Impact of Climate Change on Water Resources in Madhya Pradesh

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Impacts of Climate Change on Water Resources in Madhya Pradesh

- An Assessment Report

This report is prepared under the financial support by Department for International Development (DFID) for the project Strengthening Performance Management in Government (SPMG) being implemented in Madhya Pradesh state of India. SPMG is an initiative of Department for International Development (DFID) to provide assistance to Government of Madhya Pradesh for strengthening planning and governance systems. One of the key focus areas of SPMG is to ensure environmental sustainability and climate compatible development in the state. As part of this initiative, Development Alternatives (DA) is recognized by Government of MP and DFID to provide technical support to Madhya Pradesh State Knowledge Management Centre on Climate Change (SKMCCC), EPCO. DA is assisting SKMCCC in facilitating integration of climate change concerns into departmental activities and plans, through strengthening technical capacities and generating strategic knowledge.

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Contents

1.0 Introduction

Climate change is one of the most serious challenges facing the world today, which is expected to have long term impacts on sustainable living. Climate change is considered to impact the environment, water, health, agriculture, power, transportation and other allied sectors that are vital for the existence of mankind. The Earth's average temperature has increased by about 0.85°C from 1880 to 2012, which is also projected to increase further by another 0.3 to 4.5°C over the next century. In the Northern Hemisphere, where most of Earth's land mass is located, the last three decades from 1983 to 2012 were likely the warmest 30-year period of the last 1400 years, in which the decade between 2000 and 2009 has been recorded as the hottest.

The changes in the average temperature of the earth can translate into large shifts in the climate and weather. These changes are now being evidently witnessed by the changes in rainfall pattern and distribution, resulting in frequent floods and droughts with higher severities, intense precipitation, as well as more frequent and severe heat waves. The greenhouse gases released by the human activities, like burning of fossil fuels, industrial activities and deforestation, act like a blanket around the earth, trapping the energy in the atmosphere which is responsible for the continuous warming of the earth. The risks from the climate change can be reduced by taking effective measures to reduce the greenhouse gas emissions. However some of the greenhouse gases like carbon di-oxide can stay in the atmosphere for nearly a century thereby making the earth continue to warm.

The effects of future climate under the influence of global warming can be studied in detail by the use of General Circulation Models (GCM), run with a range of possible emission scenarios. Scenarios are used in estimating the probable effects of one or more variables and can support the decision making processes for devising the most appropriate adaptation measures. The future climate scenarios have been developed based on assumptions of the change of drivers that would influence the climate system, particularly change in the atmospheric concentration of greenhouse gases (GHGs), which may vary under different pathways of the world's development in the future. Long-term future climate projections provide the basis for assessment of climate change impacts on certain sectors in specific areas. The climate state obtained by incorporating an emission scenario in global and regional climate models is called a climate scenario, while the difference between a future and current climate state resulting from consequent changes in atmospheric composition is called a climate change scenario.

India is highly dependent on its water resources for several economic activities including agriculture, which is one of the principal livelihood options of more than 70% of the population. Most of the economic and industrial activities in the country are fully dependent on the water resources. India has been blessed with abundant water resources, even though the distribution is not uniform. However, with the burgeoning population and increasing demands on the water resources, the supply-demand scenario has undergone a drastic change in the recent times coupled with water quality issues. In the Indian context, it is reported that the land surface temperature has increased at a rate of 0.2°C per decade during 1971-2007 (Kothawa le et al., 2010). An enhanced hydrological cycle is therefore expected due global increase in average water vapour, evaporation and precipitation as a consequence of the temperature increase. While there is an increase in rainfall intensity at many places, the change in climate makes some other areas, especially semi-arid regions, susceptible for drought occurrences.

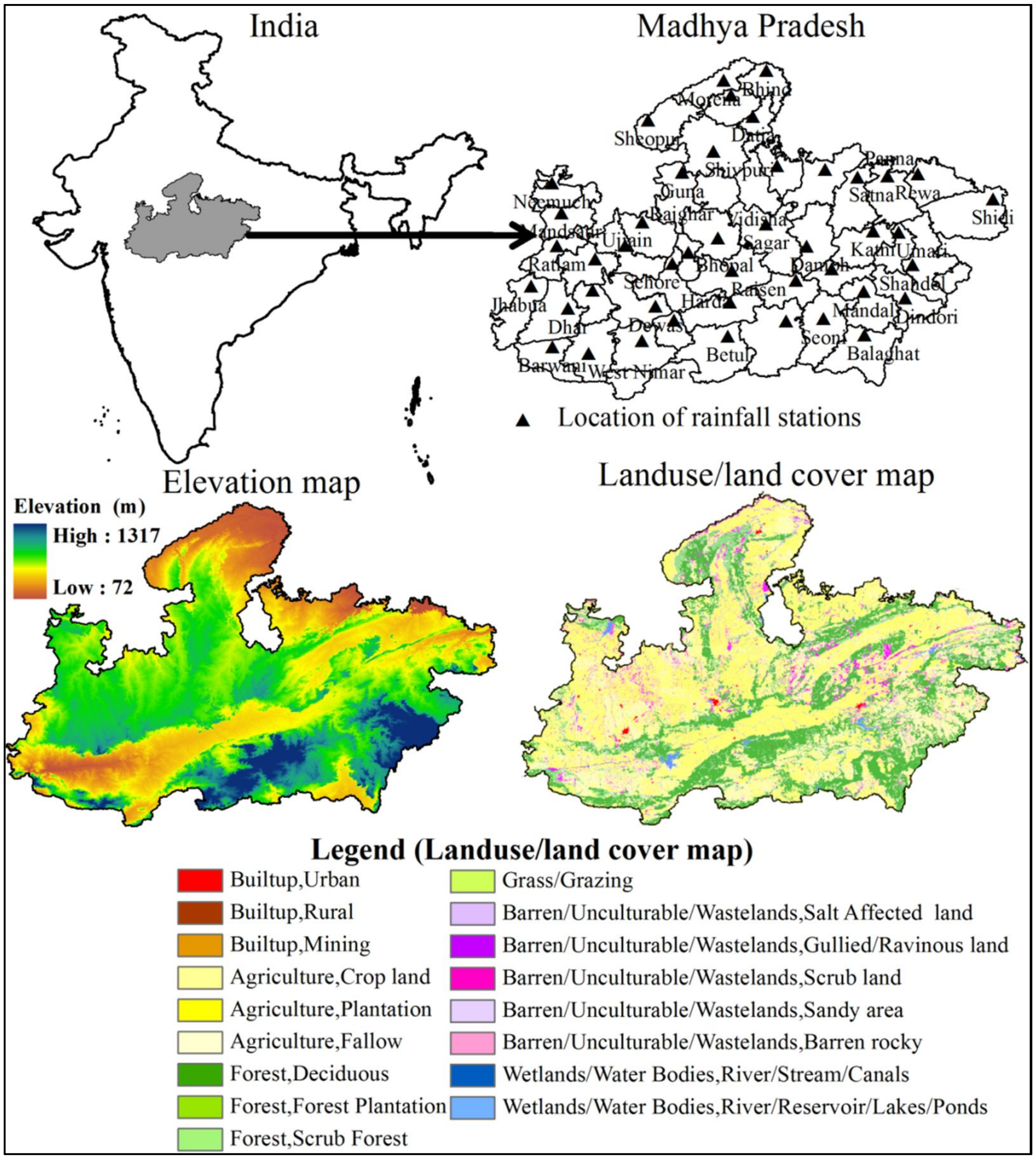
It is widely understood that changes of runoff is the result of the combined effects of climate, land cover and human activities in a basin. In the recent decades, increasing shortages of water resources in most of the river basins are mainly due to the human activities and climate change (Vorosmarty et al. 2000). Madhya Pradesh is also undergoing rapid development both in the industrial sector as well as the agricultural sector. Madhya Pradesh is now the leading producer of food grains for the last few years. The State has set higher targets for its industrial and agricultural growth, which requires creation of additional water storage structures, adoption of water efficient agricultural technologies, optimal utilisation of available water resources including conjunctive use of surface and groundwater, and artificial recharge of groundwater aquifers, as much of the demands are met through the exploitation of the groundwater resources.

Looking into the future scenario, where demands are anticipated to exceed the water availability, along with water quality related issues expected to be more pronounced, a detailed investigation is necessary for the assessment of the water resources scenario of Madhya Pradesh. The future water resources scenario of Madhya Pradesh shall also have an impact on the water resources scenario in the neighbouring states viz., Gujarat, Uttar Pradesh, Andhra Pradesh, Chhattisgarh, Maharashtra and Rajasthan as most of the major river systems including Narmada, Mahi, Tapti, Mahanadi, Wainganga and the north flowing tributaries of Ganga originate here.

Considering the large aerial extent of Madhya Pradesh (308245 sq. km.) and the large number of river systems originating here, the assessment of the future water resources scenario in all the river systems is a herculean task. Moreover, the river systems including Chambal, Kunwari Sindh, Betwa, Dhasan, Ken, Son, and Tons are all sub-basins of the Ganga river system for which the hydrological data is classified. Therefore the study has been conceptualised to have the following major components. The hydrological studies for the assessment of the impact of climate change on water resources in the present and future has been limited to the Narmada basin in Madhya Pradesh, whereas the hydro-meteorological studies for the assessment of the changes in the climatic variables has been carried out for the entire state of Madhya Pradesh. The index map of Madhya Pradesh is given in Figure 1.

2.0 Observed Changes in the Present Climate

The Indian Summer Monsoon Rainfall (ISMR) is the major source of water for most of the regions in India (Dash et al., 2011). The agriculture, forestry, wetlands and fisheries sectors, which are the main livelihood of most Indian population is strongly influenced by the water-based ecosystems that primarily depend on ISMR. It has been reported that the seasonal mean of ISMR series over the past century has remained stable in spite of the steady rise in global mean temperature (Goswami et al., 2006; Rajeevan et al., 2008). On the contrary, Kothawale



Source: *(Elevation map): ASTER GDEM [product of ministry of economy, trade, and industry (METI) and National Aeronautics and Space Administration (NASA)] Landuse/Land cover map: National Remote Sensing Centre (NRSC), Indian Space Research Organization (ISRO)*

Figure 1: Index map of Madhya Pradesh (India)

et al. (2008) observed that the ISMR has decreased at the rate of 1.5 mm/year over the period 1971-2002. It is also reported that the intra-seasonal variability of ISMR has weakened since the 1970's (Kulkarni et al., 2009; Kulkarni, 2011). Nonetheless, the extreme rainfall events, associated with the increasing trend of sea surface temperatures and latent heat flux over Indian Ocean are increasing over Central India (Rajeevan et al, 2008). Studies on the long term trends of ISMR indicate the absence of any trend due to the rainfall being random over the Indian continent (Mooley and Parthasarathy, 1984; Guhathakurtha and Rajevan, 2006). However trends do exist on the spatial scales (Parthasarathy, 1984; Rupa Kumar et al. 1992).

The high resolution gridded data ($1^o \times 1^o$) daily rainfall and daily maximum and minimum temperature (Rajeevan et al., 2006) prepared by the India Meteorological Department (IMD) over the Indian land mass (6.5^o–38.5^o N and 66.5^o–100.5^o E) has been used in this study. The State of Madhya Pradesh is covered by 40 grids ($1^o \times 1^o$) fully or partially in the IMD interpolated information as given in Figure 2.

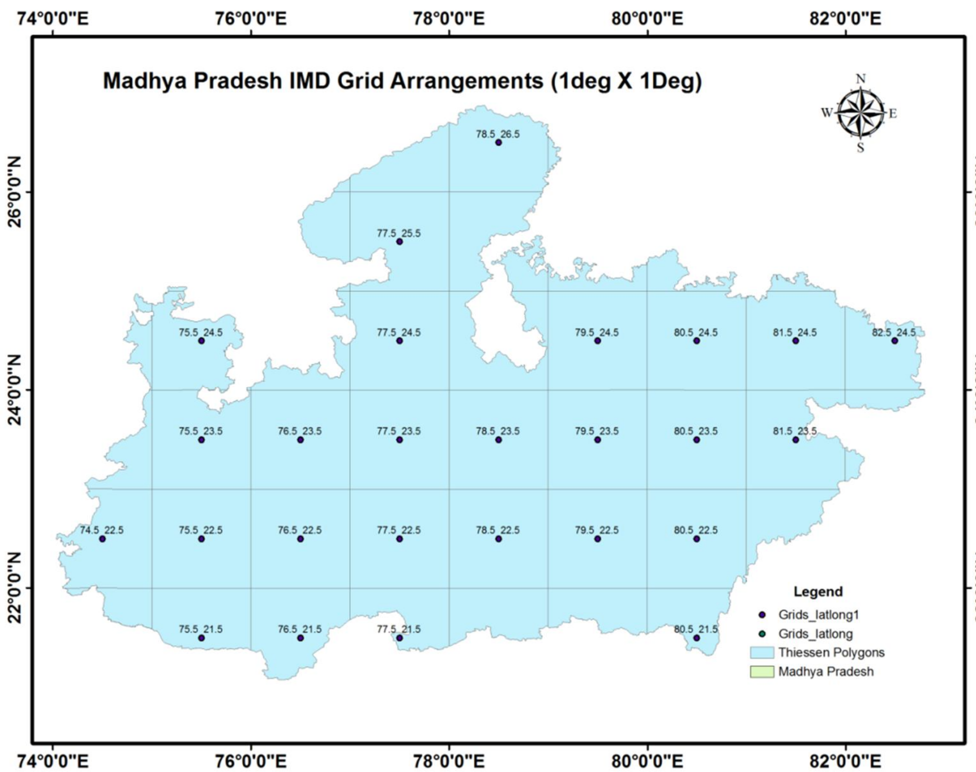


Figure 2: Grid map ($1^o \times 1^o$) for climatic data in Madhya Pradesh

Concerns over global warming and its associated impact on the hydrologic cycle have led to many studies on sustainable development and adaptation strategies in recent years. These studies typically analyse historic data sets in order to extract trends in hydro-climatic data. The Mann–Kendall (M–K) test (Mann, 1945; Kendall, 1975) has been commonly used to extract such trends from historic data sets. Numerous recent examples of such trend analyses can be found in literature, for e.g., temperature and precipitation (Zhang et al., 2001; Gan, 1998), river flow (Burn et al., 2004; Burn and Elnur, 2002; Gan, 1998; Xu et al., 2003; Yang et al., 2004; Novotny and Stefan, 2007), groundwater level variation (Panda et al., 2007), evapotranspiration trends (Yu et al., 2002) and potential and pan evaporation (Burn and Hesch, 2007). This study also followed a similar procedure for the analysis.

2.1 Changes in Precipitation in the Present Climate

The time series on monthly rainfall, quarterly rainfall (viz., pre-monsoon, monsoon, post-monsoon and winter), and annual rainfall has been extracted from the IMD gridded precipitation daily datasets. The trend analysis has been performed on these observed time series of rainfall, which gives an overall idea of the rainfall pattern changes in the various districts of M.P. Homogeneity test is applied to the data series by Standard Normal Homogeneity Test (SNHT) at the significance level of 5% (Alexandersson, 1986; Alexandersson and Moberg, 1997). The test gives the homogenous, heterogeneous series and indicates the break point in the series. Mann-Whitney-Pettitt (MWP) test is applied to detect break point in the series (Pettitt, 1979). The year 1978 has been identified as the change-point year. Therefore the trend analysis has been carried out for these two distinct time periods i.e., 1901-78 and 1979-2002. The district wise general trend in the annual rainfall during 1901-78 is given in Figure 3 and that during 1979-02 is given in Figure 4.

