the station of observation (Khan and Singh 2013).

Reservoir operation

CWC (2005) has used Acres Reservoir Simulation Program (ARSP) at monthly time step to simulate reservoir operation in Ukai- Kakrapar system. The program is a multi- purpose multi-reservoir network simulation program. The program requires initial state of the system and inflows as input. It requires constraints to be specified by linear or piece-wise linear. In the network schematic reservoirs are represented as nodes and natural and manmade flow path are represented as channels. The channels may be flow or demand channels. Carrying capacity of the flow channels are broken in to discrete ranges. Ranges have user specified bounds and penalties. Penalties in flow channels are based on desirability of flow and those in demand channels are based on whether demands are met or not. In the simulation study, flood cushion was maximized without effecting fulfilment of other demands. Irrigation, urban and power demand are to be met at 875, 95 and 90% dependability. Irrigation diversions are provided from Ukai dam (ULBMC) and Kakrapar weir (URBMC, KLBMC and KRBMC) and Water supply diversion for Surat city is provided at Singanpur Weir. The Ukai reservoir is operated for meeting these demands from these two weirs situated downstream.

Rule curve based operating procedure was adopted. Initially operation was simulated based on existing rule curve. For storage zone penalty structure, for zones namely two above rule curve and two below rule curves, namely spill, flood, conservation and dead storage zones are selected. Eight channels are specified for power, spill (surplus flow to power house), river flow, diversion (urban water supply), power control channel, diversion (irrigation), return flow and consumptive use. Penalties assigned are 999, 99999, zero, 9999, zero, 1111, zero and 1111 respectively. Thus, penalties spill (surplus flow to power house), diversion (urban supply), diversion (irrigation), flow (power channel) are in order from high to low. Simulation was done for period of 26 years. Simulation was done for three strategies, namely existing rule curve without power demand, existing rule curve with firm power demand and monsoon rule curve lowered with firm power demand. In strategy I, one failure year occurred in irrigation demand. In strategy II and III both, failure years were one, one and two in meeting urban water supply, irrigation and firm power demand respectively. In revised rule curve, water level was lower in July and August by 0.5 and 0.63 m. Thus, operation was recommended as per strategy III.

Reservoir operation rule were devised for Tehri multi-purpose reservoir. The reservoir cater to domestic, irrigation, flood control and hydropower uses and located on Bhagirathi River. Releases of domestic and irrigation are done in to the river channel. Irrigation uses are planned for non-Kharif season only. Filling period was assumed to be between 21st June to 20th October. Upper bound of the conservation storage was provided. The zone between this curve and FRL provide extra flood cushion. Water level is allowed to exceed rule curve during flood temporarily. DSL is maintained at the beginning of the filling period. Rule curve allows reservoir to fill even in worst year of low inflows. Power demands were not imposed in the simulation. Emergency power generation is resorted to when reservoir water level lies between rule curve and 75% dependable

level. Excess flow is released through power house, spillway, ILO in that order. The reservoir level may be allowed to be lower than rule curve for meeting domestic demand. Rule curve is also specified for depletion period. No rules were specified for managing flood which may occur during November period. Domestic demands may be met in all periods as inflows are more than this demand (CWC 2005).

Drought

Saad et al. (2013) studied drought Ghareh Chai and Karkheh basins in Hamedan province of Iran. Yearly SPI values were computed. SPI value are negative for the two areas for years 1989- 1991. For Ghareh Chai values are negative for period 1996- 2008. For Karkheh basins, values are negative for 1983- 1986, 1996- 2006 and 2007- 2008. Values have nonlinear relationship with basin runoff.

Drought index SPI was investigated for two districts of Ananthpur and Khammam. Normal annual rainfall in two districts is 449 and 997 mm respectively. In Ananthpur very high negative deviations (-60 to -80%) in rainfall is associated with SPI values of -1.00 to -1.50. Similarly, rainfall deviations of -40 to -60 % of normal correspond to SPI values of -0.5 to -1.0. In Khammam, the SPI values are on lower side compared to Anantpur for the higher negative rainfall deviations. Year 2006 and 2002 were drought years in the two districts. Yield of groundnut crop was 67, 355 and 1118 kg/ha in 2006, 2002 and 2000 respectively. The values of SPI in the drought year 2002, ranged between 0 and -1.0 and in year 2006 ranged between -0.05 and -1.5. The range of SPI values is higher with stretching beyond -2 and +2, for longer time scale SPI compared to 1-month SPI. In drought years of 2002 and 2006, the SPI values are around -1.5 (Kumar et al.).

3.0 STUDY AREA, DATA AND SOFTWARE

Krishna basin

Krishna River is a major east flowing river in India. In terms of basin area, it is 4th large basin in India (first three basin are Ganga, Indus and Godavari). Area of Krishna basin is nearly 2.59 lakh sq. km (8% of the geographical area of the country). In CWC basin classification, the basin is assigned code '04'. The river is also mentioned in Indian ancient scripture as Krsnavena, Krsnaveni, Kanhapenna and Kanhapena. The river flows in Maharashtra, Karnataka, Telangana and Andhra Pradesh. Largest area of the basin is in Karnataka, followed by Talangana and Andhra Pradesh (total area in two states together) and Maharashtra. Area in Maharashtra is nearly 69 thousand sq. km. The basin has a maximum length and width of nearly 701 km and 672 km respectively. It is bounded by Balaghat range on the north, by the Eastern Ghats on the south and the east and by the Western Ghats on the west. The Krishna River rises from the Western Ghats near Jor village of Satara district of Maharashtra at an altitude of 1337 m just north of Mahabaleshwar. The major part of basin is covered with agricultural land (nearly 76%). Area under forest, wasteland and waterbodies are 10, 7 and 4% respectively. Principal tributaries of the River are Ghataprabha, Malprabha, Tungabhadra, Bhima, Musi and Munneru. Length of the River is nearly 1400 km. Average surface and groundwater potential of the basin are 78.1 and 26.4 BCM.

