

Monsoon rainfall variability and rainfed agriculture in the water-scarce Karha Basin, western India

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(Received 10 November 2015, Accepted 6 July 2016)

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सार – हाल ही के जलवायु प्रोजेक्शन मॉडलों से पता चला है कि विश्व के अर्धशुष्क क्षेत्र जलवायु परिवर्तन के प्रभाव के प्रति अधिक संवेदनशील हैं। हालांकि जल के विवेकपूर्ण उपयोगिता और वितरण के लिए वार्षिक योजना बनाने के लिए योजनाकारों को वर्षा की परिवर्तनशीलता को समझना और जल की कमी वाले क्षेत्रों में जल स्रोतों को उपलब्ध कराना बहुत ही कठिन है। इस अध्ययन में पश्चिमी घाट के वर्षा आभासी वाले क्षेत्र में स्थित कारहा बेसिन के जल मौसम वैज्ञानिक लक्षणों का आकलन करने का प्रयास किया गया है। मॉनसून की वर्षा की प्रवृत्तियों, बांध जल संग्रहण और कुछ प्रमुख फसलों के तहत आने वाले क्षेत्रों में उनके अंतरी संबंध का पता लगाने के लिए विश्लेषण किए गए। विश्लेषणों से मॉनसून वर्षा में उच्च अंतर - वार्षिक परिवर्तितता और मॉनसून वर्षा के औसत से ऊपर और औसत से नीचे की स्पष्ट घटनाओं का पता चलता है। हाल ही के दशकों में बढ़ी हुई मॉनसून की परिवर्तित- और एल-नीनो की घटनाओं के साथ संबद्ध कमजोर मॉनसून की प्रवृत्ति के पर्याप्त संकेत मिले हैं। यह अध्ययन मॉनसून की वर्षा में बहु-वर्षीय उतार चढ़ावों सहित प्रमुख फसलों के तहत आने वाले क्षेत्रों में परिवर्तनों और बांध जल संग्रहण के साक्ष्य भी उपलब्ध कराता है। तथापि ये संबंध आशानुरूप उतने प्रबल नहीं रहे हैं और हाल ही के अधिकांश दशकों में, अंशतः सिंचाई पर निर्भरता बढ़ने के कारण पैटर्न अत्याधिक अनियमित और भ्रंतिपूर्ण हो गए। कारहा बेसिन में पहले से ही अत्यधिक जल की कमी है। बढ़ती हुई मॉनसून की परिवर्तितता मौसमीकरण और भूजल पर निर्भरता के कारण कृषि और खाद्य सुरक्षा के लिए संकट की संभावना हो सकती है। बेसिन में पहले से ही चल रही कठिन जल प्रबंधन चुनौतियों में जलवायु परिवर्तन संबंधी प्रभावों के शामिल होने की संभावना है। अतः जलवायु परिवर्तन परिदृश्यों के तहत नई चुनौतियों के लिए योजना बनाने की आवश्यकता है।