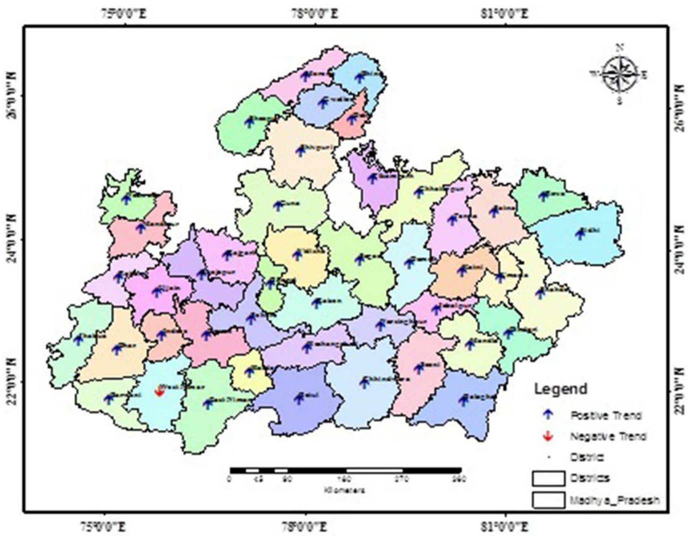


Figure 3: Trend of annual rainfall in Madhya Pradesh during 1901-78

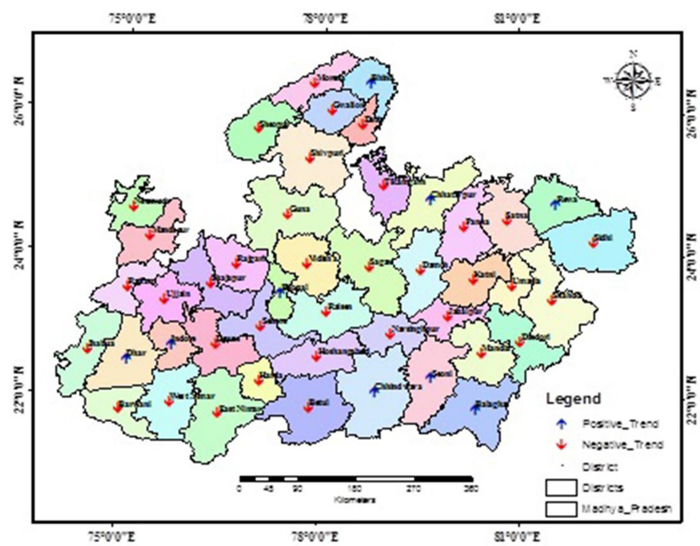


Figure 4: Trend of annual rainfall in Madhya Pradesh during 1979-02

It can be observed that during the period of 1901-78, in general, there has been an increasing trend of annual rainfall in all the districts of Madhya Pradesh except West Nimar. However significant rising trends at 95% significance level have been observed only at Balaghat, Barwani, Betul, Bhind, Bhopal, Chhtarpur, Chhindwara, Damoh, Datiya, Dhar, Dindori, Panna, Raisen, Ratlam, Rewa and Sehore. However, during 1979-02, it has been observed that the annual rainfall in most of the districts is depicting a decreasing trend, except at Bhind, Chhattarpur, Rewa, Dhar, Indore, Chhindwara, Seoni and Balaghat; but none of them were significant decreasing trend at 95% significance level.

The analysis of the monsoon rainfall (June to September) during 1901-78 indicates that the significant rising trends in monsoon rainfall (at 95% significance level) is observed at Balaghat, Barwani, Betul, Bhind, Bhopal, Chhtarpur, Chhindwara, Damoh, Datiya, Dhar, Dindori, Panna, Raisen, Ratlam, Rewa, Sidhi and Sehore. On the contrary, during 1979-02 significant falling trend in rainfall has been observed in Tikamgarh district only. An important aspect found in the analysis of the monthly rainfall is that for the predominant rainfall month of August, significant rising trends were observed at Balaghat, Barwani, Betul, Bhind, Bhopal, Chhtarpur, Chhindwara, Damoh, Datiya, Dhar, Dindori, Indore, Jabalpur, Khabua, Katni, Mandla, Mandsaur, Narsinghpur, Neemuch, Panna, Raisen, Rajgarh, Ratlam, Rewa, Sagar, Satna, Sehore, Shahdol, Shajapur and Sidhi, whereas significant falling trends have been observed during 1979-02 at Katni, Mandla, Mandsaur, Morena, Narsinghpur, Neemuch, Panna, Raisen, Rajgarh, Satna, and Shahdol districts. Also during the same period (*i.e.* 1979-02), significant falling trends were observed at Jhabua, Katni, Mandla, Mandsaur, Morena, Narsinghpur, Neemuch, Raisen, Rajgarh, Ratlam, Sagar, Satna, Sehore, Shahdol, Shajapur, Sidhi, Umaria, Vidisha and West Nimar.

As considerable area under agriculture is rainfed, the farmers are dependent on the monsoon rains for the kharrif crop. Over the years some of the regions, viz, Bundelkhand region and Malwa region, have witnessed droughts on a regular basis and this has led to the agricultural livelihood options being no longer being lucrative. A falling trend in the winter rainfall has been observed in all the districts in M.P., as given in Figure 5. The rabi crops grown during the post-monsoon and winter season need irrigation water and the farmers are dependent on winter rains in non-command areas. The reduction of the winter rains during 1979-02 also calls for comprehensive planning for provision of supplemental irrigation facilities particularly to tide over the dry spells.

2.2 Precipitation Indices

The grid-wise analysis has been performed on all the important rainfall characteristics that may be responsible for floods. Various threshold values have been used by various researchers (Goswami et al., 2006; Sen Roy and Balling 2004; Stephenson et al., 1999) for classifying the total rainfall received on any given day. A day which receives a rainfall equal to or greater than 2.5 mm is considered to be a wet day. Some of the rain indices developed for the deriving the information from the time series of daily gridded precipitation include i) number of wet days (P > 2.5 mm), ii) total rainfall in wet days, iii) rainfall intensity in wet days, iv) number of heavy rainy days (P > 10mm/day), v) number of very heavy days (P > 20mm/day), and vi) maximum 1-day rainfall. All these indices have been computed on a monthly, quarterly, seasonal and annual time scales for the Narmada basin. The location map of Narmada basin is given in Figure 6.

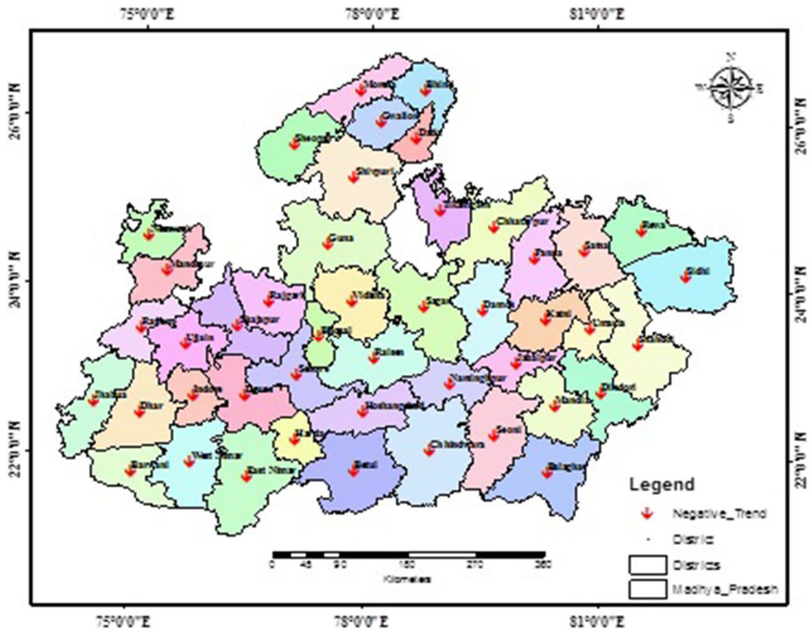


Figure 5: Trend of winter rainfall in Madhya Pradesh during 1979-02

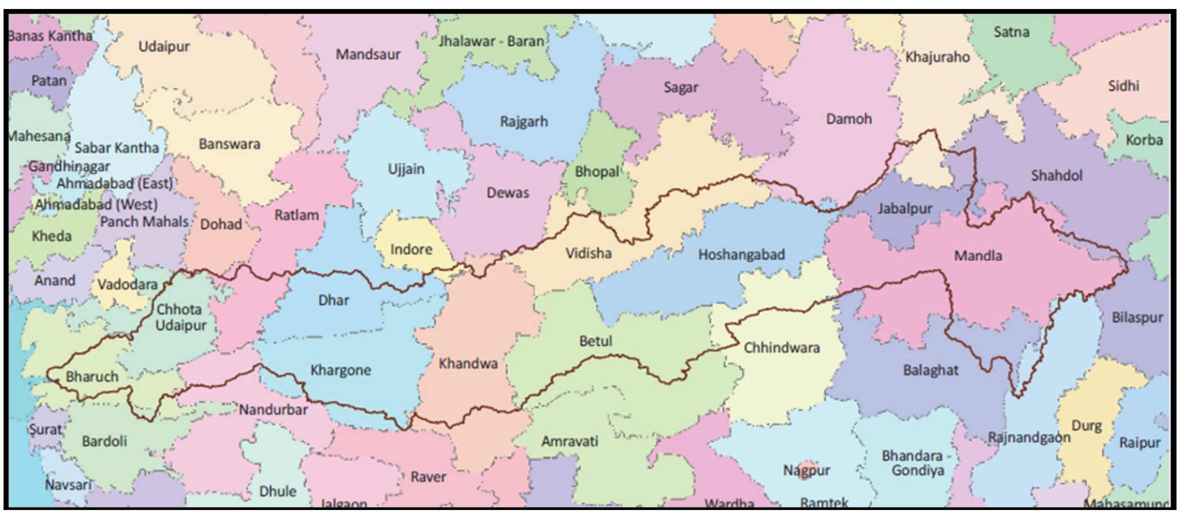


Figure 6: Location map of Narmada basin

The average number of days with heavy rainfall during the historical time period during 1970-05 varied between 1 to 13 days. The spatial distribution of the heavy rainfall events during 1970-05 is given in Figure 7. It can be observed that the maximum number of heavy rainfall events occurred in the basin area falling in Mandla, Balaghat, Hoshangabad, Betul and Chhindwara districts. The maximum area in the basin experienced 7 rainfall events, prominently falling in the districts Vidisha, Khandwa, Khargone, Dhar, Ratlam, Chhota Udaipur and Bharuch. Based on the occurrences of the number of heavy rainfall events, the basin has been classified into 5 classes viz., Low (Less than 3 days), Moderate (3-5 days), High (5-8 days), Severe (8-10 days) and Extreme (more than 10 days). About 58.6% of the basin falls under the moderate class with 3 to 5 heavy rainfall events, followed by 28.0% under high class and 13.4% under severe class with 8-10 heavy rainfall events.

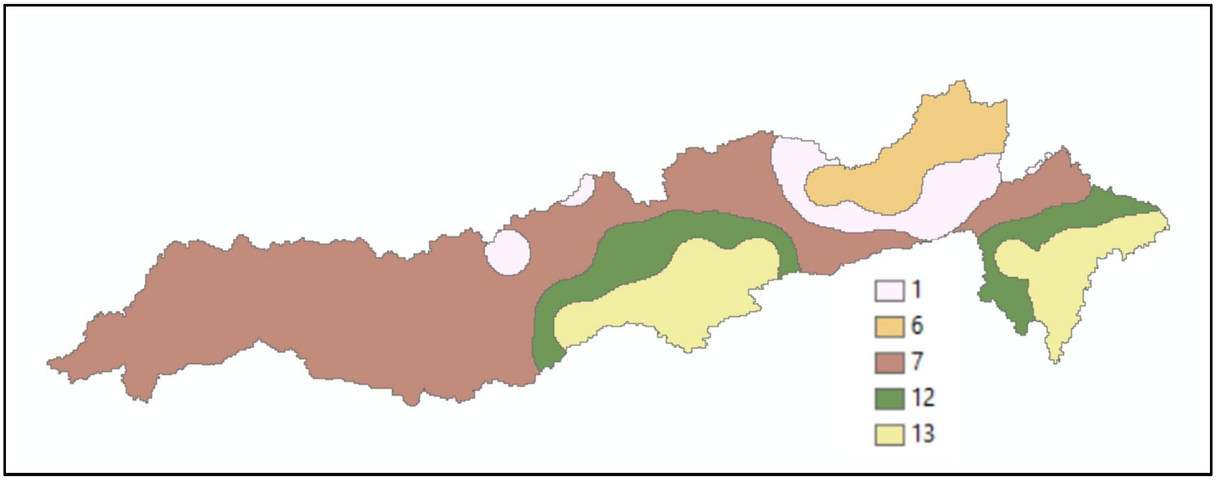


Figure 7: Average number of days of heavy rainfall during 1970-05

The spatial distribution of the very heavy rainfall events during 1970-05 is given in Figure 8. It can be observed that the variation was between 1 and 13 days over the basin with maximum number of heavy rainfall events around the districts of Betul, Chhindwara, Balaghat and Dhar. Seven events of very heavy rainfall were observed in the maximum area falling in the districts of Hoshangabad, Khargone, Dhar, Ratlam, Chota Udaipur, and Bharuch. The areas with only 1 or 2 very heavy rainfall events fall in the districts of Jabalpur, Mandla and Vidisha. About 39.7% of the basin area falls under the low class with less than 3 heavy rainfall events and the remaining 60.3% falls under the moderate class with 3 to 5 heavy rainfall events. The maximum 1-day rainfall averaged over the period from 1970-05 is given in Figure 9. It can be observed that the maximum 1-day rainfall in the highest range of 441-622 mm falls in the basin area located in Hoshangabad district followed by 366-441 mm in Betul district. The lowest range of 1-day maximum (139-228 mm) falls in the basin areas located in Jabalpur, Mandla and Balaghat districts.

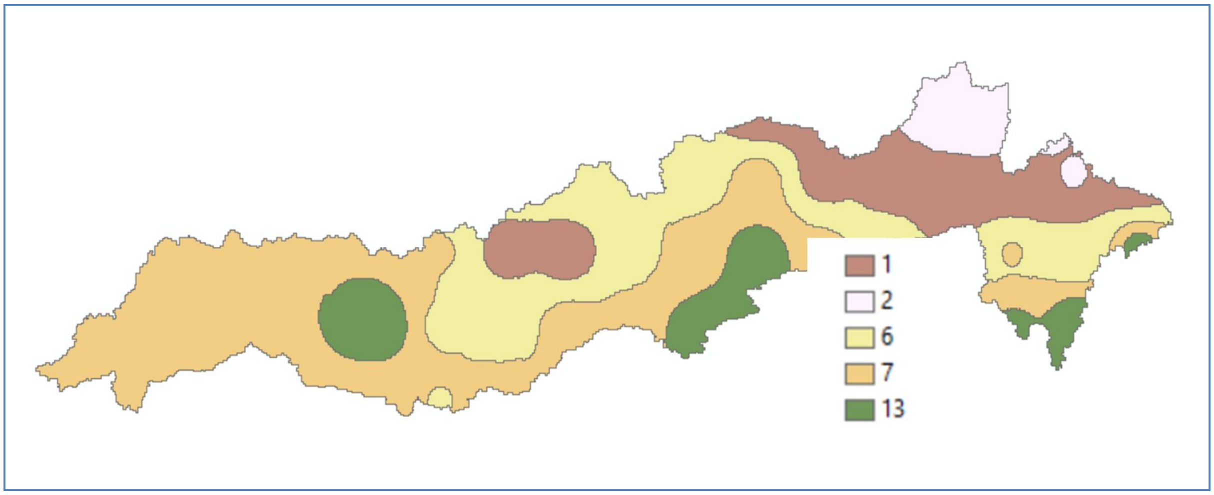


Figure 8: Average number of days of very heavy rainfall during 1970-05

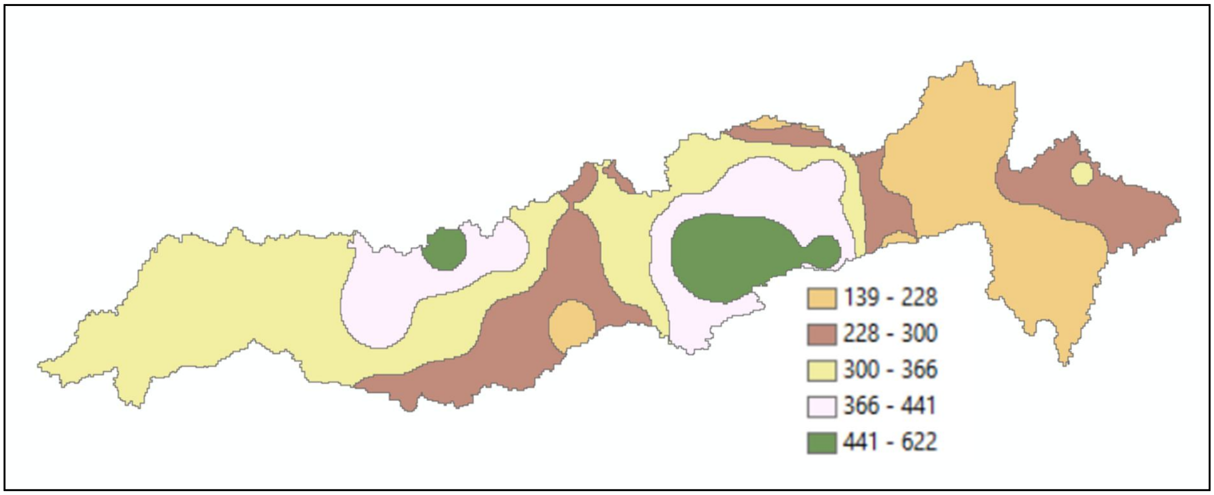


Figure 9: Maximum 1-day rainfall during 1970-05

2.3 Changes in Temperature in the Present Climate

The time series of annual maximum temperature, annual minimum temperature, seasonal maximum and minimum temperatures (viz., pre-monsoon, monsoon, post-monsoon and winter has been extracted from the IMD gridded maximum and minimum daily datasets. The trend analysis has been performed on these observed time series of temperature, which gives an overall idea of the changes in the temperature pattern changes in the various districts of M.P. The annual average maximum temperature annual and the annual average minimum temperature depicts a rising trend even though not significant at 95% significance level in all the districts of Madhya Pradesh as given in Figure 10 and Figure 11. However, during the monsoon season, there exists a mixed pattern of trend of annual average maximum and annual average minimum temperatures, with the northern districts of the state depicting a falling trend and the southern districts depicting a rising trend in the maximum temperature time series as shown in Figure 12 and Figure 13. The 1-day maximum temperatures as well as the 1-day minimum temperature have seen a significant increasing trend at 95% significance level, over most of the districts in Madhya Pradesh.