Utilization water is nearly 58 BCM. Live storage capacity of the completed projects is nearly 50 thousand MCM. The geology of the Krishna basin is dominated in the northwest by the Deccan Traps, in the central part by unclassified crystalline, and in the east by the Cuddapah Group. The Dharwars (southwest central) and the Vindhian (east central) form a significant part of the outcrops. The average annual rainfall in the Krishna basin is 784 mm. The South West Monsoon sets in the middle of June and withdraws by the middle of October. Nearly 90% of annual rainfall is received during the Monsoon period. The pre-plan water resources development in the basin was mostly through diversion works such as Kurnool-Cuddapah Canal, Krishna Delta in Andhra Pradesh and Neera canal in Maharashtra. During the plan period, many storage and diversion projects were taken up and completed. Important among them are Tungabhadra, Ghataprabha, Nagarjunasagar, Malaprabha, Bhima, Bhadra and Telgu Ganga. Krishna basin is further divided into seven sub basins. Out of these Krishna, Tungabhadra and Bhima have three, two and two sub basins each. The major Urban Centers in the Basin are Pune and Hyderabad. Some parts of the basin, especially the Rayalaseema area, Bellary, Raichur, Dharwar, Chitradurga, Belgaum, Bijapur, Pune, Sholapur, Osmanabad and Ahmednagar districts are drought-prone. Major and medium irrigation projects in the basin are 76 and 135 respectively. Number of hydroelectric projects are 30. Number of dams, barrages, weirs and anicuts are 660, 12, 58 and 6 respectively. Number of lift schemes are 119.

Bhima basin

The river flows through Maharashtra, Karnataka and Telangana, before entering the Krishna River. The basin is the second largest basin in Krishna basin after Tungabhadra basin. Bhima River originates near Bhimashankar temple in the Bhimashankar hills in Western Ghats. The elevation near origin is 945 m. It has a total length of 861 km and falls into the Krishna nearly 26 km. north of Raichur at an altitude of 343 m. Most upstream dam across the river is Chaskaman, which is located near village Chas in Khed Taluka of Pune district. Bhima basin is divided into two sub basins, namely upper and lower Bhima basins. Areas of upper and lower Bhima basin are 44.8 and 23.6 thousand sq. km (17.6 and 9.3% area of Krishna basin) respectively. Bhima, Sina, Nira and Man are major tributaries in Upper Bhima basin. Bhima, Bori, Dodda Halla, Amarja, Benithora, Mullamari and Kanga rivers are major tributaries in lower Bhima basin. The Bhima major irrigation project comprises Ujjani Dam on the Bhima river. Districts benefited by this project are Solapur, Pune and Ahmednagar. GCA, CCA & UIP of the Bhima major irrigation project are 205, 199 and 260 Th. ha. respectively. Dams, weirs and lift schemes in upper Bhima basin are 273, 1 and 30 respectively. Dams, barrages and lift schemes in lower Bhima basin are 68, 5 and 2 respectively.

Upper Bhima basin (up to Ujjani)

The Upper Bhima basin covers a geographical area of 14,712 sq. km. Of the total geographical area, 25 % is hilly & highly dissected, 55 % plateau and nearly 20 % plain & valley filled. Nearly 25 % of the Bhima basin lying in the western zone falls in good rainfall region. Remaining 75 % is rainfall deficit region having annual areal rainfall less than 700 mm. In the Parner/ Shirur region, rainfall is normally less than 600 mm. Average annual water yield of the Upper Bhima basin up to Ujjani is 7,594 MCM. There are 14 major and medium dams in the Upper Bhima basin. Major dams in the basin include Pavana, Ghod, Mulshi (Tata), Khadakwasla, Chaskaman and Ujjani. The municipal corporations of Pune and Pimpri-Chinchwad, forming the Pune Metropolitan Region, constitute a part of this basin. The main tributaries of the river are Ghod and Mula-Mutha rivers. Mula rises in Mulshi taluka, and Mutha in Velhe. River Ghod and its tributaries Kukadi and Meena

also rise in the Western Ghats. The places of origins of the tributaries of Bhima fall in comparatively heavy rainfall region. Length of Bhima up to Ujjani is 275 km. The basin is spread over the three districts of Pune, Solapur and Ahmednagar in Maharashtra.

Table 3.1 River system of Upper Bhima basin

S No	River	Length in km	Origin		Confluence	
			Place	Altitude	With	Altitude in m
Bhima						
1	Bhima	275	Bhimashankar	700	Krishna in Raichur distt., Karnataka	343
2	Indrayani	83	Aapti	900	Bhima	
3	Kundalika				Indrayani	
4	Bhama				Bhima	
5	Wel	60			Bhima	
Mula-Mutha						
1	Pawana	55	Mula	900	Mula near Dapodi	439
2	Mula	50	Mazgaon		Bhima near Pargaon	522
3	Mutha	64	Davjhar	900	Mula near Khadki	564
1	Ghod	170	Gawadewadi	1000	Bhima near Daund	498
2	Meena	53	Amboli		Ghod	
3	Kukadi	85	Ghatghar		Ghod near Shirur	562
4	Pushpavat	35	Khireswar			
5	Arr					
6	Hanga					
7	Palsi					