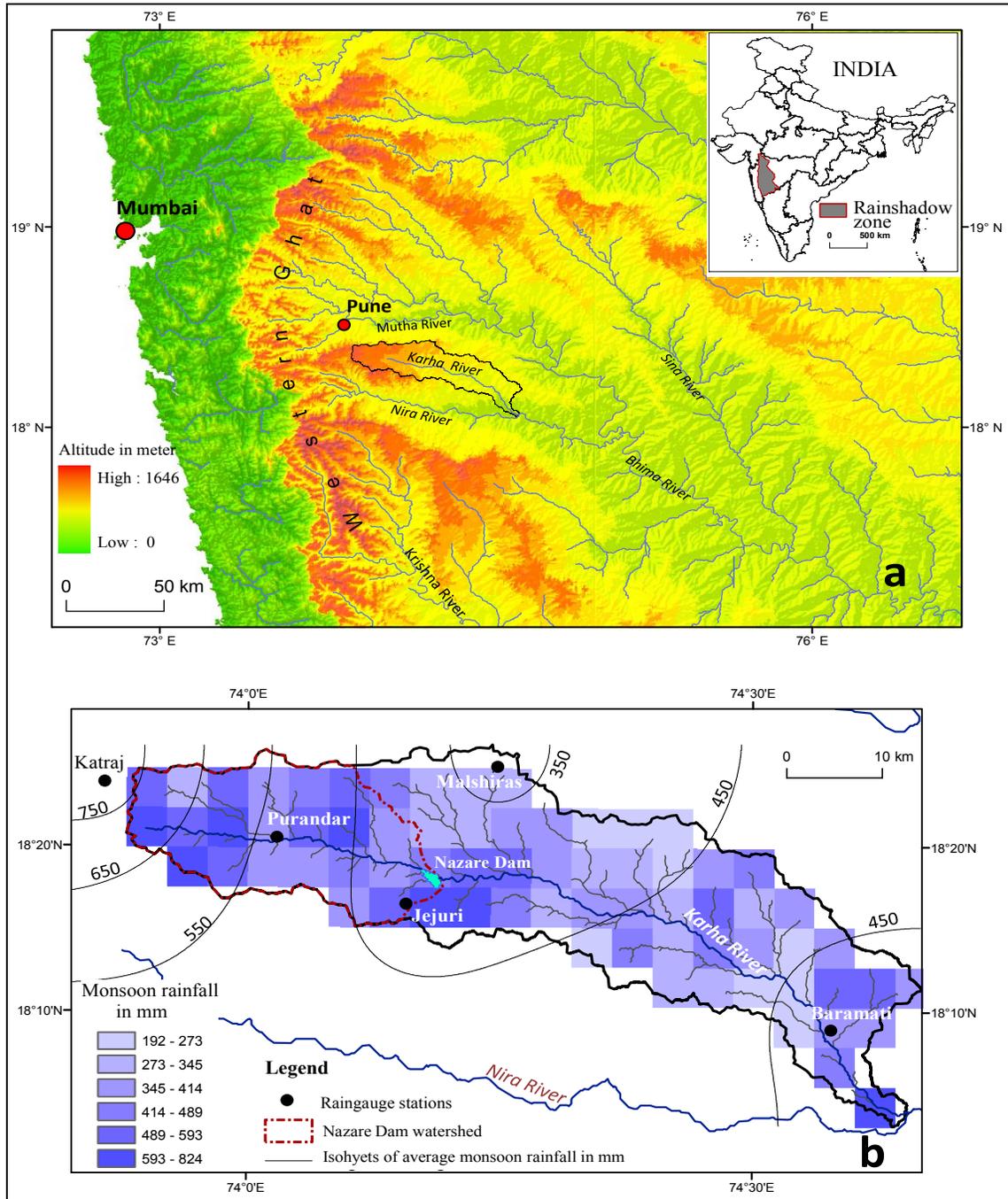
ABSTRACT. Recent climate projection models indicate that the semi-arid regions of the world are most vulnerable to the impact of climate change. Hence, the understanding of rainfall variability and availability of water resources in water-scarce regions is crucial for planners to formulate annual plan for judicious utilization and distribution of water. In the present study, an attempt is made to evaluate the hydro-meteorological characteristics of the Karha Basin, located in the rain shadow zone of the Western Ghat. Trends in monsoon rainfall, dam storage and the area under some principal crops were analyzed to ascertain their interrelationship. The analyses indicate high inter-annual variability in monsoon rainfall and distinct episodes of above - and below-average monsoon rainfall. There is enough evidence for enhanced monsoon variability during the recent decades and a tendency for weaker monsoons to be associated with El Niño events. The study also provides evidence of changes in the area under major crops with the multi-year fluctuations in monsoon rainfall and dam water storage. The relationship, however, is not as strong as expected and the pattern gets more erratic and confusing in the most recent decades, partly on account of increasing dependence on irrigation. The Karha Basin is already suffering from severe water scarcity. Increasing monsoon variability, seasonality and dependence on groundwater is likely to threaten agriculture and food security. Climate change related impacts are likely to further add to already difficult water management challenges in the basin. It is therefore necessary to plan for new challenges under climate change scenarios.

Key words – Semi-arid area, Monsoon variability, Assured rainfall, Dam storage, Climate change, Agricultural crops.