2.4 Changes in Groundwater Levels in the Present Climate

Groundwater is an important source of fresh water to meet the demands of growing industries such as agriculture, fisheries, mining, and manufacturing and the municipal water demands due to rise in population. Efficient management of groundwater is an essential task in different regions, especially in arid and semi-arid climates that faces chronic shortage of fresh water. Although groundwater systems are likely to respond more slowly to climate change than surface water systems, the impact of climate change on recharge, and hence longer-term availability, remains unclear. Existing data on groundwater conditions and trends is extremely limited, and present quantities and patterns of recharge are uncertain. Moreover, long term projections of rainfall and temperature reveal little about how recharge may change. Hydraulically effective rainfall that contributes to groundwater recharge is affected as much by within-year rainfall variation, and the timing, intensity and duration of rainfall events, as it is by total seasonal or annual amounts.

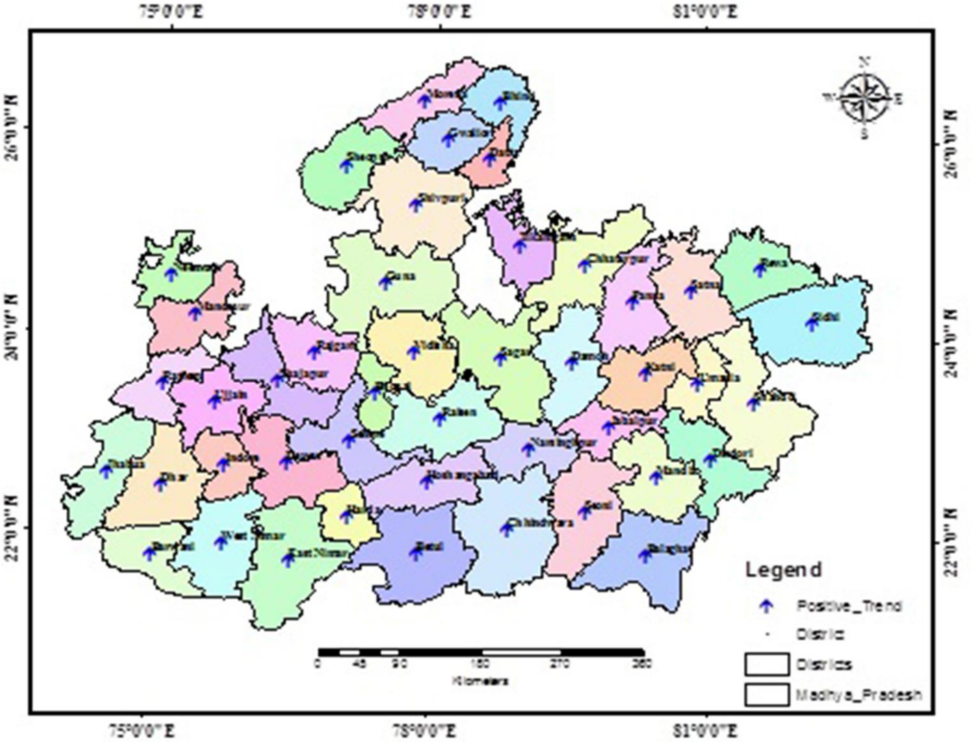


Figure 10: Trend of annual average maximum temperature during 1970-05

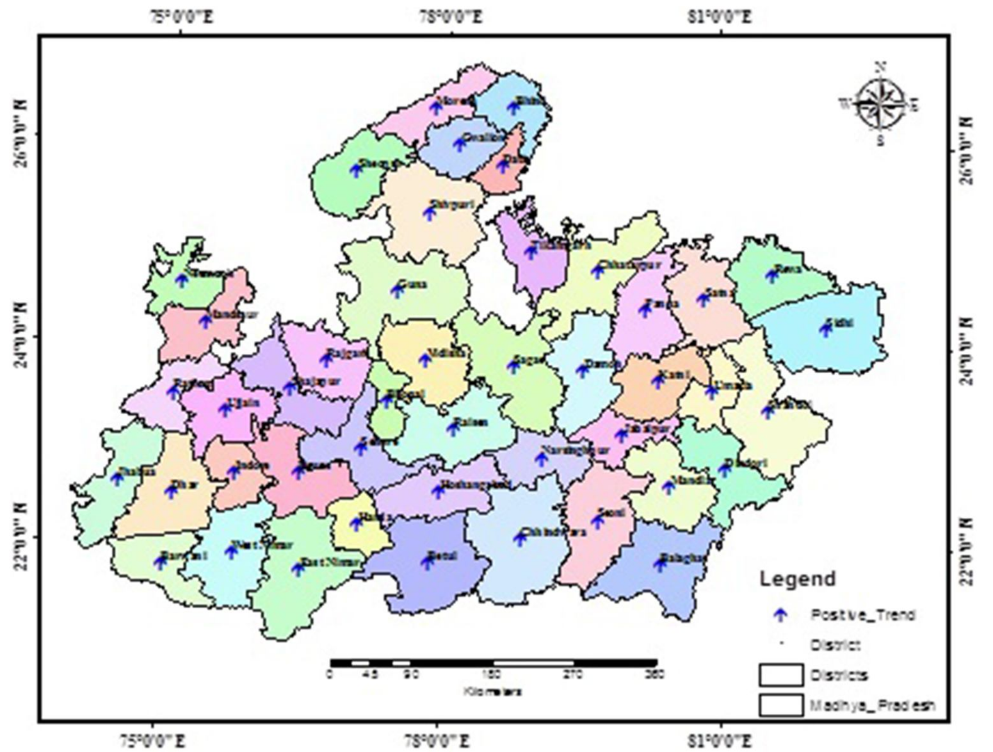


Figure 11: Trend of annual average minimum temperature during 1970-05

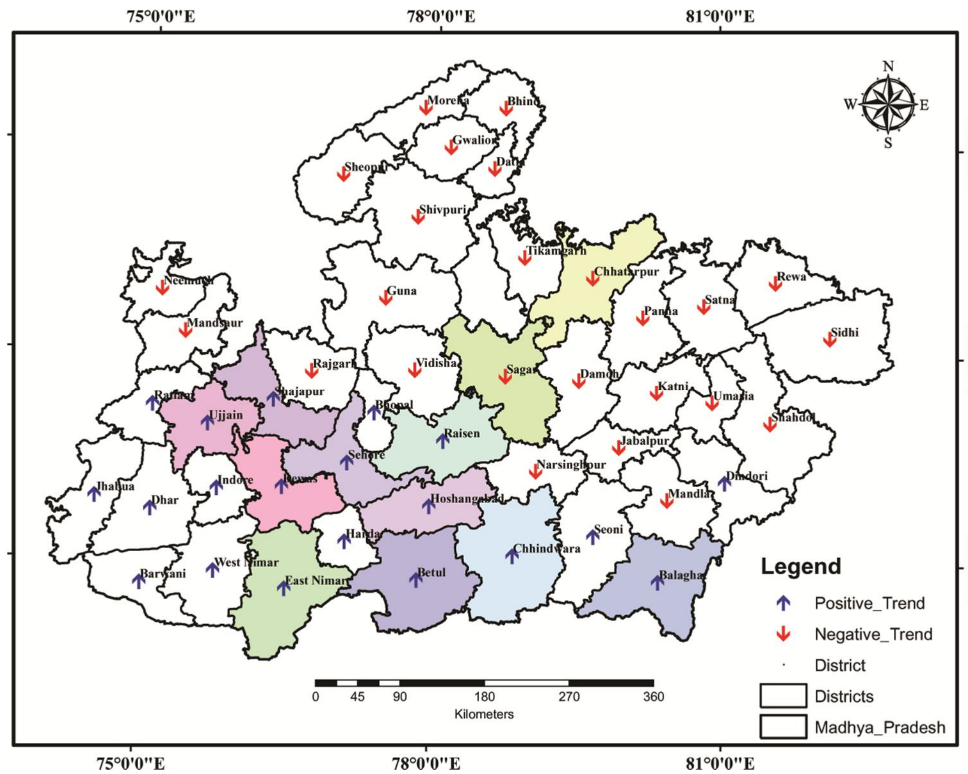


Figure 12: Trend of average maximum temperature in monsoon season

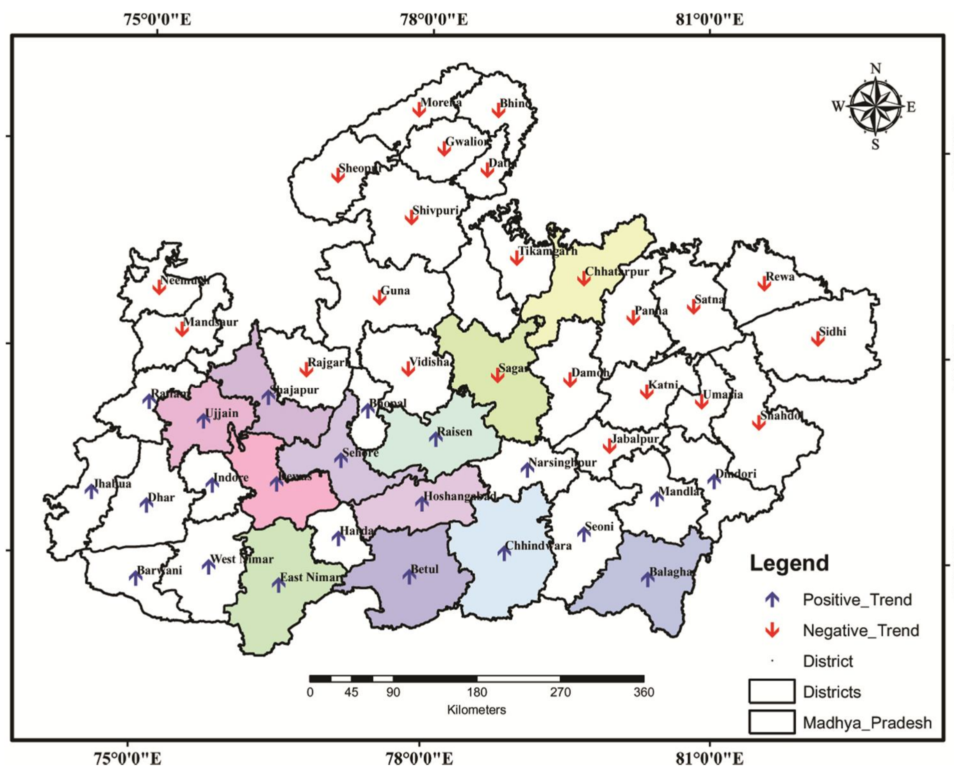


Figure 13: Trend of average minimum temperature in monsoon season

The detection of trends in groundwater levels is very essential in order to constantly monitor the levels of the ground water table. The MK non-parametric methods have been used for trend analysis of groundwater level for Narmada basin in India. The application of MK test statistics has resulted in the identification of trend direction in the groundwater levels in the Narmada basin. A negative trend indicates the decline of groundwater levels and a positive trend indicates the rise of groundwater levels over the years. As each monitoring well reflects the groundwater dynamics of the surrounding area, each trend value gives an idea about the water table fluctuations of that area over the time period.

Groundwater level data is available from 1984 to 2015 for nine districts of Narmada basin in different time scales. Time series data of May (pre-monsoon) and November (post-monsoon) has been extracted from the available data considering a random sample of ten wells in each district and used for trend analysis. In the analysis it is found that most of the observation wells of Hoshangabad, Narasingpur, Khandwa, Khargone, Dhar, Ratlam and Betul districts exhibit negative trend during pre-monsoon and post monsoon period except Mandla. The trend of the groundwater levels during the pre-monsoon and post-monsoon season is given in Figure 14 and Figure 15. The analysis indicates that the groundwater levels of few districts falling in Narmada basin are showing a declining trend which calls for conservation measures and recharge of the aquifer systems through artificial recharge techniques to avoid any future groundwater crisis. It is also recommended that future groundwater resources planning should incorporate the hydrological response of the aquifer systems to the large scale exploitation of groundwater, for its better management for the continued availability of base flow sustained flows in the river system as well.

3.0 Hydrological Model, Setup, Calibration and Validation

Once the climate change signals are clear for the present climate, the next step in the analysis is the assessment of the future climate scenarios on the hydrological variables in the watershed, more pronouncedly the change in the runoff magnitude and pattern. This includes the setup of a distributed model well suited for carrying out climate change assessments at the large basin scales. Since Madhya Pradesh is placed at a higher altitude as compared to the surrounding stations, most of the major river systems flowing towards the north, west and south directions originate here. Since much of the river systems viz, Chambal, Betwa, Sind, Dhasan, Ken and Son are tributaries of Ganga basin which is a trans-boundary river system, the discharge data is classified fall and not available readily. Moreover modelling the runoff in all the river systems is a herculean task, which requires considerable amount of time and resources. Therefore the hydrological modelling and the climate change impact assessment on the water resources sector have been confined to Narmada basin in Madhya Pradesh up to the Mandleshwar gauge-discharge site.

The Narmada basin lies between 72°32' to 81°45'E longitude and 21°20' to 23°45'N latitude extending over an area of 98,796 sq. km. Narmada, the only non-snowed perennial river in India, originates from Narmada Kund located in the Amarkantak hill in the Shahdol district of Madhya Pradesh, India at an elevation of 900 m and flows westwards over a length of 1312 km before draining into the Arabian Sea. The topographical map of Narmada basin is shown in Figure 16. The average annual rainfall in the basin is 1178 mm, 90% of which is received during the monsoon months (June to September). The Narmada valley is a rift valley situated in an active fault zone located between the Narmada north fault and Narmada south fault and the Deccan Traps formed due to the extensive basaltic flows from these faults underlie most of the basin. The upper hilly regions of the basin are mostly covered with shallow red and yellow soils of low fertility. The upper plains are fertile areas well suited for cultivation with deep black soils with alluvial deposits on the banks of its major tributaries. About 32% of the basin is forested, 45% being the net sown area with an average cropping intensity of 135%.