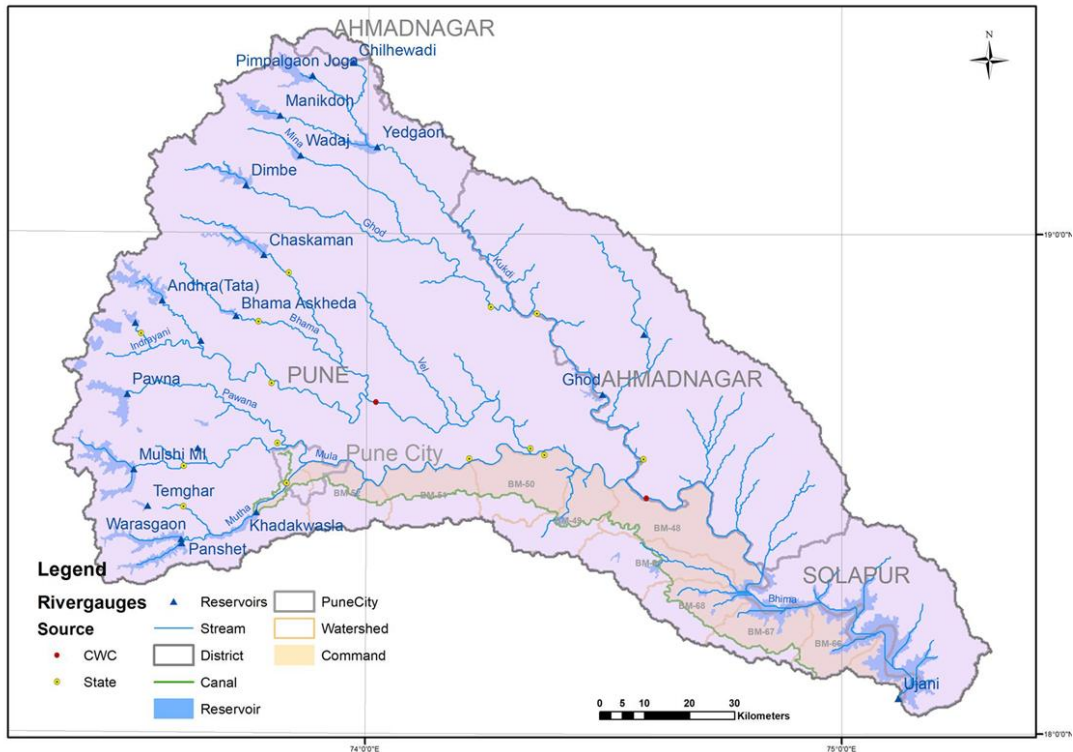


Fig. 3.1 Upper Bhima basin up to Ujjani

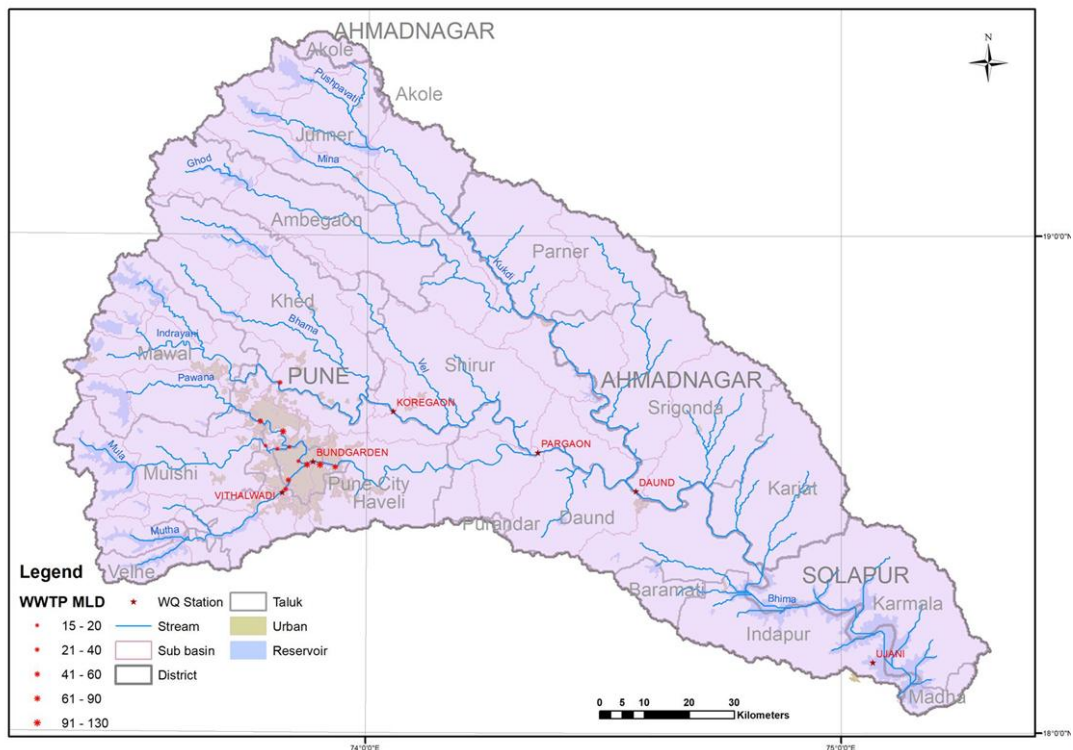


Fig. 3.2 Urban centers, STP and water quality stations in Upper Bhima basin

4.0 METHODOLOGY

Water quality modeling

The major Urban Centers in the Krishna Basin are Pune and Hyderabad. Pune city is located in Upper Bhima basin up to Ujjani Dam. The municipal corporations of Pune and Pimpri-Chinchwad, form the Pune Metropolitan Region. Dominant pollution source is municipal wastewater in this basin. The pollutants are released in Mula- Mutha. The pollutants are subject to self purification in the river system downstream. Pollutant concentration is further reduced due to dilution due to the tributaries joining the river system. Mula have tributaries namely Mutha and Pawana. Further downstream, Mula confluence with Bhima. Bhima confluence with Ghod near Dhond station (Fig. 4.1). Water quality simulation for BOD and DO was done for historic, reduced flow time series (by 20%) and improved STP capacity scenario (equal to 90% of the load generated) for basin up to Dhond. Constant 1st order decay parameter for BOD and DO and constant temperature were assumed. BOD and DO simulation was done in MS Excel. Steps are briefly described below:

- Historic flow in the river channels were obtained through Mike Hydro Basin model simulation.
- BOD load for untreated waste water was computed using per capita load.
- Return flow from water supply was computed using per capita water supply and return flow fraction.
- Effluent load is computed using BOD concentration in the effluents.
- Total load was computed by adding BOD load of untreated wastewater and STP effluents.
- Point load from PMC was applied at Mula Mutha confluence.
- PCMC load was distributed between Pimple Gurav and Nighoje.

Multi reservoir operation

Reservoir operation rule curves were devised for Khadakwasla reservoir complex. The complex consists of four reservoirs, namely Panshet, Warasgaon, Temghar and Khadakwasla (Fig. 4.2). Panshet and Warasgaon reservoirs are multipurpose reservoirs with hydro power, irrigation and municipal purposes. The reservoir operation was done for two scenario, namely historic inflows (scenario A) and reduced inflows (scenario B). In reduced flow scenario, historic flow was reduced by 20%.