1. Introduction

The rural economy of the semi-arid region of the Maharashtra State in western India is predominantly dependent on rainfed agriculture, which in turn is strongly influenced by the year to year variations in the summer

monsoon rainfall. High inter-annual variability in monsoon rainfall and occurrence of frequent droughts are inherent characteristics of the monsoon climate of Maharashtra, especially in the rain shadow zone of the Western Ghat (IMD, 2005; Guhathakurta and Saji, 2013). In this water - scarce zone, the annual rainfall is



Figs. 1(a&b). (a) Location of the Karha Basin. (b) TRMM-based average annual precipitation. TRMM data Source : <http://www.geog.ucsb.edu/~bodo/TRMM/>

less than 500 mm and this amount is received only within 30-50 days in a year. Occurrence of dry spells during the monsoon season, late arrival of monsoon rains and uneven spatio-temporal distribution of rainfall further exacerbates the situation. The high rainfall variability has a severe impact on the agricultural production, livestock and the

rural economy of the region (Udmale *et al.*, 2014). Increasing trend in seasonality in the rain shadow zone of the Maharashtra State was inferred by Guhathakurta and Saji (2013). On the basis of analysis of rainfall and stream flow data of five semi-arid rivers of Madhya Maharashtra, Kale *et al.* (2014) concluded that by and large

there was a decreasing trend and that there is a good association between the low discharge years and the El Niño years.

Such water-scarce regions are most vulnerable to the impact of climate change. Several recent studies predict that climate change in this century will have a profound effect on rainfall patterns and stream flows in the arid and semi-arid regions of the world. According to the 5th Assessment Report of IPCC, one of the foremost consequences of human-induced global warming is increased risk of drought-related water and food shortage in South Asia (CDKN, 2014). For Maharashtra, climate modelling results show that temperature and rainfall are projected to increase all over the state and increase in temperature is likely to lead to decrease in yields for some crops (TERI, 2014). Gosain *et al.* (2006) and Jain & Kumar (2012) found that the Krishna Basin, including the rainfall deficient areas in Maharashtra, is likely to experience reduction in the precipitation, water yield and evapo-transpiration in future by 20, 30-50 and 5 per cent, respectively. It is, therefore, a major challenge for water resource managers to provide water for irrigation to the parched lands and drinking water for livestock and millions of people living in the water-scarce areas under projected climate change scenarios.

For future planning of water resources in such rainfall-deficient areas, recourse is taken to better understand the behavior of hydro-meteorological processes, principally rainfall and surface/groundwater conditions. The main purpose of the present study is to analyze the trends in the monsoon rainfall and dam storage in the catchment area of the Karha River. The river is a modest-size river and originates in the rain shadow zone and supports a population of about one million. An attempt is also made to evaluate the trends in the area under principal crops (rainfed and irrigated) *vis-à-vis* basin rainfall and dam storage.

2. The Karha Basin: Geomorphology and hydrology

With a catchment area of about 1140 km² and a length of 103 km, the Karha River Basin [Fig. 1(a)] falls in the severely to chronically drought-prone area over the Maharashtra Plateau. It is the left-bank tributary of the Nira River, and eventually forms a part of the Krishna drainage [Fig. 1(a)]. The Karha River flows through Purandar and Baramati Talukas. Geomorphologically, the river occupies a high-level surface on the water divide between Nira and Mula-Mutha Rivers. Geologically, the basin is underlain by Deccan Trap Basalts of Cretaceous-Eocene age. Due to the dominance of hard rock terrain and the geomorphic setting, the availability of

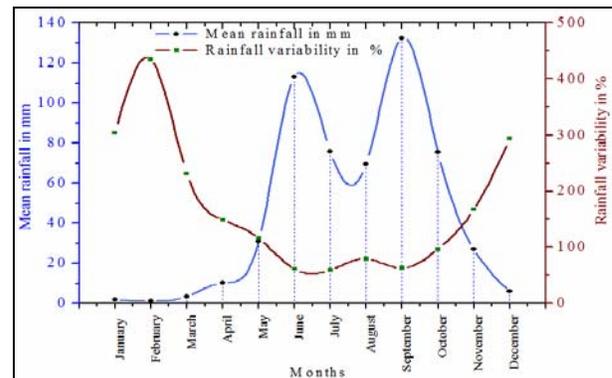


Fig. 2. Average monthly rainfall and variability over Karha Basin

groundwater is generally low and there is severe water scarcity, especially during the long (6-8 months) dry season. As a result, dry farming and rainfed agricultural practices are dominant in the basin.