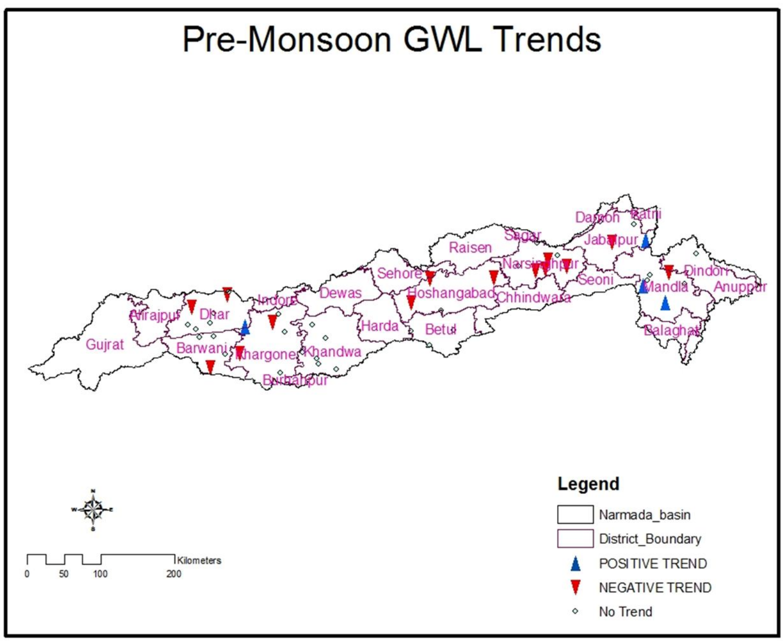


Figure 14: Trend of groundwater levels in Narmada basin during the pre-monsoon season

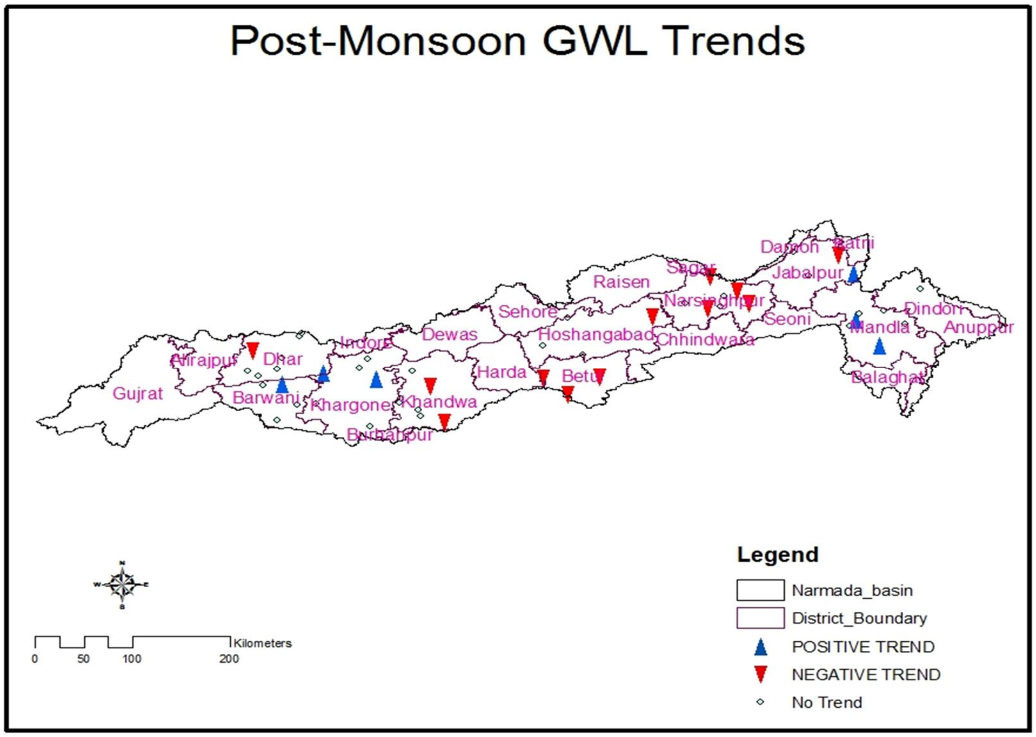


Figure 15: Trend of groundwater levels in Narmada basin during the pre-monsoon season

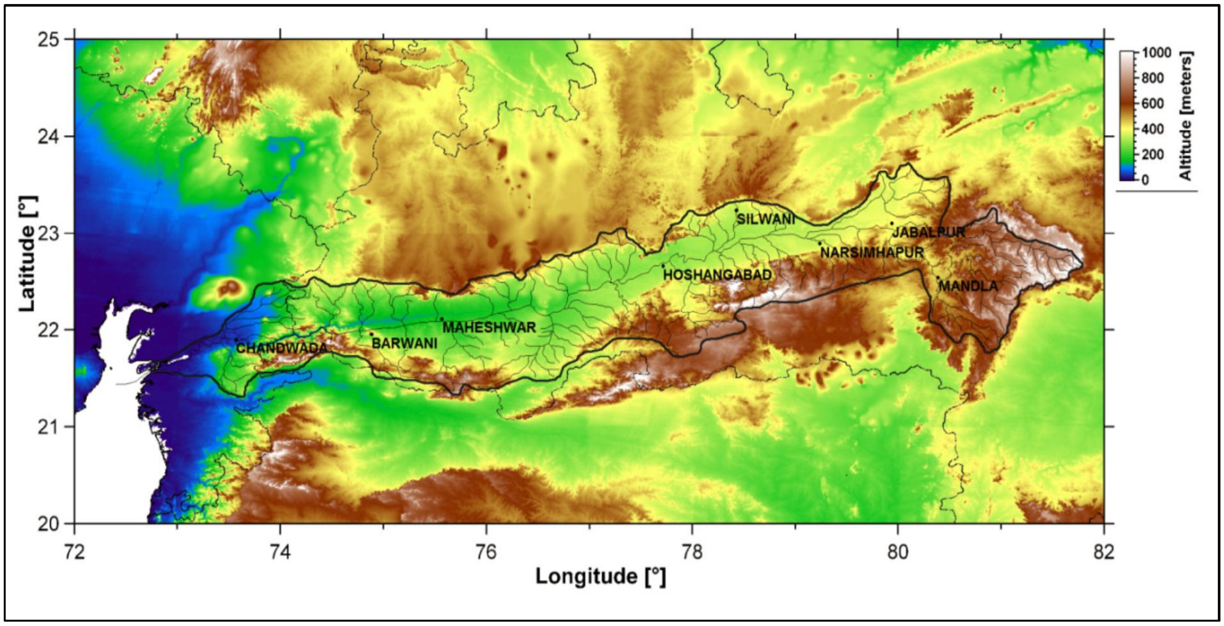


Figure 16: Topography of the Narmada basin

The future plans of large scale utilization the water resources in Narmada and its tributaries foreshadow the construction of 30 major projects and 150 medium and minor projects. It is therefore prudent to investigate the signals of climate change in the basin and its likely impacts on water availability under climate change.

In order to evaluate the impacts of climate change on the hydrology and water resources of a river basin, the first step is to setup a hydrological model capable of modelling large scale river basins with the hydro-meteorological inputs viz., precipitation, temperature, wind speed, radiation etc. along with the actual land use pattern, soil type with its properties and the digital elevation model (DEM). The hydrological model should also be capable of incorporating the reservoirs and account for their multi-purpose use. The Soil and Water Assessment Tool (SWAT) model, which is employed in various climate change studies, is considered to model the stream flows in Narmada basin. The SWAT is a physically-based continuous-event hydrologic model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time. For simulation, a watershed is subdivided into a number of homogenous sub-basins (hydrologic response units or HRU's having unique soil and land use properties. The input information for each sub-basin is grouped into categories of weather; unique areas of land cover, soil, and management within the sub-basin; ponds/reservoirs; groundwater; and the main channel or reach, draining the sub-basin. The loading and movement of runoff, sediment, nutrient and pesticide loadings to the main channel in each sub-basin is simulated considering the effect of several physical processes that influence the hydrology. SWAT has been applied universally in many important river basins for the assessments related to the impacts of climate change under alternate emission scenarios.

The SWAT model has been setup for Narmada basin up to Mandleshwar G/D site with the inputs of DEM, land use, soil type, and climatic datasets. The SRTM DEM at 90 m resolution was used for the topographical inputs whereas the Land use/Land cover prepared by NRSC for Madhya Pradesh has been used. The soil map prepared WATERBASE has been used for the inputs of soil type and various hydrologic soil properties. The high resolution (0.5^o x 0.5^o) precipitation and temperature (1^o x 1^o) prepared by IMD (Rajeevan et al, 2006) has been used for providing the climatic inputs to the model. After setting up the model, a virgin run of the model was carried out, without incorporating any dam. Thereafter, various reservoirs have been incorporated along with their hydraulic properties and reservoir outflows at the appropriate location on the main river as well as the tributaries. The reservoirs considered include Bargi Project, Tawa dam, Barna dam, Kolar dam, OSP, Indira Sagar Project (ISP) and Maheshwar Project. The map showing the SWAT setup along with details of dams, discharge sites, weather stations and drainage network is given in Figure 17.

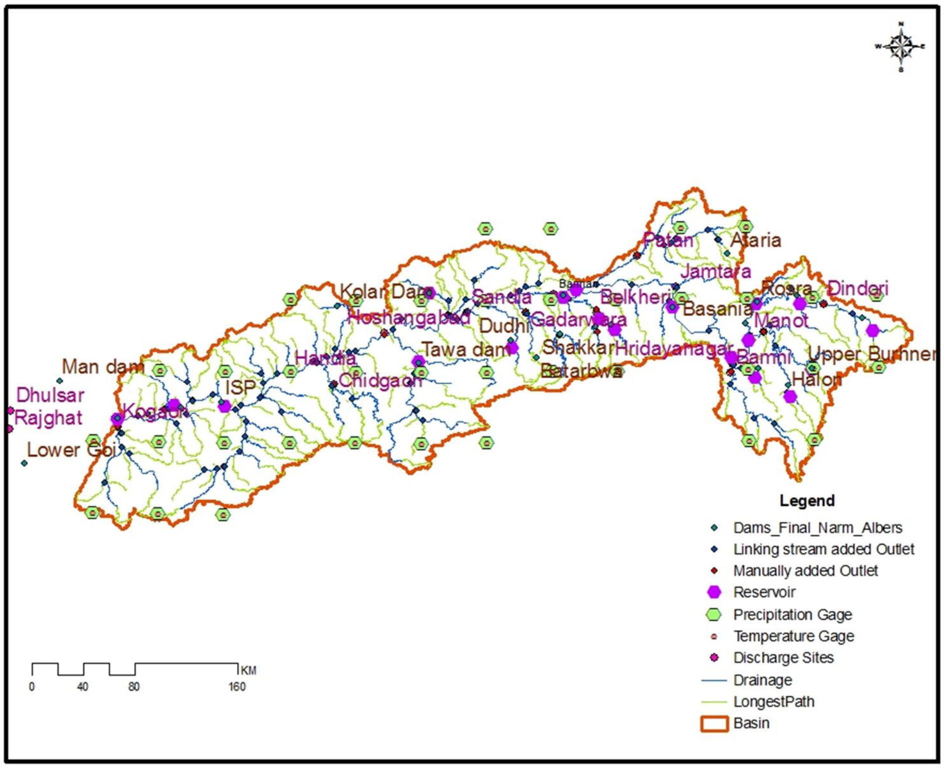


Figure 17: SWAT setup for Narmada basin upto Mandleshwar G/D site

The sensitivity analysis have been performed using the One at a time (OAT) technique and the 6 sensitive parameters have been identified for the basin based on the computation of the sensitivity index viz., CN_f, SOL_AWC, ESCO, GW_REVAP, ALPHA_BF and GW_DELAY. The multi-site calibration of the SWAT model has been carried out with the available discharges at Dindori, Manot, Patan, Mohgaon, Belkheri, Barmanghat, Gadarwara, Chidgaon, Kogaon, Sandia, Hoshangabad, Handia and Mandleshwar. The calibration has been performed using the automatic calibration technique for the period 1988-00. The comparison of the observed and simulated flows during calibration at Manot, Belkheri, Hoshangabad and Mandleshwar (outlet) is given in Figure 18 to Figure 20 respectively. It can be observed that the model has been well calibrated and the simulated flows closely follow the observed flows at all the tributaries as well as on the main river after taking into effect the storages in the dams and routing through the reservoirs and rivers. The measure of efficiency as expressed by Nash-Sutcliffe Goodness of fit at the various gauging sites during calibration is given in Table 1. The efficiency varies between 52.62% a Patan to 87.16 at Manot, which can be considered to be reasonably good calibration.

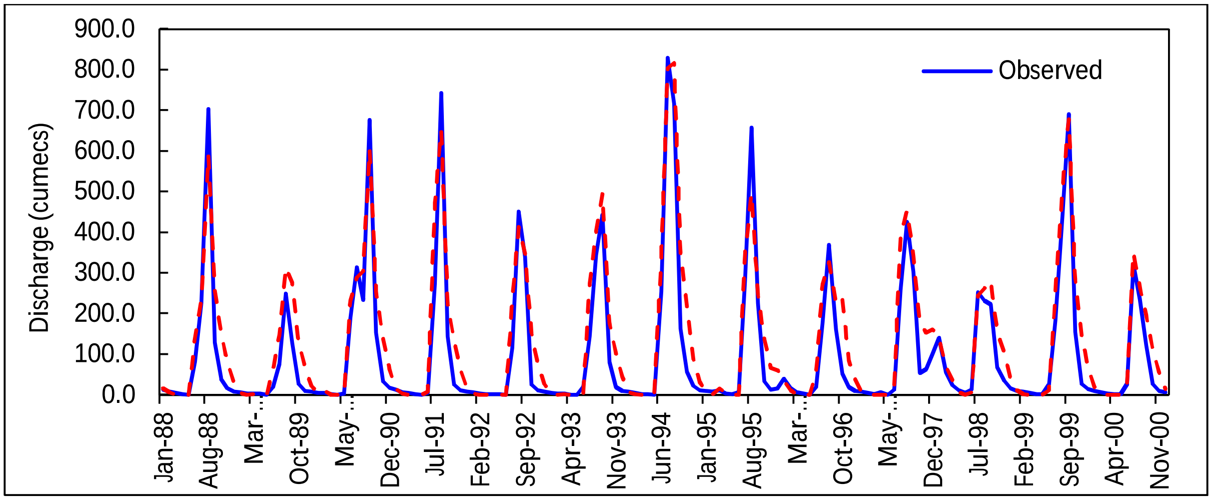


Figure 18: Comparison of observed and simulated flows during calibration at Manot

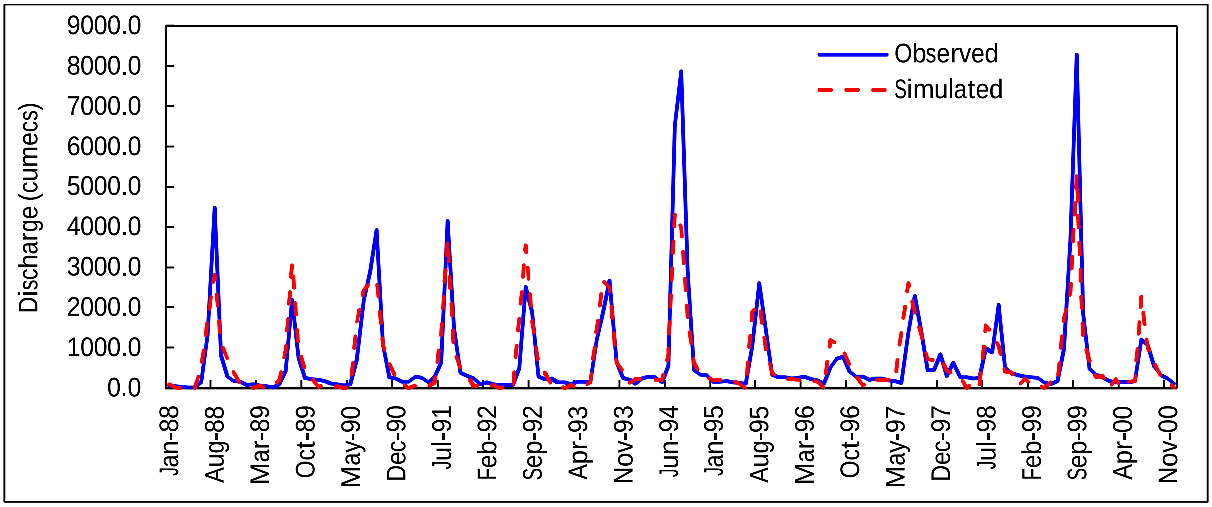


Figure 19: Comparison of observed and simulated flows during calibration at Hoshangabad

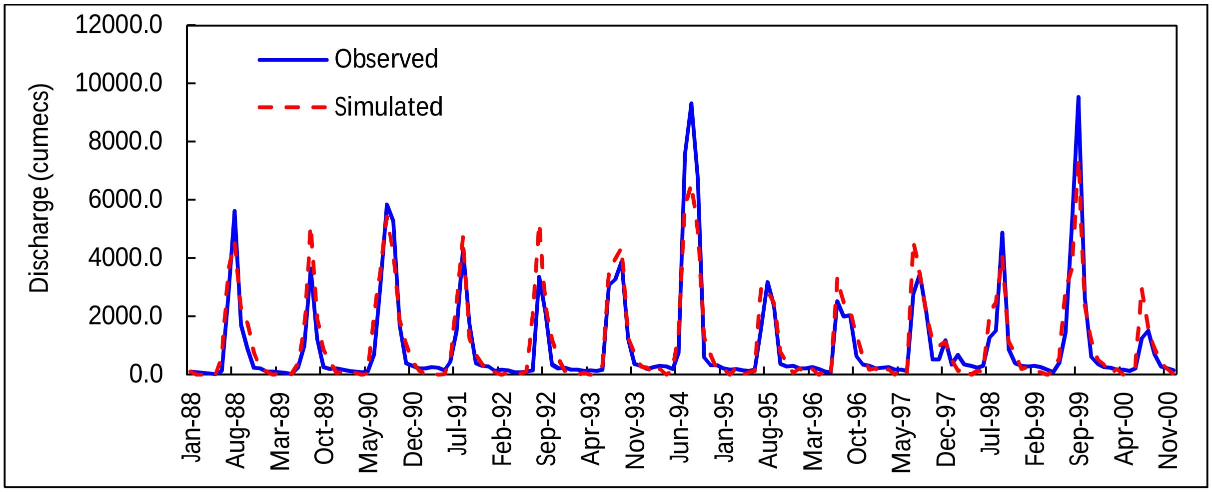


Figure 20: Comparison of observed and simulated flows during calibration at Mandleshwar

Table 1: Simulation efficiency during calibration (1988-00)

S. No.	Gauging site	Nash efficiency
1.	Manot	87.16
2.	Dindori	73.28
3.	Patan	52.62
4.	Barman	68.80
5.	Belkheri	85.57
6.	Gadarwara	84.92
7.	Sandia	80.36
8.	Hoshangabad	78.79
9.	Handia	82.42
10.	Chidgaon	81.43
11.	Kogaon	75.97
12.	Mandleshwar	86.61

Once the model has been calibrated effectively, the model needs to be validated with the independent data sets with the new climate data sets. The model has therefore been validated with the independent data set spanning 2001-05. The comparison of the observed and simulated flows during validation at Manot, Belkheri, Hoshangabad and Mandleshwar (outlet) is given in Figure 21 to Figure 23 respectively. The measure of efficiency as expressed by Nash-Sutcliffe Goodness of fit at the various gauging sites during validation is given in Table 2. The efficiency varies between 50.62% a Patan to 94.45 at Manot, which can be considered to be reasonably good validation. This model which has been calibrated and validated can now be used for the assessment of climate change impacts on water resources.