Rule curve

Rule curves are devised using spreadsheet computation with 10-daily inflow of various dependability. Rule curves for filling and depletion periods were separately derived. For filling periods, different rule curves were varied for scenario. In the depletion period, reservoirs are assumed to be at same percent storage for each reduction curve. The procedure is given below.

Filling period

- Apportioning of demands in filling period was done between reservoirs based on reservoir capacity, inflow at 75% dependability and monsoon demands.

- Ten-daily simulation was done for filling period for individual reservoirs. Releases were curtailed at lower water availability in the system.
- From the simulation, rule curve were derived for different reduction in releases.

Depletion period

- Ten- daily simulation was done in the depletion period for different reduction in storages.
- Rule curves were derived for depletion period for different reduction level.

Drought

Basin wide drought categories were derived for using monthly rainfall data for monsoon months. The procedure utilize rainfall data for raingauge stations in the basin. The procedure uses drought categorization based on drought magnitude, SPI (June- September). Both categories are further combined in to one category using a table criteria. A table criteria was also devised for basin wide drought category based on percent of raingauge station in combined drought category. Procedure is stated as below.

- Monthly rainfall data are preprocessed to fill data gaps.
- SPI for rainfall for duration June, June- July, June- August and June- September was computed.
- Using four SPI values, drought magnitude was computed.
- Drought categories from drought magnitude, SPI (June- September) and combined drought category was computed for each raingauge- year data.
- Percent of raingauge stations in combined drought category were determined in each year.
- Basin wide drought category for each year was computed.
- Raingauge station were divided in to upper and lower part of the study basin.
- Annual rainfall, normal rainfall and departure of rainfall from normal was determined for each region and complete study area.

Conjunctive use

Conjunctive use simulation was done for a sub command of NMRBC lying in watershed BM51. The demand for the command was estimated using Irrigation module of Mike Hydro Basin (Fig. 4.3). The model setup is described here.

Irrigation module setup

Seven fields were specified with area of 6, 6, 4, 8, 2, 6 and 4 sq. km and crop shifts of Bajra, Jowar and Groundnut (HW), Green manure and wheat, Groundnut (Kharif) and Jowar, Jowar, Chilli, Cotton and Wheat respectively. Thus, total area under irrigation in Kharif, Rabi and Hot Weather was 24, 28 and 12 sq. km respectively. Average irrigated area was taken as 26 sq. km. Irrigation trigger and application was based on readily available water (RAW) of zero value and minimum cycle time was specified as 5 days. Potential evapotranspiration was estimated using FAO 56 method and climate data for the region. Rainfall time series was also given in the model for allowing availability of infiltrated water in to the soil profile for crop consumptive use. Soil was assumed to be clay with wilting point, field capacity and porosity of 0.2, 0.32 and 0.45 respectively.

Runoff coefficients were assumed to be 0.4 and 0.6 with daily rainfall value lower and higher than a threshold value of 60 mm respectively.

Water allocation model

Water allocation model was set up for the command in Mike Hydro Basin (Fig. 4.4). The elements of the model were as follows.

- NMRBC irrigation water release node (user node)
- BM51 irrigation water release node (user node)
- BM51 catchment
- Flow loss node in stream channel in BM51 catchment
- BM51 irrigation water user (regular user type)

NMRBC irrigation water release node (user node): Water releases for irrigation in the system was set to a very large value to allow all demand to be met in a BM51 water user created to obtain canal releases in to the sub command.

BM51 irrigation water release node (user node): Canal releases in BM51 were assumed to be equal to irrigation water requirement adjusted for release of water in NMRBC from the reservoir complex in a particular year. NMRBC canal releases were obtained from a model simulation for Khadakwasla reservoir complex. Trend in the release series was removed. From daily value of releases, yearly releases were obtained. Yearly water releases varied from 34 to 100%. In the years with release of more than 90% dependability, the demand in BM51 was set equal to proportionately reduced demand.

Rainfall recharge : Normal yearly rainfall recharge was assumed to be 60 mm. Monthly rainfall recharge was estimated by multiplying normal yearly rainfall recharge by ratio of monthly and normal yearly rainfall. Monthly rainfall recharge was expressed in unit of mm/day.

BM51 catchment: Area of the catchment was set equal to the net crop area. A value of 26 sq. km was assigned. Runoff time series was set to zero. Two layers groundwater model was selected. For shallow water layer, initial water level, outlet level and time constant are set to 0.02 m, 0.02 m and 100 hrs respectively. For deep water layer, initial water level, outlet level, bottom level and time constant are set to 0.15 m, 0.15 m, 0.25 m and 2400 hrs respectively. Time constant for shallow to deep groundwater interface was set to 100 hrs. Groundwater recharge was assigned equal to monthly rainfall recharge in mm/day.

Flow loss node in stream channel in BM51 catchment: Stream flow loss was assigned equal to 20% to simulate irrigation water flow loss.

BM51 irrigation water user (regular user type): In conjunctive use model, the water requirement is assumed to be met from both irrigation water and groundwater. The water available at a node will be equal to irrigation water at field level and groundwater available. Irrigation water at field level will be obtained by subtractive flow loss in the system from canal release. Flow loss will recharge groundwater. Further groundwater will also be recharged from rainfall. Since, part of the seepage water is lost through drainage processes, total water available is lower than the irrigation water release. The water user draws water from the irrigation channel and groundwater in BM51 catchment. First, irrigation water requirement is met from irrigation channel. Remaining demand is met from groundwater in BM51 catchment.