About 85 to 95% of annual rain in the basin falls during the monsoon season (June to October). The basin receives annual rainfall between 350 and 750 mm. On account of its location in the rain shadow zone and due to its elongated shape [Fig. 1(b)] the basin experiences noteworthy variations in the monsoon rainfall from west to east. The zone of minimum rainfall is centered around Malshiras station in the middle domain of the Karha Basin [Fig. 1(b)].

The basin as a whole receives an average monsoon rainfall of about 480 mm, which is very scanty as compared to other rivers heading in the Western Ghat (such as Nira, Krishna, Bhima, Godavari, etc.). As a result, the Karha Basin suffers from annual soil moisture deficiency of about 800 to 1100 mm (Dikshit, 2002). The distribution of rainfall during the monsoon season is bimodal (Fig. 2). September contributes the highest amount of rainfall (130 mm), followed by June (110 mm). During the non-monsoon season (November to May) there is nil to negligible rainfall and the Karha river channel remains mostly dry. Droughts are frequent and on an average occur once in three years (Deosthali, 2002).

A medium dam project is situated on the Karha River at Nazare near Jejuri Town [Fig. 1(b)]. There are seven other minor irrigations projects and about two dozen weirs within the catchment area. The Nazare Dam has designed live and total storage capacities of 16.63 and 22.31 million cubic meters (MCM), respectively. The catchment area upstream of the dam is about 400 km² (35% of the basin area). The dam irrigates about 3200 hectares of agricultural land in the Karha Basin. After the construction of Nazare Dam in 1974, the

TABLE 1
Rain gauge stations considered in the present study

S. No.	Rain gauge stations	Location	Length of rainfall data records (Years)	Mean monsoon rainfall (mm)	Coefficient of variation (%)
1.	Baramati	18° 14' N 74° 57' E	112 (1901-2012)	431	40.80
2.	Jejuri	18° 16' N 74° 09' E	105 (1902-2006)	398	33.64
3.	Malshiras	18° 41' N 74° 24' E	26 (1981-2006)	298	51.47
4.	Purandar (Saswad)	20° 50' N 74° 17' E	105 (1902-2006)	522	42.13
5.	Katraj Tunnel	18° 24' N 73° 51' E	41 (1966-2006)	836	32.11

downstream reach of the river channel is frequently dry even within the monsoon season, especially during the deficient monsoon years.

2. Data and methodology

Three types of data were used in this study - daily rainfall data, dam storage and spillway data, and data regarding the area under principal crops. Daily rainfall data for five stations in the Karha Basin were acquired from the India Meteorological Department (IMD), the Hydrological Data User's Group (HDUG) and the Agriculture Department of Maharashtra State for variable duration (Table 1). Only Katraj Tunnel gauging station is not located within the catchment. Homogeneity and relative consistency of the daily rainfall data were checked by using double mass curve method (Muthreja, 1986). Statistically significant correlation (at 0.05 level) and high explained variance ($r^2 \geq 0.98$) indicate that the available rainfall data are reasonably homogeneous and consistent. The missing values in the daily rainfall time series were filled by using linear regression equation. For this, the nearest gauging station was considered.

In order to understand the inter-basin variability in water availability, monthly and annual storage and spillway data for Nazare Dam for about three decades were obtained from the Irrigation Department of Maharashtra State. The total volume of water available at Nazare Dam site for each year was estimated by adding the dam water storage and the spillway discharge.

One of the objectives of the present study is to understand the impact of the inter-annual variability in

monsoon rainfall on agriculture. The principal crops grown in the area are jowar, bajra, wheat, sugarcane and onion. Jowar (sorghum) and bajra (pearl millet) are drought resistant crops and require much less water than wheat. In the absence of yield and production data, the area under some important rainfed crops (jowar, bajra and wheat) and predominantly high-water requiring crops (sugarcane and onion) available for Purandar (upper Karha Basin) and Baramati (lower Karha Basin) Talukas, were considered. It should be mentioned here that these two Talukas also include some part of the Nira Basin. The data regarding area under these five crops, available for about three decades, were obtained from the Agriculture Department of Maharashtra State. The missing values in the data in the cropped area were filled by taking the mean of the preceding and the following years' data.