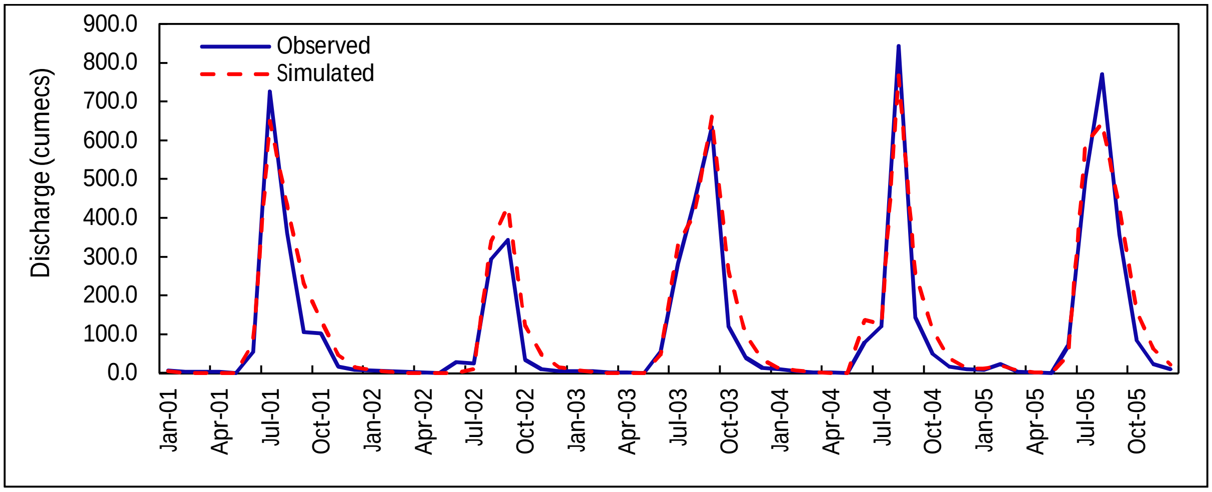


Figure 21: Comparison of observed and simulated flows during validation at Manot

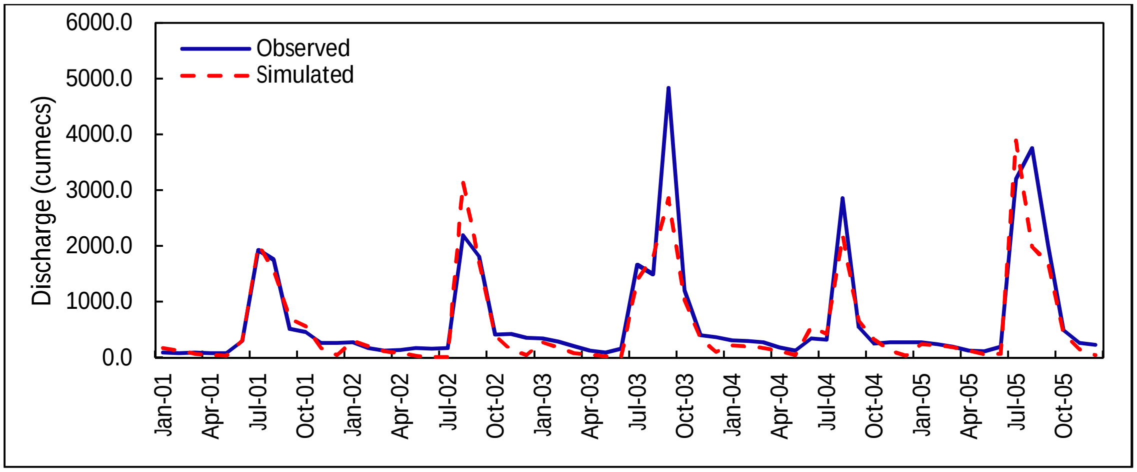


Figure 22: Comparison of observed and simulated flows during validation at Hoshangabad

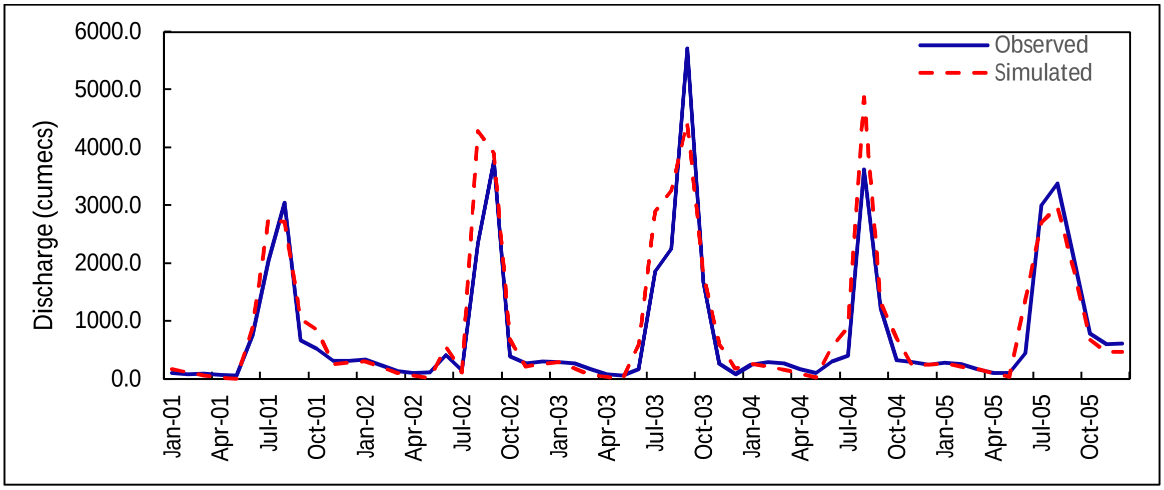


Figure 23: Comparison of observed and simulated flows during validation at Mandleshwar

Table 2: Simulation efficiency during validation (2001-05)

S. No.	Gauging site	Nash efficiency
1.	Manot	94.45
2.	Dindori	77.29
3.	Patan	63.18
4.	Barman	72.69
5.	Belkheri	50.62
6.	Gadarwara	68.52
7.	Sandia	76.35
8.	Hoshangabad	82.67
9.	Handia	83.88
10.	Chidgaon	89.60
11.	Kogaon	84.77
12.	Mandleshwar	85.28

4.0 Dynamically Downscaled RCM Data for Narmada Basin

The climate data for the future is available from the Global Climate Models (GCM). The GCM's are essentially computer programmes which describe the most important components, processes and interactions in the climate system. Scientists insert greenhouse gas concentrations, pollution, and changes in land use and land cover to their models in order to calculate how human activities could affect the climate system. How much emissions and land use change scientists should add depends on future social and economic development, including economic growth, technological change, innovation, population growth and urbanization. This information is provided by scenarios produced by the integrated assessment models.

The Representative Concentration Pathways (RCP) is the latest generation of scenarios that provide input to climate models. The emission scenarios describe how the future may evolve with respect to a range of variables including socio-economic change, technological change, energy & land use changes and Green House Gas (GHG) emissions. RCPs are time and space dependent trajectories of concentrations of greenhouse gases and pollutants resulting from human activities, including changes in land use. Radiative forcing, (expressed as Watts per square metre), is the additional energy taken up by the Earth system due to the enhanced greenhouse effect. RCP's, are set of four new pathways developed for the climate modelling community (forcing values from 2.6 to 8.5W/m^2) at the end of the current century in 2100.

Mitigation scenario leading to a very low forcing level (RCP2.6), Low emission scenarios (RCP4.5), Intermediate emissions scenarios (RCP6) and High emission scenarios (RCP8.5). The mitigation scenario assumes the stabilisation of the GHG emissions at the current level (2.6 W/m^2) until 2100, which seems is highly optimistic and seemingly less realistic. However, the RCP4.5 assumes that the emissions continue to increase till the mid-century after which it stabilises to 4.5 W/m^2. RCP8.5 denotes the business as usual scenario, which means that the emissions will continue at the current rate and reach 8.5 W/m^2 by 2100. The RCP6.0 is an intermediate scenario and falls between RCP2.6 and RCP8.5 with the emissions reaching 6.0 W/ m^2 by the end of the century. The four RCP scenario projections as given in the Assessment Report 5 (AR5) is given in Figure 24.

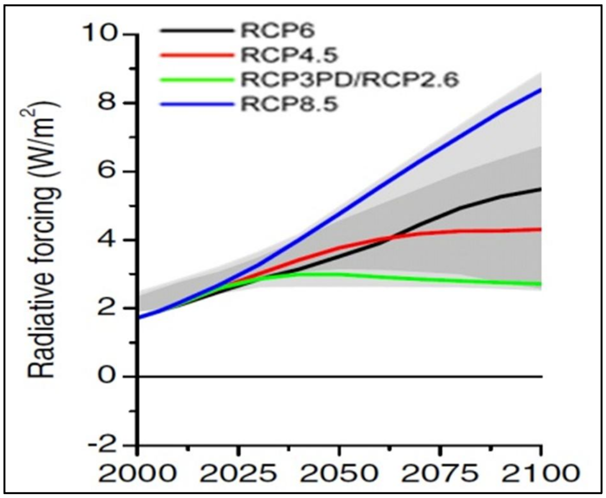


Figure 24: RCP scenarios of AR5

The GCM's give climate projections on global scales with coarse resolutions which may not be suited for assessment of hydrological impacts as the basin level topography and other minute details may not be represented accurately in the projections. So, the direct use of GCM outputs may lead to erroneous assessments of the climate change impacts on water resources as hydrological impacts are needed at regional and basin scales, the resolution of which are very fine as compared to the resolutions of the GCM's. Therefore the GCM outputs need to be downscaled so that it can be used for any meaningful hydrological analysis. Downscaling is the process of relating data at coarse spatial and temporal scale to desired data at finer spatial and temporal scales. There are basically two types of downscaling techniques viz., statistical downscaling and dynamical downscaling. The statistical downscaling involves the development of robust relationships between large-scale parameters that are well-resolved by a global models and available observations at smaller spatial scales. (For example, sea-level pressure and atmospheric moisture fields may be used to downscale regional precipitation).

There are various methodologies available in statistical downscaling including the delta change method, bias corrected statistical downscaling, support vector machine approach, support vector machine, weather typing, multiple linear regression and Statistical Downscaling Model (SDSM). However the dynamic downscaling_techniques employ regional climate models (RCM), using relatively fine grid spacing (10-50 km), to explicitly simulate fine-scale meteorological processes and feedback mechanisms. The RCM's provide projections with much greater detail and more accurate representation of localized extreme events. For the assessment of the climate change impacts, the climate projections from the six RCM models have been considered. The RCM's used for the analysis include CCSM4, CNRM-CM5, GFDL-CM3, ACCESS 1.0, MPI-ESM-L and NOR-ESM-M at 0.5^{o} resolutions for four time horizons, viz., 1970-05 (historical), 2006-70 (near-term), 2041-70 (mid-term) and 2071-99 (end-term) for two scenarios viz., RCP4.5 (low emission scenario) and RCP8.5 (high emission scenario).

5.0 Future Water Resources Scenario in Narmada Basin

The variables pertaining to the maximum temperature, minimum temperature, and precipitation, projected for the future, have been used in the calibrated and validated SWAT model for Narmada basin up to Mandleshwar G/D site. The SWAT model has been run with the alternate climate scenarios from the six RCM's for the low emission scenario (RCP4.5) and high emission scenario (RCP8.5). The simulated outflows obtained from the SWAT model under these alternate climate scenarios have been analyzed further to detect the changes in the extreme events and water availability in the basin. The dependable flow analysis have been performed by fitting an empirical distribution (Weibull, 1951) to the simulated flows, and the dependable flows at 5%, 10%, 20%, 50%, 75%, 90% and 95% dependability have been identified. The dependable flows corresponding to 5% and 10% dependability are indicative of the extreme flood events, 50% dependability indicates the median flow, 75% dependable flow corresponds to the water availability for agriculture, and higher dependable flows corresponds the water availability for domestic drinking requirement. The comparison of the annual dependable flows at Barmanghat G/D site, generated by the four RCM based SWAT simulations for RCP4.5 (low emission scenario) during the time horizons of 2006-40, 2041-70 and 2071-99, is given in Figures 25 through 27. It can be observed that all RCMs simulate the dependable flows in comparable range.