Case 1: Irrigation demand is set to 95% of the release

Case 2: Irrigation demand is set to 97.5% of the release

Case 3: Irrigation demand is set to 99 and 97.5% of the release at less than and more than 50% dependability respectively

Case 4: Irrigation demand is set to 95 and 99% of the release at less than and more than 50% dependability respectively

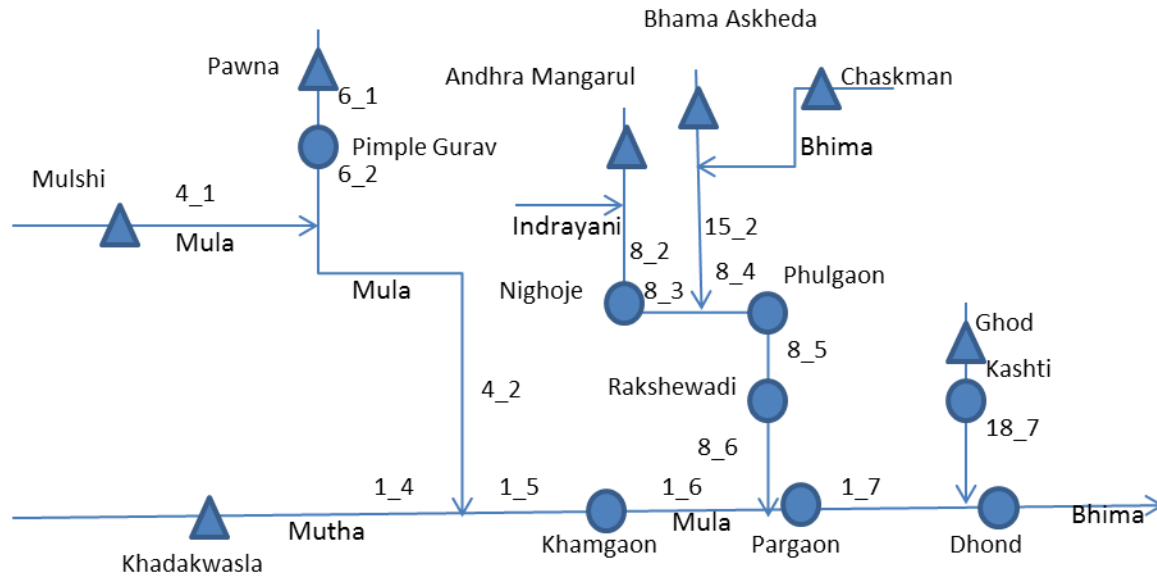


Fig. 4.1 Basin schematic for water quality modeling

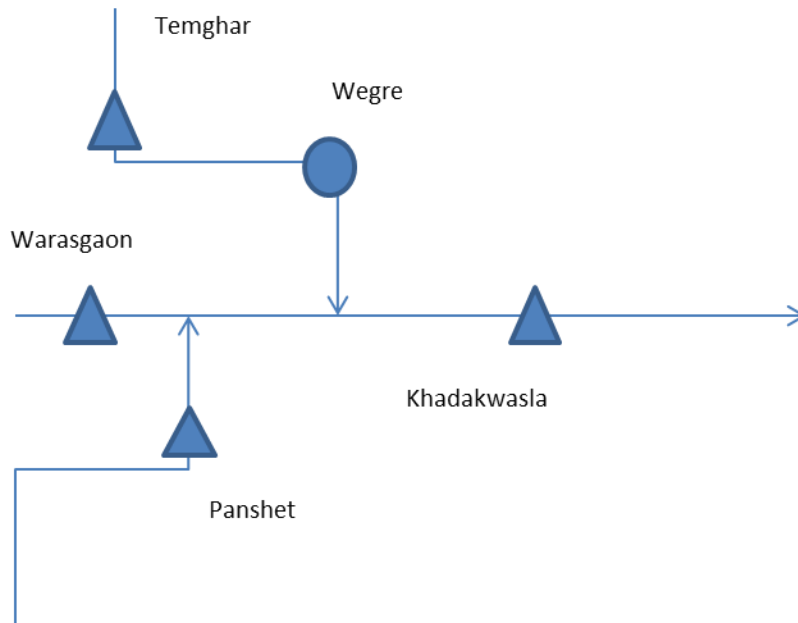


Fig. 4.2 Basin schematic for reservoir simulation

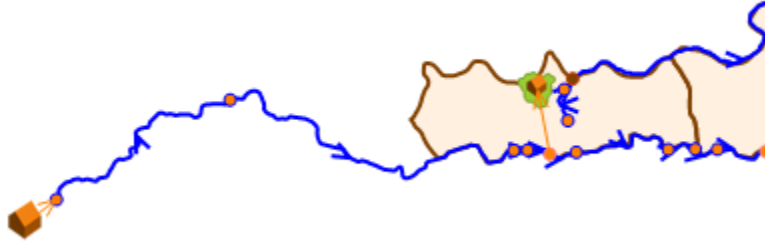


Fig. 4.3 Mike Hydro Basin Irrigation module setup for command BM51 (NMRBC)

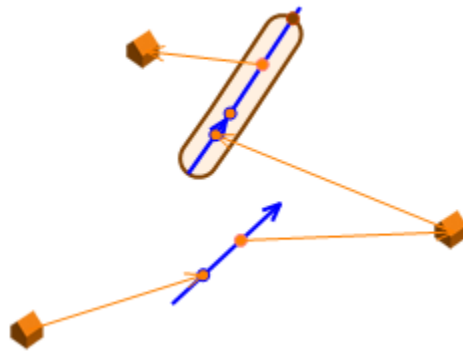


Fig. 4.4 Mike Hydro Basin setup for command BM51 (NMRBC)

5.0 RESULTS AND DISCUSSIONS

Water quality

BOD Simulation results are presented in form of median and quartile statistics for combined data of all stations and individual station wise for all three scenario. Four stations are considered, namely Mula- Mutha confluence, Khamgaon, Pargaon and Dhond. Khamgaon is located on Mula River downstream of Mula- Mutha confluence. Pargaon is located downstream of Bhima- Mula confluence. Dhond is located downstream of Bhima- Ghod confluence. BOD improves for stations in this order due to self purification and dilution processes. DO is lower at Khamgaon compared to that at Mula- Mutha confluence due to BOD degradation process (Fig. 5.1, 5.2).