To compute the average rainfall over the Karha Basin and over the upstream area of the Nazare Dam, the Thiessen polygon method was used. Comparison of the coefficients of variation (CV) shows that there are noteworthy differences in rainfall variability among the stations (Table 1). However, the CV does not provide a measure of departure from the average. Therefore, the standard score or z-score method was adopted to understand how the monsoon rainfall differs from the mean in terms of the inherent variability. The precipitation data were standardized by subtracting the mean and dividing by its standard deviation

In order to identify the long-term and step changes in the monsoon rainfall, the dam storage and the area under different crops, trend analysis was carried out by applying standard parametric and non-parametric statistical

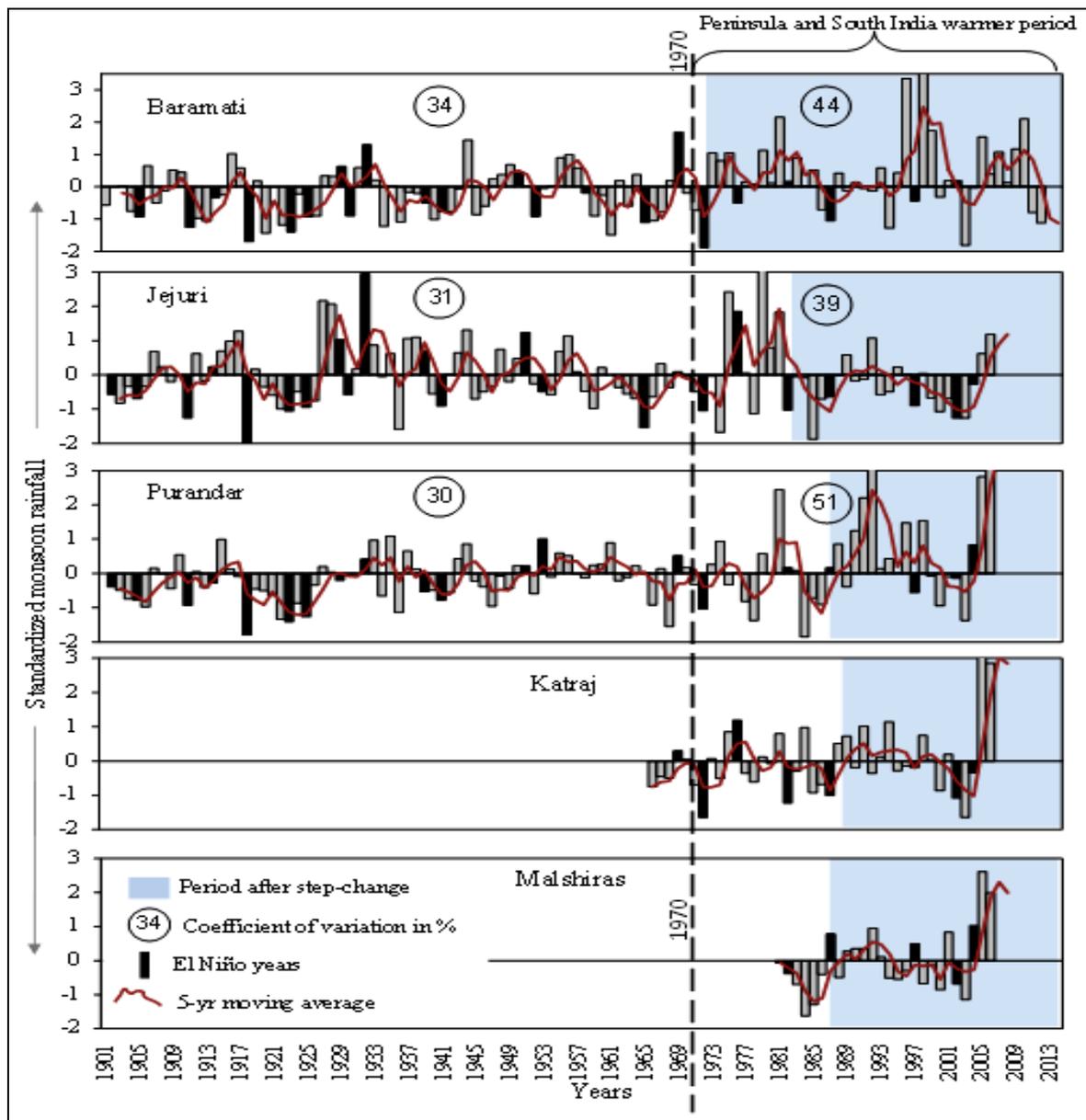


Fig. 3. Stationwise normalized departures in monsoon rainfall

methods. For detecting the trend in the monsoon rainfall and dam storage data, the linear least squares fitting method was used. The results were verified by using non-parametric Mann-Kendall Statistics. An attempt was also made to determine the point of initiation of change in rainfall, dam storage and cropped area in the basin under review. For this, the trend Catchment Modeling Toolkit software was used. Further, in order to smoothen out the high-frequency fluctuations in monsoon rainfall and to identify distinct above- and below-average rainfall epochs, the Cramer's t values were calculated for 11-year running means. It compares running mean with the average of entire data series (Kripalani *et al.*, 2003). To understand

the short-term decadal monsoon rainfall variability, the coefficient of variation for corresponding 11-year running means was also calculated. Earlier studies have observed a noteworthy shift in the temperature and other climatic parameters over the Indian region approximately after 1970 (Dash & Hunt, 2007; Jain & Kumar, 2012; Subash & Sikka, 2014). According to Nayak & Mandal (2012), western India is getting warmer by $0.13\text{ }^{\circ}\text{C}$ per decade since 1973. In this study, therefore, the period since 1970 has been referred to as the 'recent warmer period'.

The Gamma probability distribution model was used for computing the assured or dependable monsoon