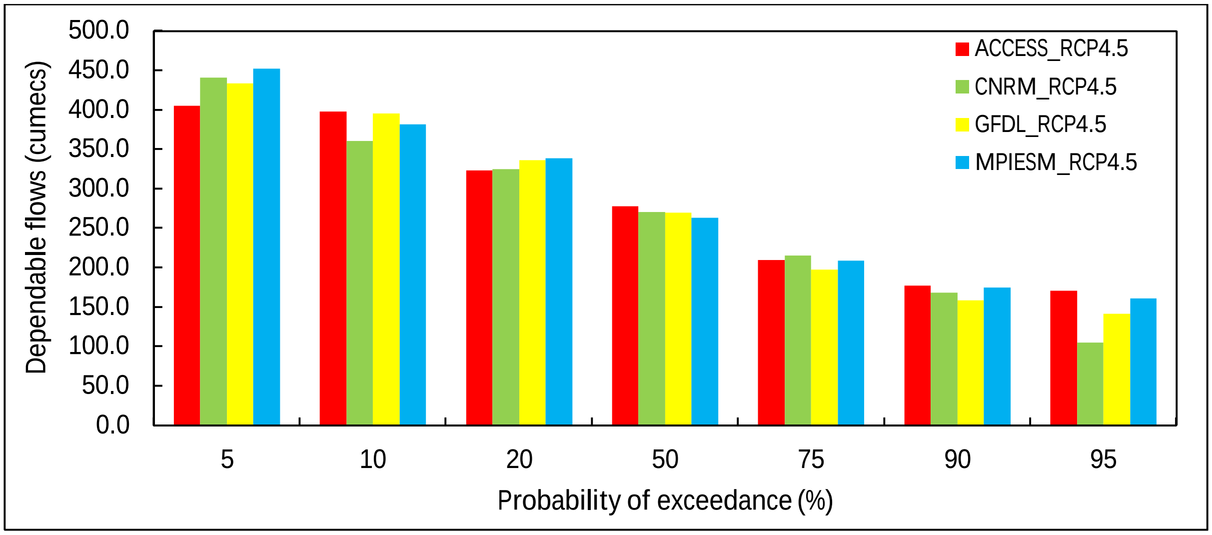


Figure 25: Annual dependable simulated flows at Barmanghat for RCP4.5 during 2006-40

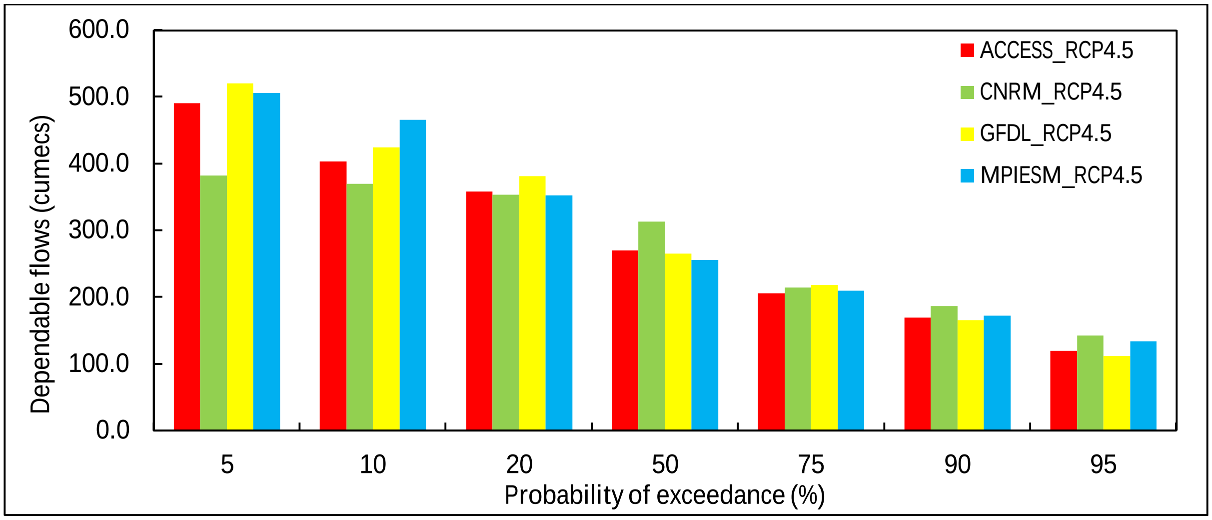


Figure 26: Annual dependable simulated flows at Barmanghat for RCP4.5 during 2041-70

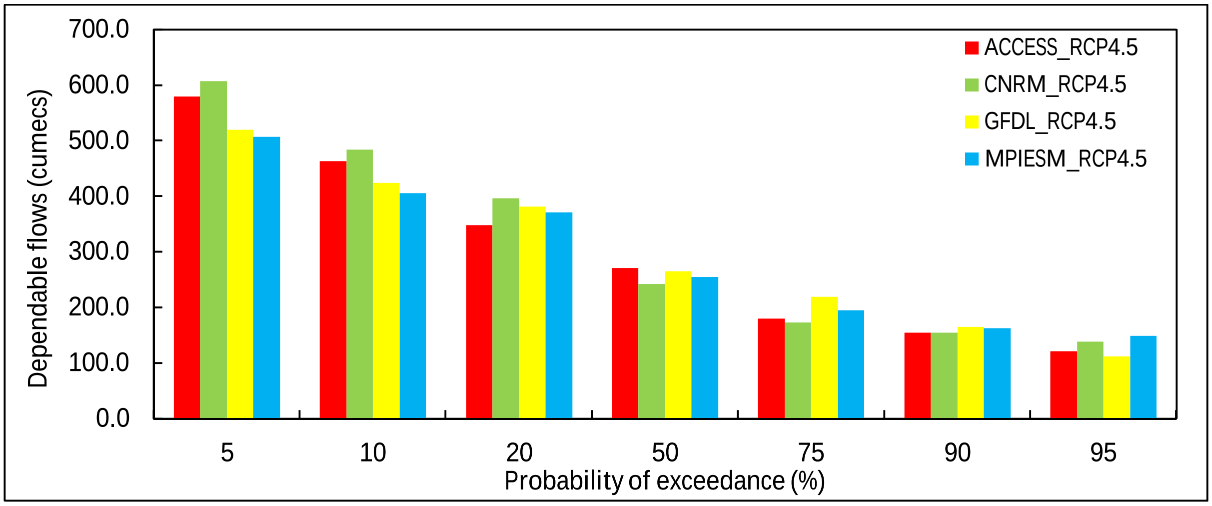


Figure 27: Annual dependable simulated flows at Barman for RCP4.5 during 2071-99

The 5% dependable flow during 2006-40 varies between 405.6 cumecs (ACCESS) to 452.2 cumecs (MPI-ESM). The situation remains similar during 2041-70, with the 5% dependable flow varying between 382.0 cumecs (CNRM) to 520.4 cumecs (GFDL). However during 2071-99, there is an increase in the 5% dependable flows which varies between 507.9 cumecs (MPI-ESM) to 607.3 cumecs (CNRM). This suggests that the extreme events causing floods may increase marginally towards the end-term (2071-99). The annual dependable flows based on the observed flow series at Barmanghat is given in Figure 28. The comparison of the 5% dependable flows with the observed discharge (915 cumecs) and the RCM simulated discharges for RCP4.5 indicate that there is a considerable decrease in the extreme event floods at Barmanghat G/D site during all the three time horizons of 2006-40, 2041-70 and 2071-99. Similarly the comparison of the 10% dependable flows based on the observed discharge and the RCM simulated discharge also indicate considerable decrease in the dependable flows.

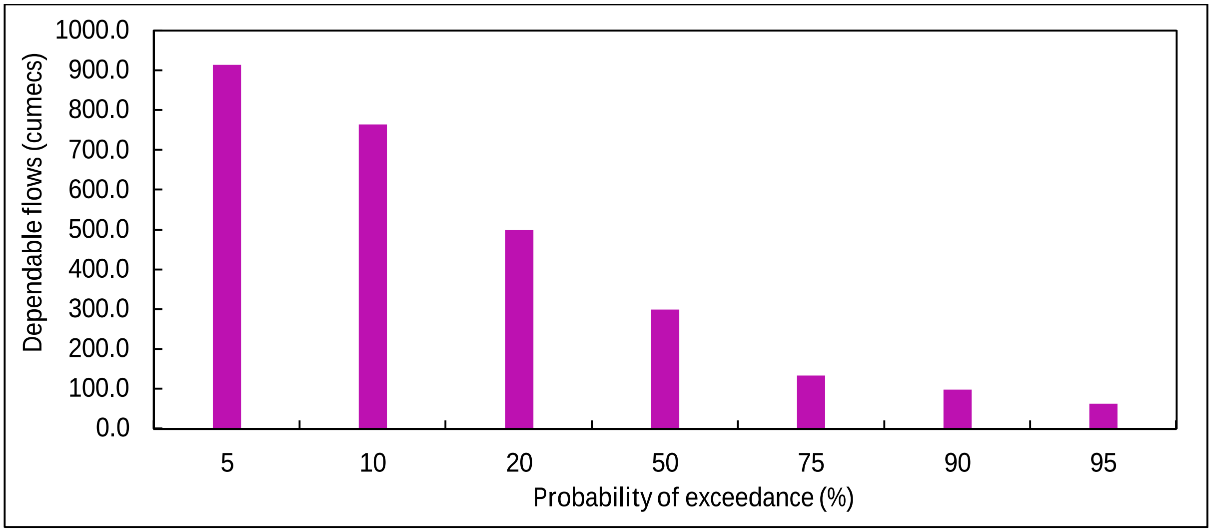


Figure 28: Annual dependable observed flows at Barmanghat (1988-2005)

The 50% dependable flows which indicates the median flow at Barmanghat varies between 263.3 cumecs (MPIESM) to 277.6 cumecs (ACCESS) during 2006-40; between 256.0 cumecs (MPIESM) to 313.4 cumecs (CNRM) during 2041-70; and between 242.6 cumecs (CNRM) to 271.3 cumecs (ACCESS), which are comparable for all the three future time horizons. The 50% dependable flow based on the observed flows during 1988-2005 is 299.5 cumecs. This indicates that there is no considerable change in the median flows in the future time horizons.

The 75% dependable flow based on the observed flows during 1988-2005 is 133.1 cumecs. However the 75% dependable flow based on the RCM simulated discharges for RCP4.5 scenario during 2006-40 varies between 197.3 cumecs (GFDL) to 215.8 cumecs (CNRM); during 2041-70 varies between 209.9 cumecs (MPIESM) to 218.9 cumecs (GFDL); and between 173.6 cumecs (CNRM) to 218.9 cumecs (GFDL) during 2071-99. This indicates considerably higher water availability for irrigation purposes in future at Barmanghat.

The 95% dependable flow which indicates the firm water availability varies between 104.8 cumecs (CNRM) to 170.6 cumecs (ACCESS) during 2006-40; between 112.4 cumecs (GFDL) to 142.7 cumecs (CNRM); and between 112.4 cumecs (GFDL) to 138.4 cumecs (CNRM) whereas the 95% dependable flows based on the observed discharges (1988-2005) is 63.6 cumecs. This suggests higher water availability to meet the firm demands including domestic water requirements and also suggest no major stress on the firm water availability during all the three future time horizons. The situation seems to be similar at other gauging sites also.

The annual dependable flow generated for RCP8.5 (high emission scenario) by the four RCMs (ACCESS, CNRM, GFDL and MPIESM) is given in Figure 29 through 31. This analysis was done with a specific interest to see the intra seasonal variability produced by different RCMs. All the three models show a similar pattern with higher extreme events during 2071-99 and for the remaining dependable flows at 50%, 75%, 905 and 99% the pattern is slightly different with more flows in the mid-term (2041-70) as compared to the other time horizons.

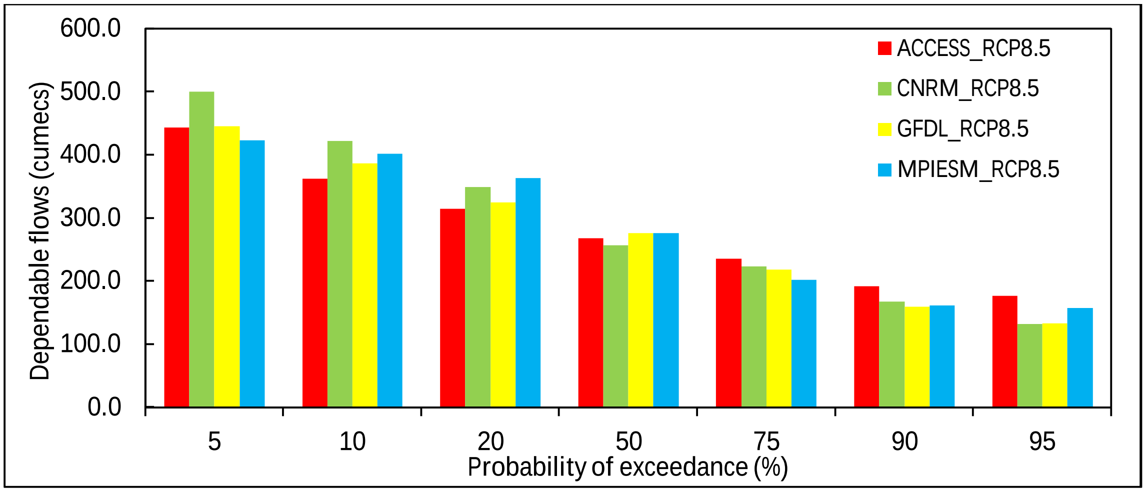


Figure 29: Annual dependable simulated flows at Barmanghat for RCP8.5 during 2006-40

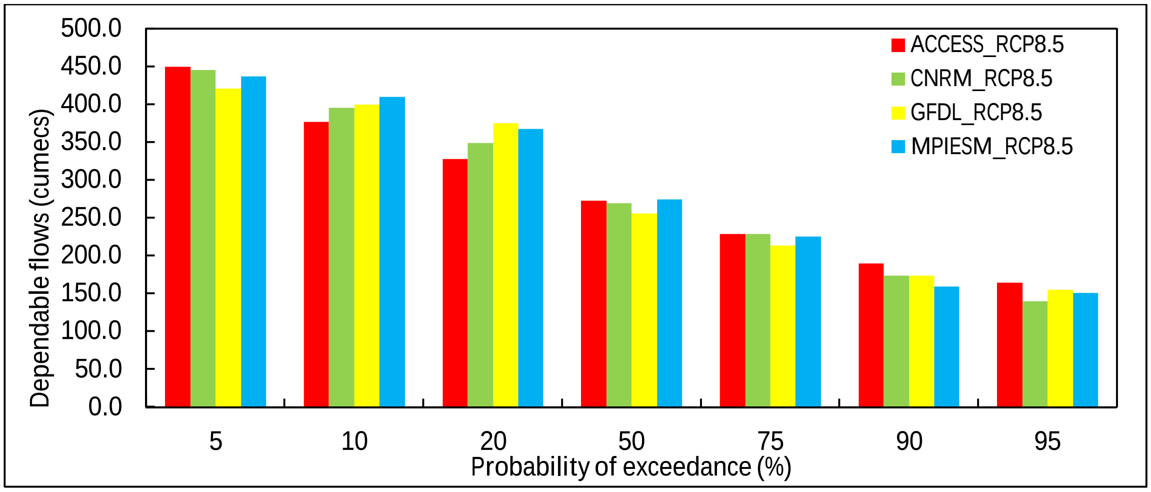


Figure 30: Annual dependable simulated flows at Barmanghat for RCP8.5 during 2041-70

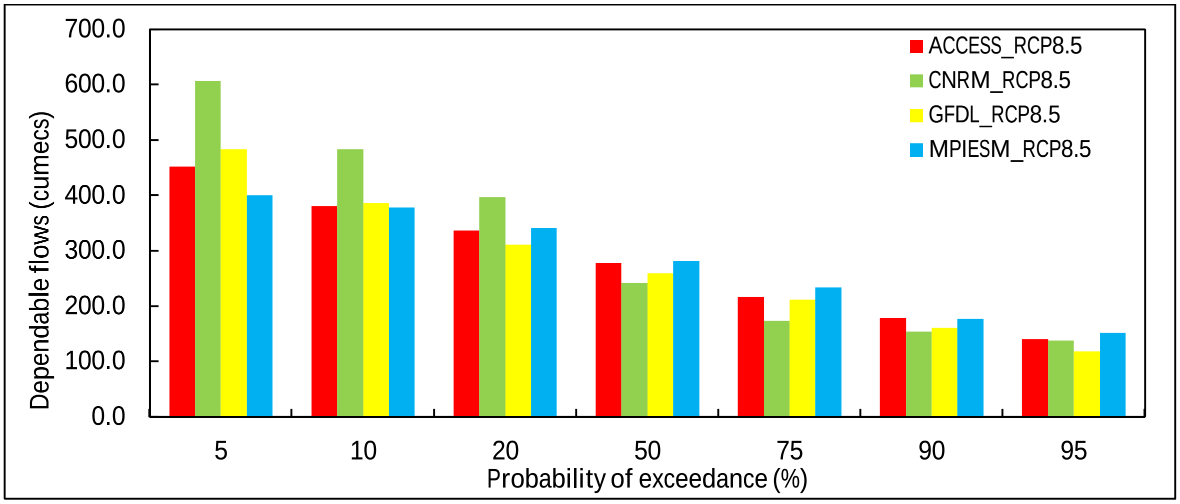


Figure 31: Annual dependable simulated flows at Barmanghat for RCP8.5 during 2071-99

The 5% dependable flow during 2006-40 varies between 422.9 cumecs (MPIESM) to 500.3 cumecs (CNRM). The situation remains similar during 2041-70, with the 5% dependable flow varying between 420.8 cumecs (GFDL) to 449.8 cumecs (ACCESS) and during 2071-99, varies between 404.7 cumecs (MPI-ESM) to 610.3 cumecs (CNRM). This suggests that during the three future time horizons, the extreme events causing floods may increase marginally towards the end-term (2071-99). However, the comparison of the 5% dependable flows with the observed discharge (915 cumecs) and the RCM simulated discharges for RCP8.5 scenario indicate that there is a considerable decrease in the extreme event floods at Barmanghat G/D site during all the three time horizons of 2006-40, 2041-70 and 2071-99. Similarly the comparison of the 10% dependable flows based on the observed discharge and the RCM simulated discharge also indicate considerable decrease in the dependable flows.

The 50% dependable flows which indicates the median flow at Barmanghat varies between 257.0 cumecs (GFDL) to 276.1 cumecs (MPI-ESM) during 2006-40; between 255.9 cumecs (GFDL) to 274.9 cumecs ((MPI-ESM) during 2041-70; and between 242.6 cumecs (CNRM) to 281.5 cumecs (MPI-ESM), which are comparable for all the three future time horizons. The 50% dependable flow based on the observed flows during 1988-2005 is 299.5 cumecs. This indicates that there is no considerable change in the median flows in the future time horizons which are similar to the RCP4.5 scenario based simulations.