Reservoir operation

Reservoir operation was simulated for Khadakwasla complex. The complex has four reservoirs, namely Warasgoan, Panshet, Temghar and Kharakwasla. Khadakwasla reservoir is a pondage reservoir. Water is withdrawn from Khadakwasla reservoir for municipal and irrigation uses. These supply was apportioned amongst the reservoirs in the system. For monsoon water releases the flows from free intermediate catchments are also accounted. Release are mainly made in to New Mutha right bank canal (NMRBC). Water is withdrawn for municipal uses of Pune city from the NMRBC. Operation of the reservoir complex was simulated using reduction levels for different scenario. There is maximum 30% decrease in reservoir yield in reduced flow scenario. Drop in yield in the scenario increases at higher dependable supply (Fig. 5.3).

Drought

Basin wide drought categorization was done as well as departure from annual rainfall was calculated for upper part, lower part and complete basin for each year. It is indicated that consecutive years 1971- 75, 1978- 79, 1982- 1988, 1993- 95 and 1999- 2003 have basin wide drought/ dry weather conditions. Drought/ dry conditions were categorized as extreme, severe, moderate, mild drought and mild dry. These categories had probability of occurrence 11, 8, 5, 19, 22% respectively. In most drought years, basin wide rainfall departure is less than -10%. Consecutive year of 1985- 1987 and 1999- 2003 have basin wide rainfall departure of order of -15% or less. Year 1972, 1982, 1985, 1987, 1995 and 2003 have year departure of order of -25% or less. Years 1972 and 1987 had less than -40% departure from mean annual rainfall (Fig. 5.4).

Conjunctive use

Conjunctive use simulation for BM51 was done for different case 1- 4. Case- 3 is most aggressive in terms of irrigation demand and comparison was made for this case with other cases for total water supply, groundwater supply and groundwater depths. Maximum annual water supply variation between cases 1 and 3 and cases 4 and 3 was nearly 4%, whereas between cases 2 and 3 it was 1% (Fig. 5.5). Maximum annual groundwater supply variation between cases 1 and 3 and cases 4 and 3 was 20%, whereas between cases 2 and 3 it was 5% (Fig. 5.6). Long term water table change of 3.5 m occurred in case 1. In other case, change was nearly 2.5 m (Fig. 5.7).

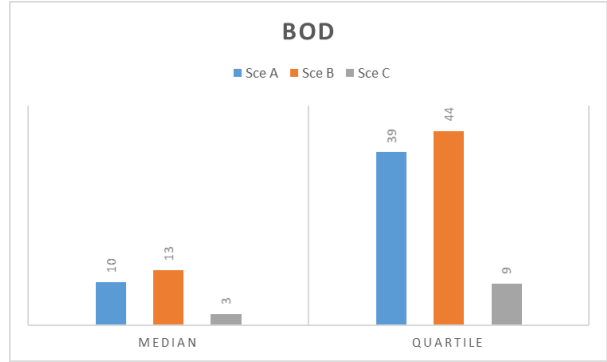
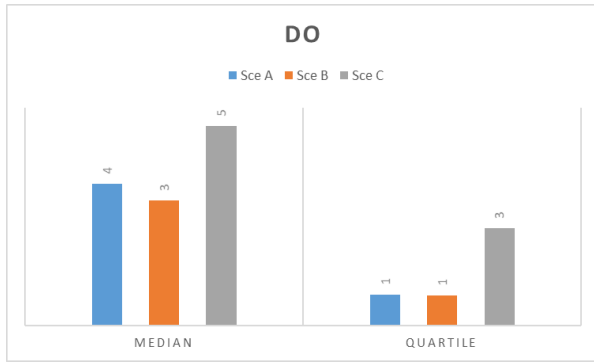


Fig. 5.1 River water quality in Mula- Bhima river reach for Scenario A, B and C

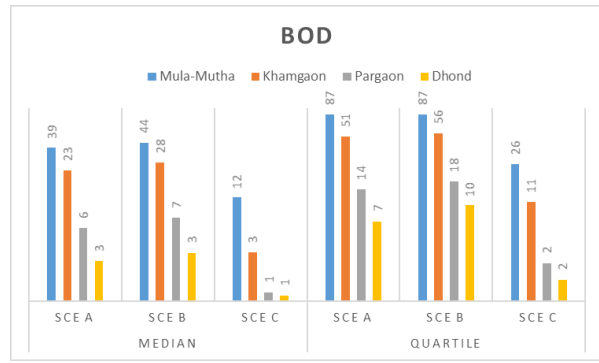
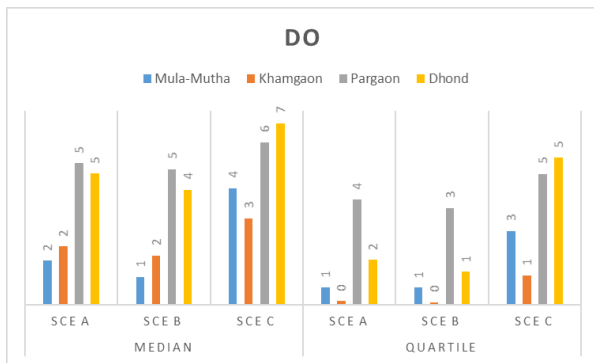