TABLE 2
Trends in monsoon rainfall, dam storage and area under principal crops in Karha Basin

Test Name →	Linear trend				Year of change			
	Mann-Kendall	Spearman's Rho	Linear regression	Rate of change (per year)**	Step-jump year	Rank Sum	Student's <i>t</i>	
Monsoon rainfall	Baramati	+	+	+	1.6*	1972*	+	+
	Jejuri	-	-	-	-0.3	1981	-	-
	Malshiras	+	+	+	8.4*	1987*	+	+
	Purandar	+	+	+	2.5*	1986*	+	+
	Katraj	+	+	+	6	1988	+	+
	Karha Basin	+	+	+	2.7	1987	+	+
	Dam catchment	+	+	+	1.1	2003*	+	+
Available water at Nazare Dam site	+	+	+	1.4 MCM	2004*	+	+	
Area under crops in Baramati Taluka	Bajra	-	-	-*	-367*	1991*	-	-*
	Jowar	-	-	-	-907	2002	-	-
	Wheat	+	+	+	264*	1990*	+	+
	Onion	+	+	+	126*	1993*	+	+
	Sugarcane	+	+	+	902*	1993*	+	+
Area under crops in Purandar Taluka	Bajra	+	+	+	-508	1996*	-*	-*
	Jowar	-*	-*	-*	-2381*	1991*	-*	-*
	Wheat	+	+	+	38	1987*	+	+
	Onion	+	+	+	82*	1994*	+	+
	Sugarcane	+	+	+	29	1995	+	+

+, - increasing and decreasing trend respectively, * represents statistically significant trend / year of step change at 0.05 level. ** based on b - coefficient or slope of the regression line. MCM = million cubic meters.

rainfall (at 75% and 50% probability level) over the basin, and for estimating the assured availability of water (at 75% and 50% probability level) at the Nazare Dam site, the Weibull probability distribution was fitted to the data series. For the estimation of the assured available water volume at the dam site, dam water storage and spillway discharge data were used for the period from 1983 to 2011.

3. Results

3.1. Trends in monsoon rainfall and available water at dam site

The standardize values of monsoon rainfall plotted in Fig. 3 provide a fairly good indication about the

precipitation history for three rain gauge stations with longer records. It is apparent from the figure that the inter-annual variability in monsoon rainfall has increased remarkably in the recent decade, particularly after 1970. The variability has increased by about 30-50% during the recent warmer period. It is also evident from the plot that two-third (about 16 out of 24 at each station) of the El Niño years during the gauge period were associated with strong to moderate negative departures in monsoon rainfall at Baramati, Jejuri and Purandar.