The 75% dependable flow based on the observed flows during 1988-2005 is 133.1 cumecs. However the 75% dependable flow based on the RCM simulated discharges for RCP4.5 scenario during 2006-40 varies between 202.5 cumecs (MPI-ESM) to 235.5 cumecs (ACCESS); during 2041-70 varies between 213.3 cumecs (GFDL) to 229.2 cumecs (CNRM); and between 170.5 cumecs (CNRM) to 234.1 cumecs (MPI-ESM) during 2071-99. This indicates significantly higher water availability for irrigation purposes in future at Barmanghat. The 95% dependable flow which indicates the firm water availability varies between 132.4 cumecs (CNRM) to 176.4 cumecs (ACCESS) during 2006-40; between 140.1 cumecs (GFDL) to 164.5 cumecs (ACCESS); and between 118.5 cumecs (GFDL) to 152.3 cumecs ((MPI-ESM) whereas the 95% dependable flows based on the observed discharges (1988-2005) is 63.6 cumecs. This suggests much higher water availability to meet the firm demands including domestic water requirements and also suggest no major stress on the firm water availability during all the three future time horizons. The situation seems to be similar at other gauging sites also. Similarly the dependable flows at Hoshangabad G/D site based on the RCM simulated flows for RCP8.5 scenario during 2041-70 and 2071-99 is given in Figure 32 and Figure 33 respectively.

However the Barmanghat G/D site as well as the Hoshangabad and Mandleshwar G/D sites are located downstream of major dams. The Barmanghat G/D site is located downstream of Bargi dam, whereas Hoshangabad G/D site is located further downstream after Bargi, Tata and Barna dams whereas the Mandleshwar G/D site is located at the downstream of the Indira Sagar Project. Therefore the dependable flows have been estimated at these sites for the future time horizons may have taken the dam effect into consideration and there lies a possibility of moderation of the extreme flows due to the storage taking place in the reservoirs.

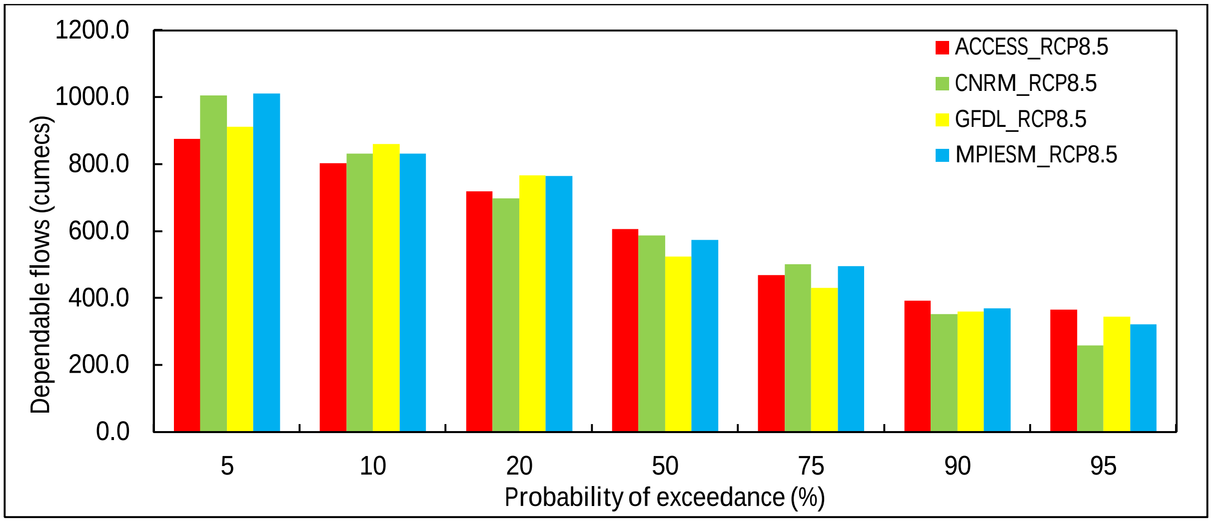


Figure 32: Annual dependable simulated flows at Hoshangabad for RCP8.5 during 2041-70

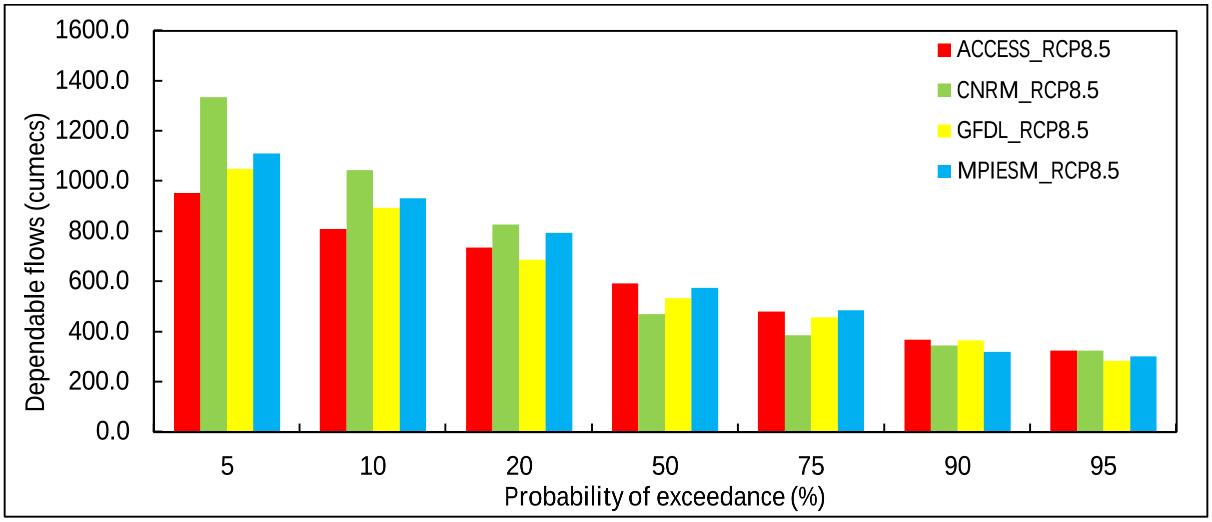


Figure 33: Annual dependable simulated flows at Hoshangabad for RCP8.5 during 2071-99

Therefore the dependable flow analysis has also been carried out for few virgin basins viz., the G/D sites located at Dindori and Manot. The dependable flows at Manot G/D site based on the RCM simulated flows for RCP8.5 scenario during 20006-40, 2041-70 and 2071-99 is given in Figure 34 through 36. The dependable flows based on the observed discharges at Manot G/D site during 1988 to 2013 is given in Figure 37.

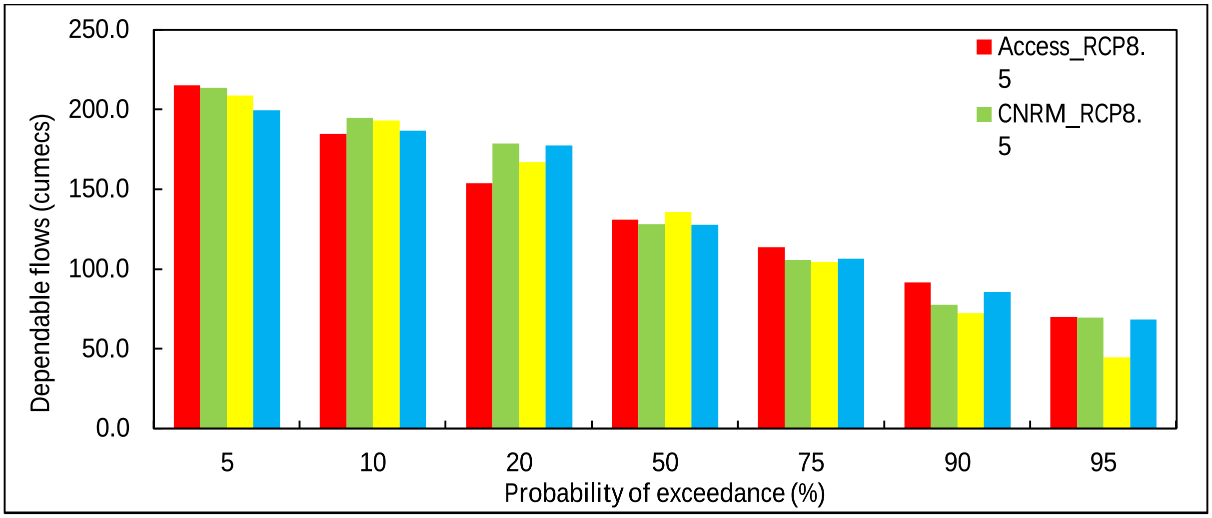


Figure 34: Annual dependable simulated flows at Manot for RCP8.5 during 2006-40

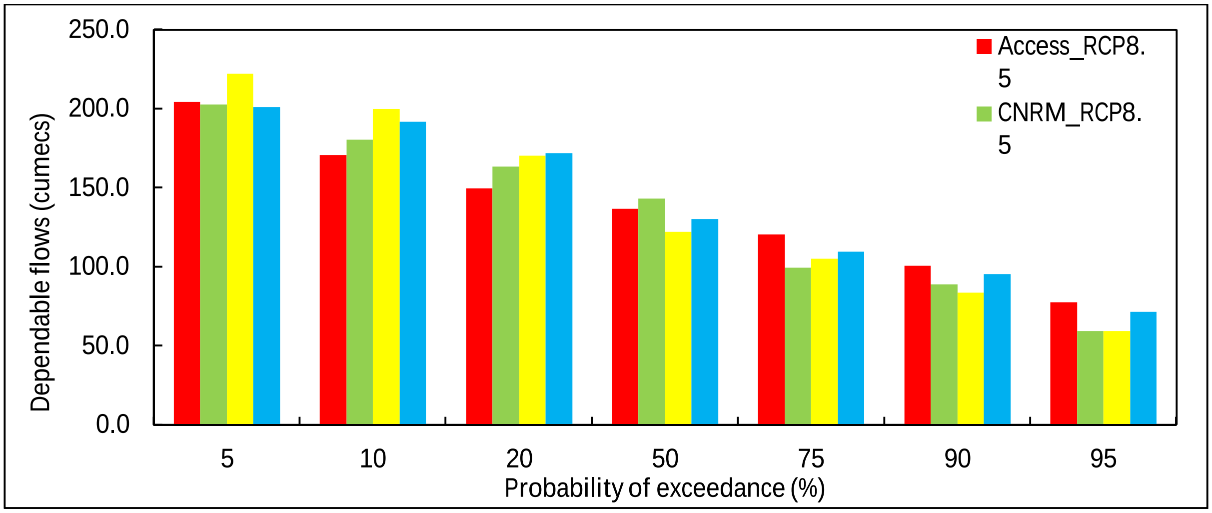


Figure 35: Annual dependable simulated flows at Manot for RCP8.5 during 2041-70

It can be observed that the extreme flood events represented by 5% dependable flows is more than 200 cumecs in all the three time horizons whereas the observed 5% dependable flow at Manot is 169.0 cumecs. This suggests a considerable increase in the extreme flood events in the basin which are generally virgin with no major/medium dams upstream of the G/D site. The comparison of the 5% dependable flows during the three time horizons indicates that the magnitude of the extreme events is considerably higher during the 2071-99 periods. The comparison of the observed and RCM simulated dependable flows for the other dependability's viz., 10%, 20%, 50%, 75%, 90% and 95% all show increased water availability as compared to the observed dependable flows. Measures should therefore be taken to provide adequate drainage capacities to drain of the excess flood waters from the urban and rural settlements located near these virgin rivers/tributaries.

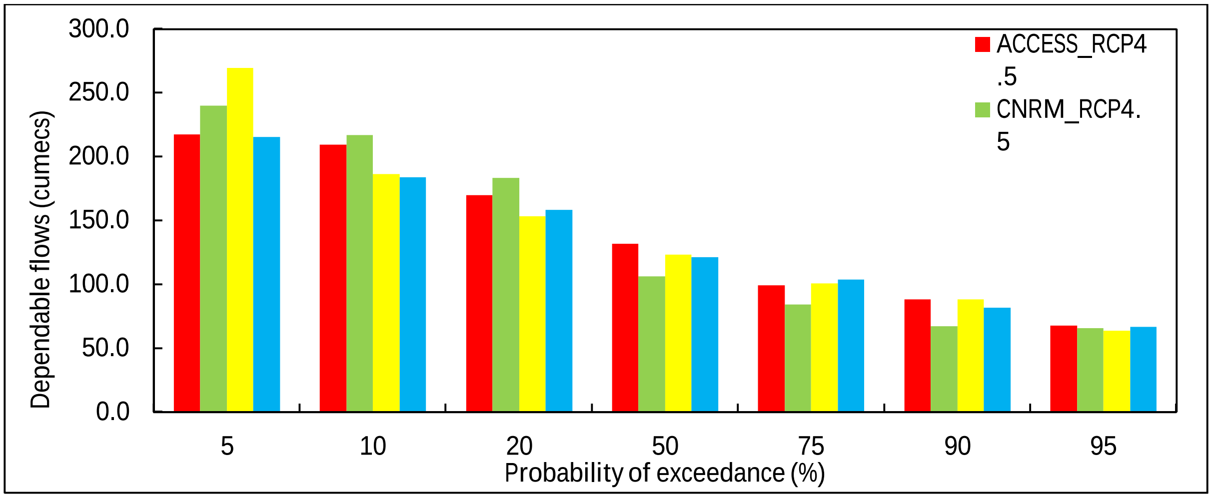


Figure 36: Annual dependable simulated flows at Manot for RCP8.5 during 2071-99

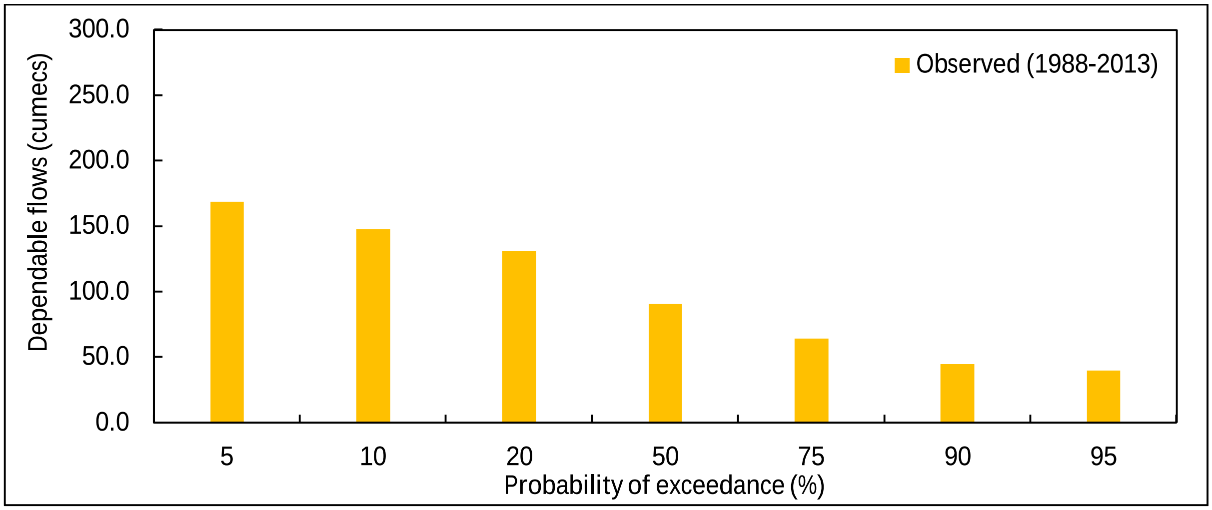


Figure 37: Annual dependable flows at Manot based on observed flows during 1988-13

The drought analysis has been performed using the SPI based on the gridded monthly precipitation time series during the three time horizons of 2006-40, 2041-70 and 2071-99. A SPI values less than -2.0 indicates an extreme drought in a grid. The number of extreme droughts over these time horizons have been estimated and interpolated to show the spatial variation on the extreme drought events in Narmada basin. The number of extreme drought events during the three different time horizons over the Narmada basin is presented in Figure 38 through 40. The results clearly indicate that the Narmada basin may not experience frequent extreme droughts in the future with the number of extreme events varying between 5 and 7 during 2006-40; between 3 and 7 events during 2041-70; and between 3 to 6 events during 2071-99. It is observed that the number of drought events in future are decreasing, and is consistent with the results presented earlier on the water availability scenario. A similar observation is made in the case of drought with severe/moderate intensity.