Fig. 5.2 DO and BOD for Scenario A- C and stations in Mula- Bhima river reach

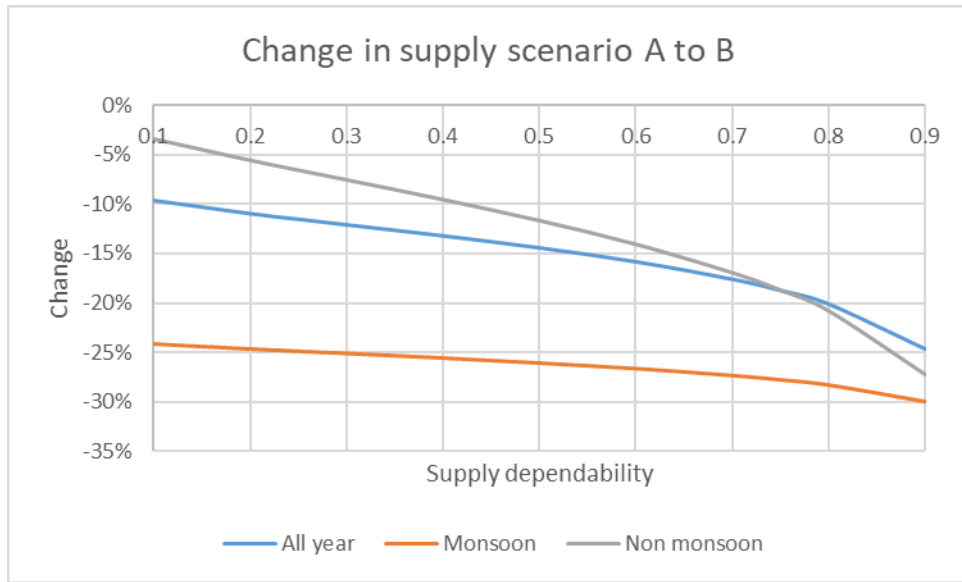


Fig. 5.3 Change in supply for scenario A to B at different supply dependability

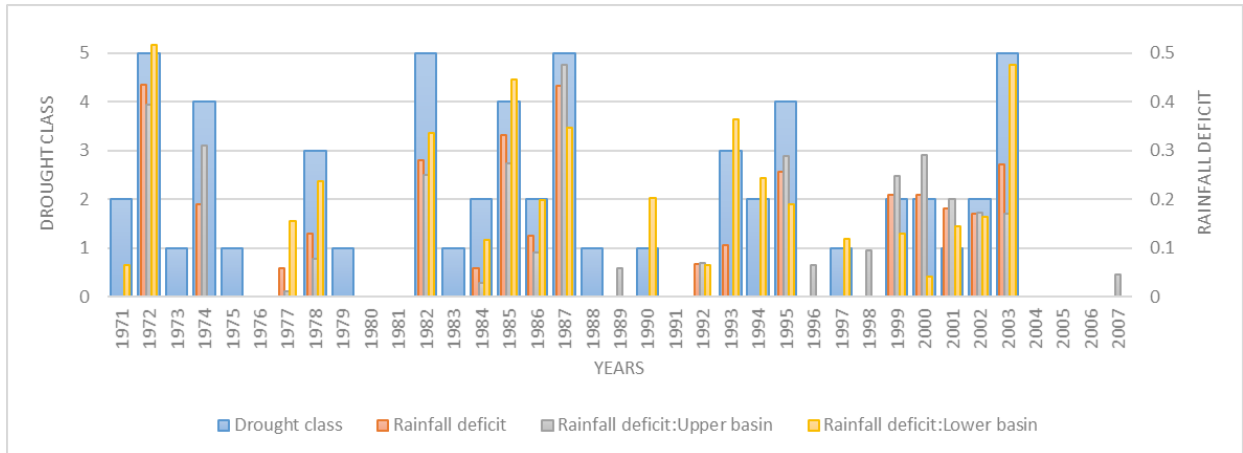


Fig. 5.4 Yearly Drought classes and percent rainfall deficit

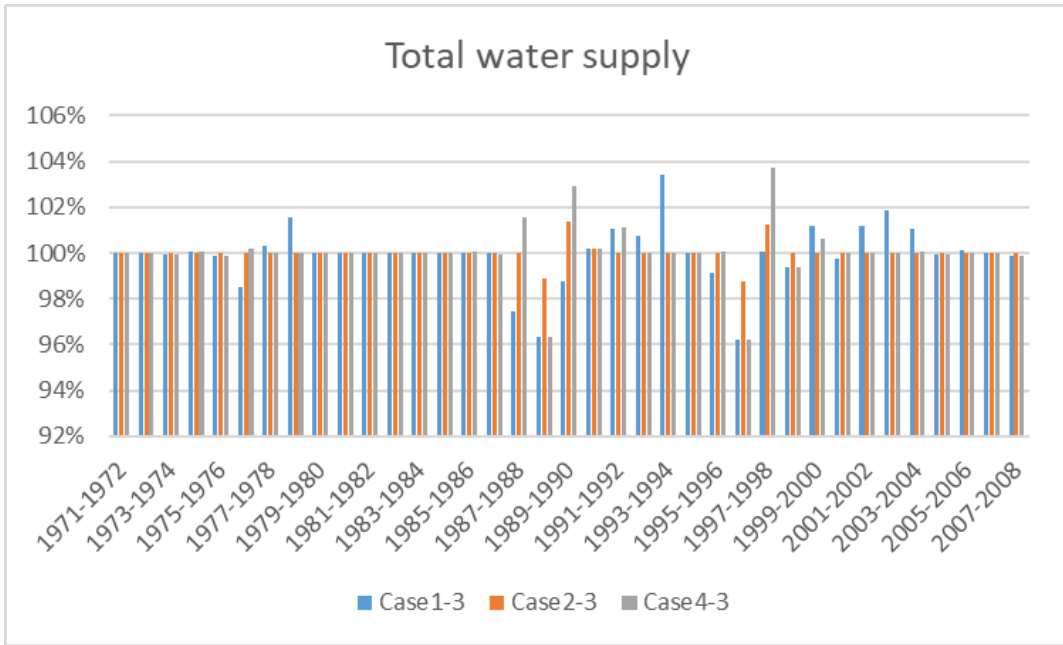


Fig. 5.5 Comparison of total water supply in BM51 for different conjunctive use cases