Table 2 summarizes the results of the trend analyses and the step change. Except Jejuri, all other stations in the Karha Basin reveal positive and significant trends in monsoon rainfall. The Jejuri station displays a decreasing trend but it is not statistically significant. The Baramati

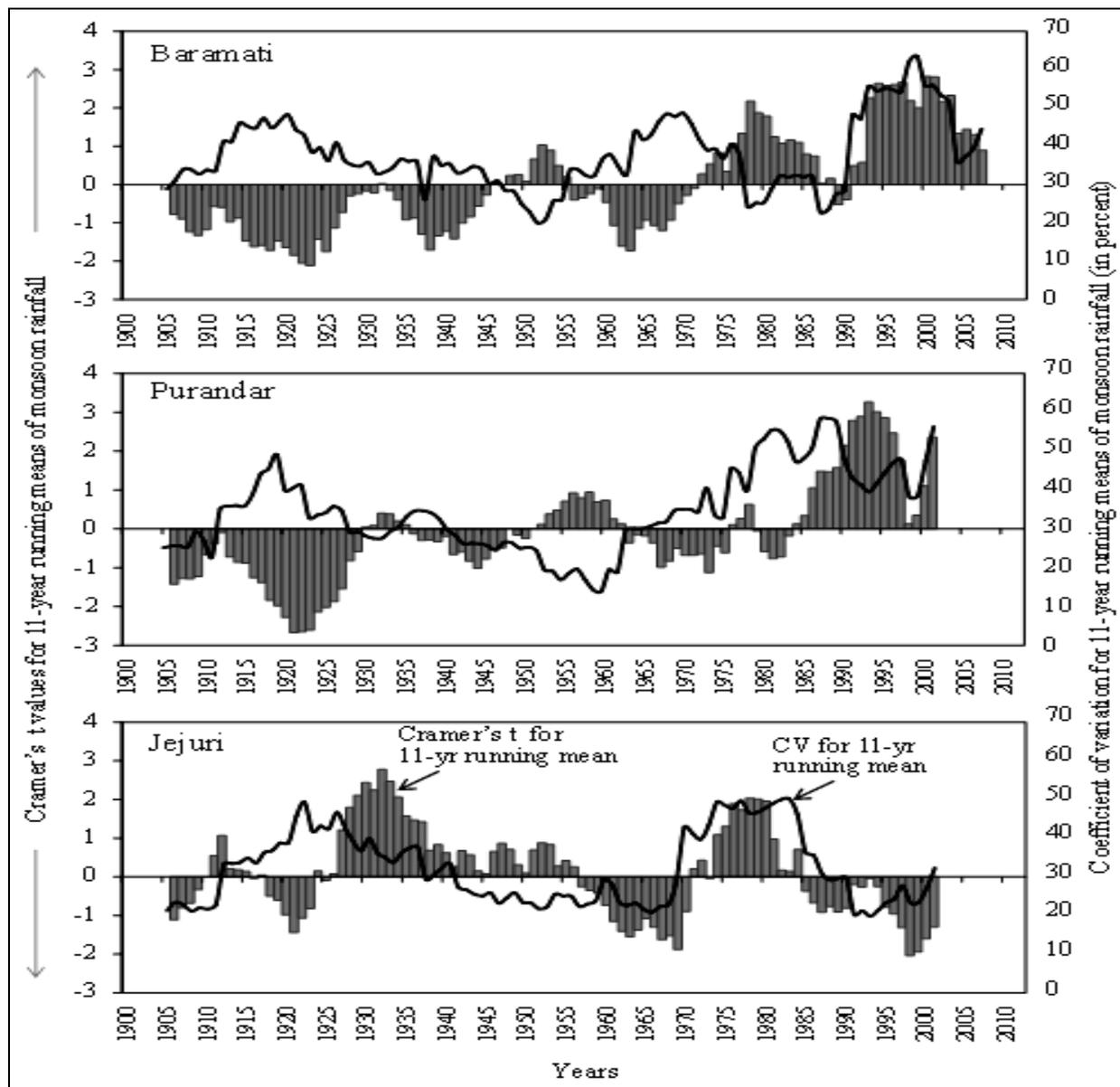


Fig. 4. Epochs of above- and below-average monsoon rainfall and rainfall variability

and Purandar rain gauging stations with longer records show significant increase in the monsoon rainfall after 1972 and 1986, respectively (Table 2). Purandar has the highest rate of increase in the monsoon rainfall (2.5 mm/yr), followed by Baramati (1.6 mm/yr). These rates are statistically significant. The remarkably high rate of change for Malshiras and Katraj stations are not meaningful due to the short duration of the rainfall records.