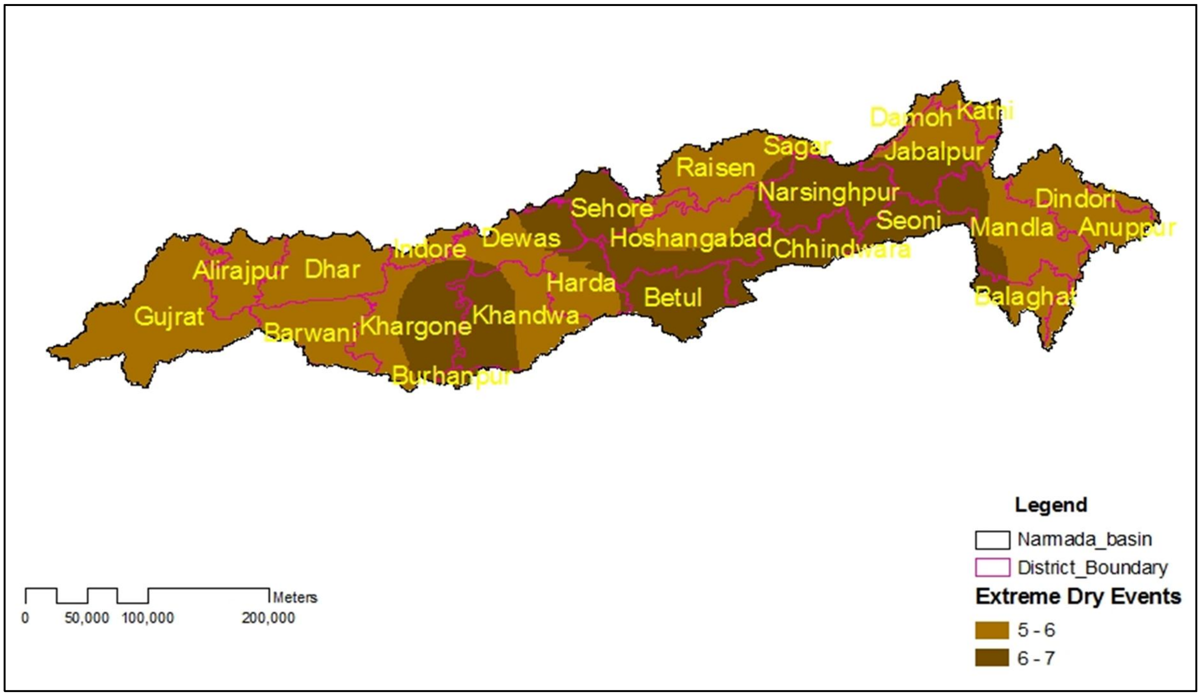


Figure 38: Variation of extreme dry events in Narmada basin during 2006-40

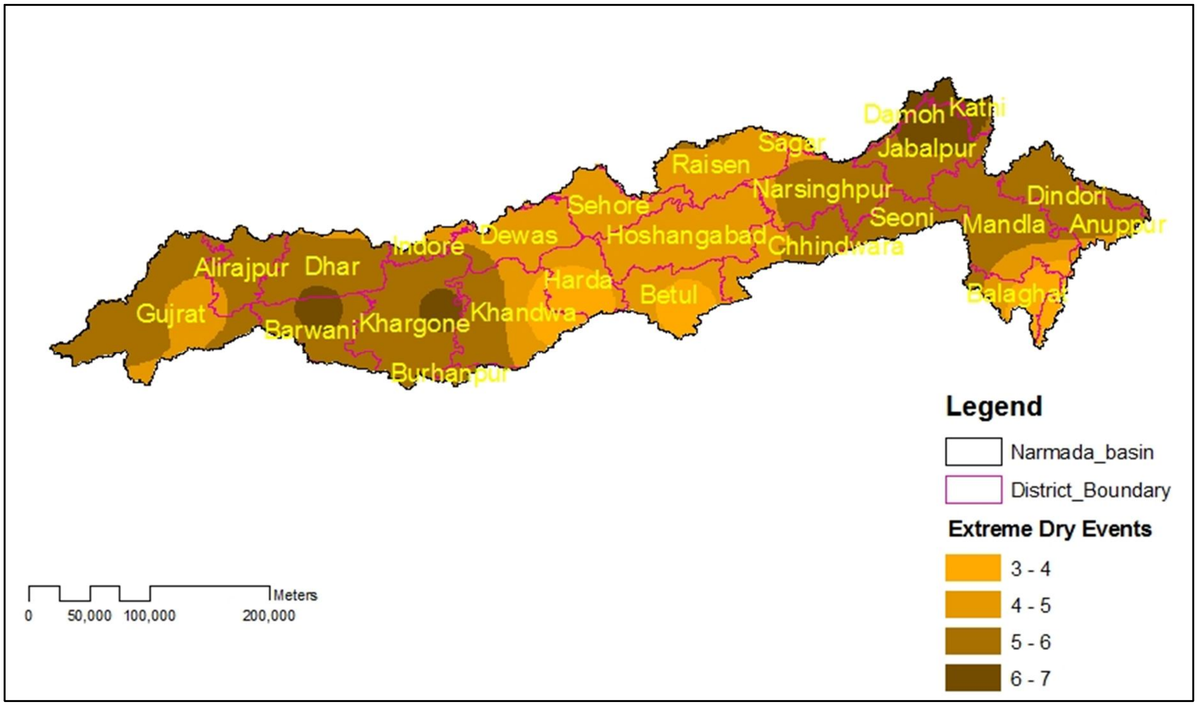


Figure 39: Variation of extreme dry events in Narmada basin during 2041-70

Therefore based on both the water availability and drought analysis, it can be concluded that no considerable increase in drought events are expected in Narmada basin whereas the extreme flood events are showing reduced magnitudes as compared to the current period. However the water availability at 50% dependability does not show any change but the 75% and 95% dependable flows show considerable increase which indicates that the basin will not be under water stress and the upcoming projects will cater to the growing demands in the basin due to the large scale development taking place in the basin. However it is to be understood that these projections have their own limitations as they are subject to several uncertainties viz., input data uncertainty, hydrological model parameter uncertainty, GCM/RCM model uncertainty, bias correction uncertainty, and scenario uncertainty. Moreover, the scenario of future water resources availability may not be similar in other basins in M.P. as most of them are no more perennial rivers and the basin characteristics and the scale of development is considerably different from Narmada basin. Therefore detailed studies are required at basin scale for each of the basin in Madhya Pradesh, to assess the impacts of climate change for adoption of suitable adaptation mechanisms.

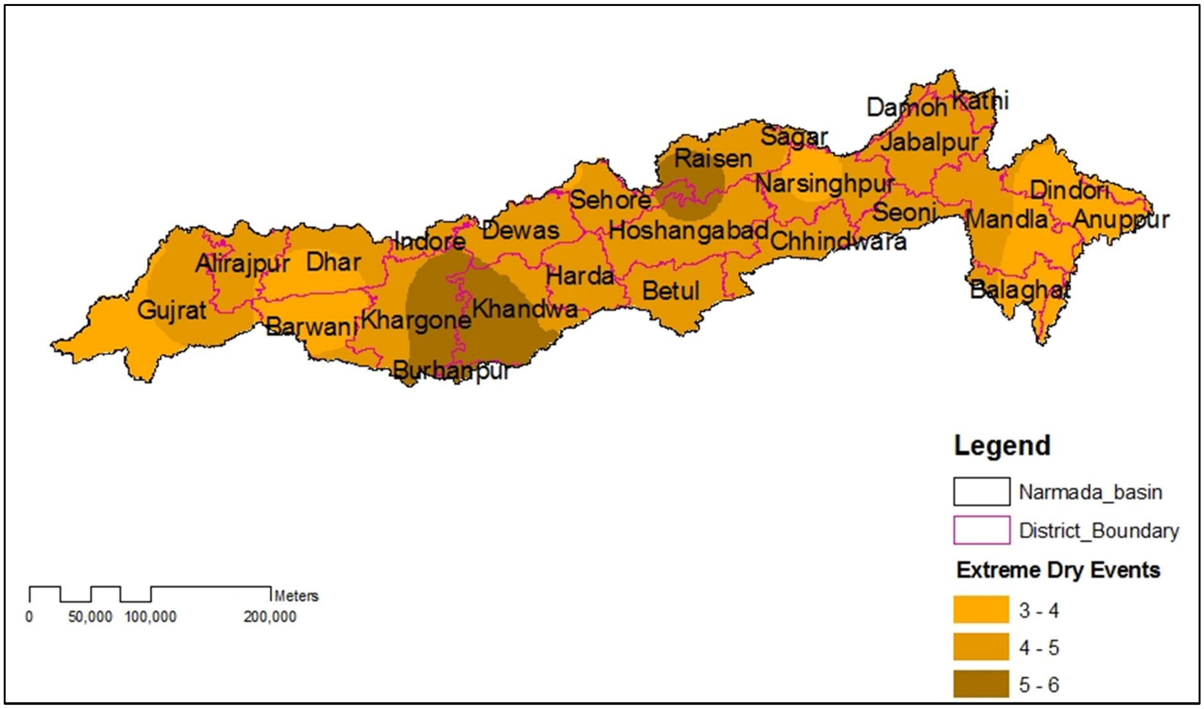


Figure 40: Variation of extreme dry events in Narmada basin during 2071-99

6.0 Conclusions

Based on the forgoing discussions, the following specific conclusions are drawn from this study.

1. During the last century, there was a change in the rainfall pattern that was experienced in the Madhya Pradesh state. The change seems to have happened in the year 1978.
2. The magnitude of the annual precipitation was having a general increasing trend during the years 1901 to 1978. However, a few districts only experienced a statistically significant (5% level) increasing trend.
3. The trend of the annual precipitation magnitude has been reversed from 1979 onwards, and was found to be significant in some of the districts.
4. The precipitation during the winter season had decreased over the years in the entire state, which caused low water availability for agricultural practices in rain-fed areas.
5. The annual average of the maximum and minimum temperature over the last century has experienced a general increasing trend in most of the districts. However, during the monsoon months, the variability of maximum/minimum temperature does not imply a clear trend, spatially as well as temporally. The temperature in the northern districts of the state has shown a decreasing trend, while the districts in the southern parts of the state experienced an increasing trend.
6. The annual 1-day maximum temperature across the century, though, has shown an increasing trend, it was not significant in most of the districts. At the same time, the 1-day minimum temperature did not show any significant trend in any of the district.
7. The extreme flood events in Narmada basin show mixed signals. For the areas located downstream of major and medium irrigation projects, the extreme flood events are expected to decrease considerably in the basin as compared to the current scenario based on the probability analysis of the annual stream flow values at few gauging sites. This may be due to the moderation effects of the dams located upstream which can possibly store the excess water generated during the extreme flood events. There is no significant variability in the extreme floods during the three time horizons, with a marginal increase during 2071-99. However, at the virgin basin sites, with no hydraulic interventions, the extreme flood events are expected to increase substantially during all the three time horizons, both for RCP4.5 and RCP8.5 scenarios.
8. The extreme drought events are not expected to increase in the Narmada basin during the three time horizons, even though there may be a spatio-temporal variation in their occurrence.
9. The water availability scenario at lower dependability’s which are more crucial for meeting the irrigation, hydropower and drinking water requirements show an increase during the three future time horizons, which indicates that there may not be any water stress in Narmada basin in the future.
10. The outcome of these studies are subject to the inherent uncertainties in the form of input uncertainty, hydrological model parameter uncertainty, GCM/RCM structure uncertainty, downscaling uncertainty, bias correction uncertainty and scenario uncertainty. Therefore these results are indicative and are subject to the uncertainties which tend to vary in a considerable wide range.

11. The comprehensive studies on climate change impact assessment need to be carried out in future for all the major river basins in Madhya Pradesh incorporating the details of the existing and proposed hydraulic structures, topography, soil and land use/land cover for devising appropriate adaptation mechanisms.

7.0 Adaptation measures

Climate change impacts have far reaching implications on the water sector with cascading effects on agriculture, forest, urban, health, economy and society. As a result, basing future water management on past hydrological trends does not protect against a range of uncertain and non-stationary future climates. Even though the hydrological modelling suggest that with the increasing temperatures and the changing precipitation pattern, there is no considerable risk the form of more frequent droughts and floods in regions where the flows are regulated by dams but virgin basins do experience higher magnitude of floods and droughts in Narmada basin. The impact assessment analysis on the water resources due to the rising temperatures and perturbed precipitation in Narmada basin based on the modelling exercise pertains to supply side scenario only. However, the altered demand scenario which may be experienced in the future, due to increased water demands due to rising temperatures, growing population, land use changes, etc., may be some of the important drivers for planning the demand side management of the water resources. Planned adaptation interventions in the water sector should include both supply and demand side measures that can be implemented using institutional, technical or market-based instruments. Looking into the chain of uncertainties in the climate model predictions, downscaling, bias correction, hydrologic modelling which all gets translated into the climate change impact assessments, a robust adaptation mechanism needs to be put in place for the Narmada basin as well as all the other basins in Madhya Pradesh.

The current investigations on the climate change revealed that the mean temperature as well as the maximum and minimum temperatures is increasing in Madhya Pradesh. The increase in temperatures is expected to change the frequency and intensity of extreme events like floods and droughts in the basin. The analysis of the observed precipitation during the baseline period, also reveals that the trend of the 1-day maximum rainfall have increased in the basin, with similar and more intense rainfall expected in the future time horizons. Also the decrease in the number of rainy days and an increase in the magnitude of the extreme rain events are a pointer towards the extreme rainfall events in the future which will get translated into floods of higher magnitudes. Coupled with these phenomena, there has been an observed decrease in the winter rainfall which put additional water demands on the reservoirs in irrigated areas and further increases the uncertainties for agriculture in rainfed areas. The hydrologic modelling has also indicated that the impacts in the form of floods shall be dominant in sub-basins where there are no watershed interventions in the form of dams/reservoirs. All these observations call for devising suitable adaptation mechanisms based on the development objectives, stakeholder considerations, resources available and vulnerability assessments. Some of the preventive adaptation measures for the extreme rainfall and floods must necessarily include,

1. Early warning systems, real time data acquisition systems and short-term weather forecasts
2. Prevention of urban development in flood-prone areas and near river banks.
3. Preparation of Emergency Evacuation Plans (EAP) for the flood prone areas.
4. Provision of safe drinking water and sanitation facilities in the flood affected areas.
5. Design of appropriate drainage systems in urban centres, to quickly drain off the accumulated flood waters in the city.
6. Up-gradation of design flood estimation techniques.
7. Dam safety, dam break and measures for emergency evacuation in case of dam failures.

Similarly to cope up with the decreasing trend in the winter rainfall and dry spells, the following adaptation mechanisms may be useful,

1. Development of water-efficient methodologies in water-dependent sectors.
2. Water demand management and technological developments.
3. Improvements in irrigation efficiency.
4. Discouraging adoption of water intensive crops like rice and sugarcane.
5. Adoption of drought-tolerant crops and crop varieties that require lower moisture
6. Intercropping, crop rotation and crop diversification to increase irrigation efficiency.
7. Conservation of soil moisture through crop residue retention.
8. Development of small scale irrigation and water harvesting schemes.
9. Optimal reservoir operation policies.

The analysis also indicated that the groundwater levels are falling in some of the districts falling in Narmada basin. The situation in the other districts also needs to be investigated, but the groundwater systems do play a major role in the overall water resources scenario in Madhya Pradesh. Therefore the concept of sustainable development and utilisation of the groundwater is important. The large scale urbanisation leading to reduction in recharge zones, high intensity rainfall events, causing more runoff and reduction in the natural recharge possibilities, calls for the sustainable exploitation and conservation of the groundwater resources. Some of the adaptation mechanisms may include, Creation of additional storage capacities and enhancing groundwater recharge.

1. Conjunctive use of surface and groundwater systems.
2. Community management by creating self-governing groundwater user organisations.
3. Collective monitoring of aquifers and behaviour of groundwater users.
4. Rain water harvesting and other artificial recharge measures.
5. Legislation to avoid exploitation of groundwater in over-exploited zones.
6. Capacity building and mass awareness programmes.

Many of these measures are already being carried out in the due course of the water resources management activities in Madhya Pradesh, which however needs to be streamlined so as to provide and integrated framework for the adaptation mechanism to address the climate change impacts on the water resources sector in the State.

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