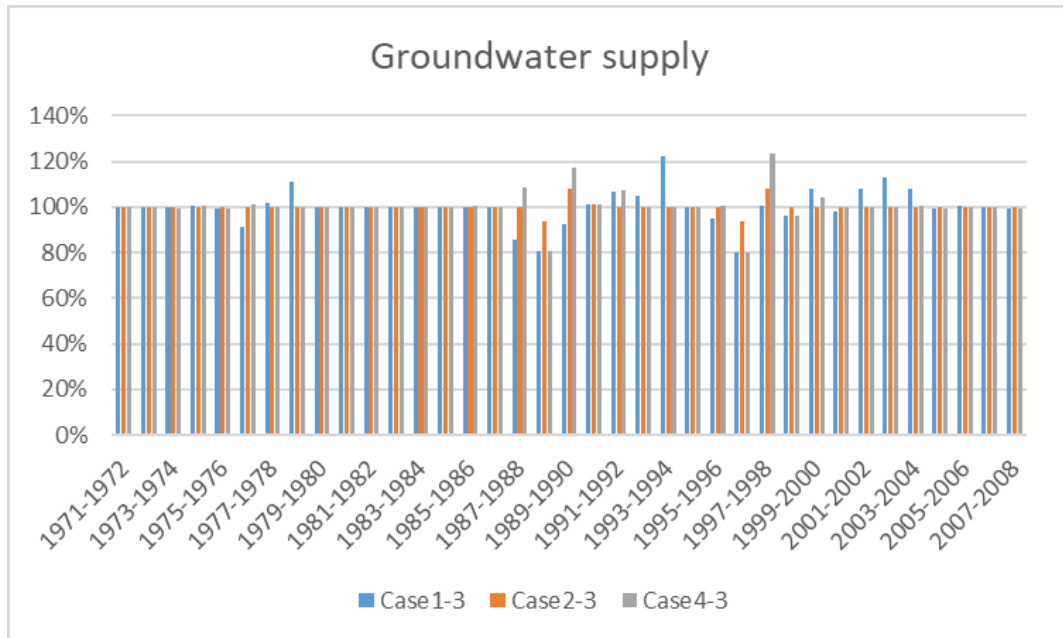


Fig. 5.6 Comparison of groundwater supply in BM51 for different conjunctive use cases

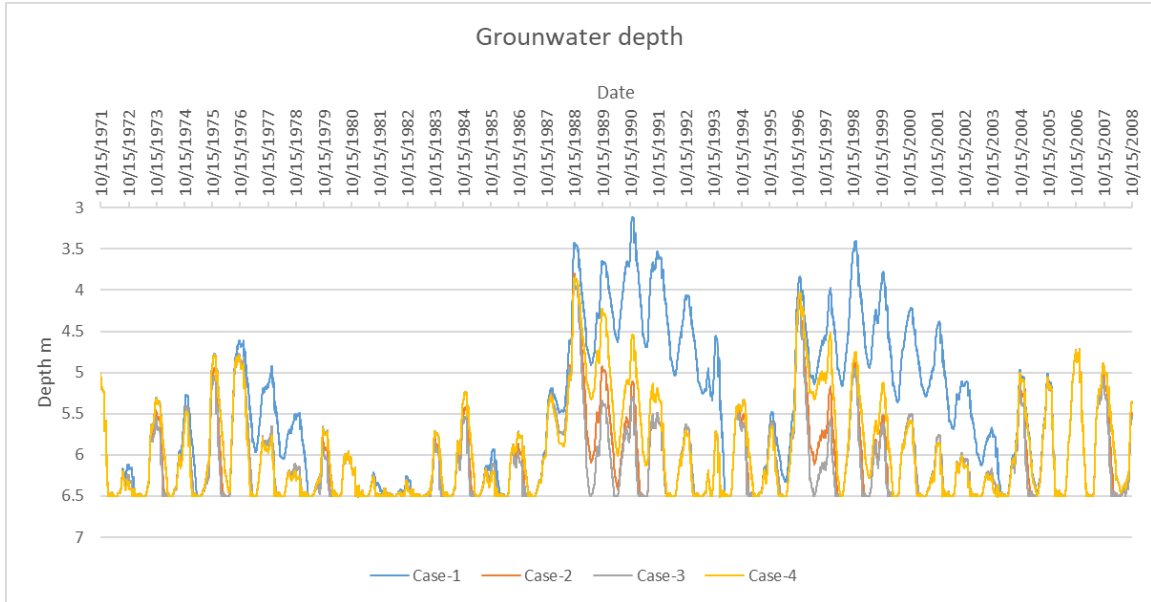


Fig. 5.7 Comparison of groundwater depth in BM51 for different conjunctive use cases

CONCLUSIONS

In a river basin, non stationary climatic forcing and anthropogenic changes pose challenges to water resources manager in making decisions for sustainable allocation of resources to uses. River basin planning model e.g. Mike Hydro Basin is a tool, which is useful in simulating water allocation for various utilization, climatic scenario and system design. The model requires certain rules in its set up, which may be derived externally and input in the model. Conventional rules are useful in operation of the reservoirs. Spreadsheet based computations is sufficient for certain applications e.g. water quality simulation for DO and BOD. Though the application does not consider all the processes involving, with limited data availability, the method provides good approximation. A river basin model e.g. Mike Hydro Basin not only computes water requirement for crop combination, climatic forcing and physical system, but also simulates conjunctive use and seepage on lumped basin. The simulation results may be processed in a spreadsheet for deriving statistical estimate for scenario.

REFERENCES

- Al- Dulaimi G.A. (2017) Evaluation of BOD and DO for Diyala River by Using Stream Water Quality Model, International Journal of Environmental Science and Development, Vol. 8, No. 8
- CWC (2005) Real time integrated operation of reservoirs
- CWPRS (2010) Optimization of streamgauge and rivergauge network for Upper Bhima Basin, Report no 4797
- Georgakakos A.A. (2004), Decision support systems for integrated water resources management with an application to the Nile basin
- Khan S, S.K. Singh (2013) Assessment of the impact of point loads on River Yamuna at Delhi stretch by DO- BOD modeling of river by MATLAB programming, International Journal of Engineering and Innovative Technology (IJEIT) Volume 2, Issue 10
- Kumar M.N., C.S. Murthy, M.V.R. Sessa Sai, P.S. Roy, On the use of Standardized Precipitation Index (SPI) for drought intensity assessment
- MOWR (2014), Krishna basin Version 2.0, Ministry of Water Resources, Government of India
- Rathore B.M.S., R. Sud, V. Saxena, L. S. Rathore, T. S. Rathore, V. G. Subrahmanyam, M. M. Roy (2014) Drought Conditions and Management Strategies in India
- Shad M.S., M. D. Marvili (2013) Study of drought with SPI index (case study: Ghareh Chai and Karkheh basins), International Research Journal of Applied and Basic Sciences, Vol. 4 (9): 2638-2644