The Mann-Kendall statistic and linear regression analyses indicate a positive trend in the dam water

storage. Although the trend is not statistically significant, a significant shift in the water volume available at Nazare Dam site is indicated after 2004 (Table 2). As the average rainfall within the dam catchment also shows a significant shift in 2003, the positive shift in the water volume available at dam site after 2004 could be attributed to a positive increase in the catchment rainfall.

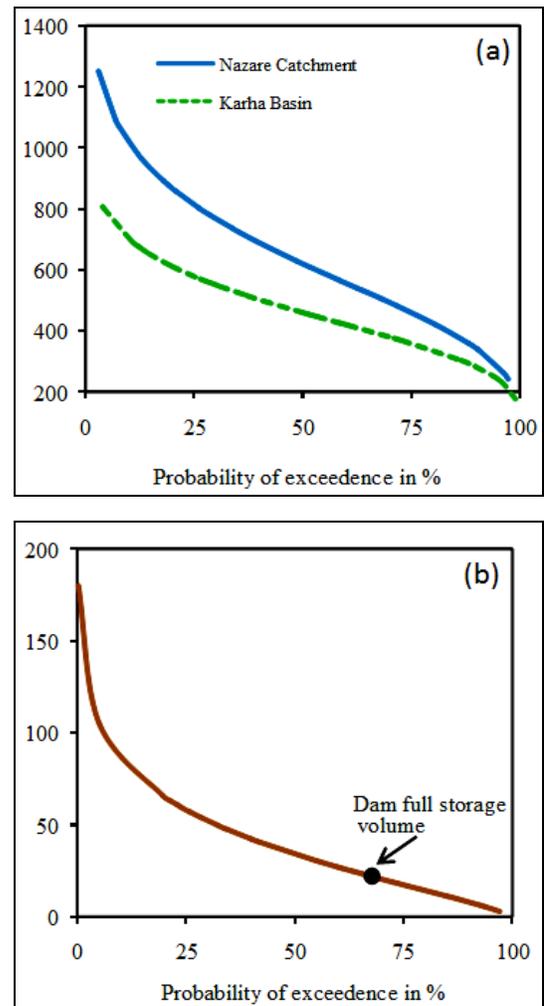
From Figs. 3 and 4 it is evident that the rainfall trends are not uniform and unidirectional during the gauge period. In fact, multiple dry and wet periods are apparent for stations with longer gauge records. About five distinct

above-average (excess) and below-average (deficit) monsoon rainfall periods of ~10-20 years duration are seen since the beginning of the 20th century. Joshi and Pandey (2011) also identified 15-year cycles of above-average (excess) and below-average (deficit) rainfall over the southwest India, including the study area. With respect to the duration and timing, Baramati and Purandar stations depict identical rainfall pattern during the gauge period. A common phase of below-average rainfall (1906 to ~1928) is observed at all the three stations with longer gauge records. At Jejuri, this drier phase was interrupted by a wetter interval for a short duration (1910-1915). The second phase of below-average rainfall (1935-1950) is observed for almost the same duration at Baramati and Purandar. However, at Jejuri, a period of above-average rainfall period is observed, which began in 1928 and lasted till 1957. Around the mid-twentieth century, the above-average rainfall phase at Baramati (1948-1955) and Jejuri (1952-1963) are of variable duration. The following phase of below-average (deficient) rainfall is also of different durations - from 1955-1970 at Baramati, from 1963-1975 at Purandar and from 1957-1971 at Jejuri. Since ~1970, all the stations exhibit a distinct period of above-average (excess) monsoon rainfall, albeit of different intervals – from 1970 to 2006 at Baramati, from 1984 to 2000 at Purandar and, from 1970 to 1984 at Jejuri. From Fig. 4 it is apparent that the Jejuri station is experiencing a period of below-average monsoon rainfall for about the last two decades.

Prior to ~1970, all the three stations with longer records exhibit an inverse relationship between the decadal average monsoon rainfall and the decadal monsoon rainfall variability (Fig. 4). The epochs of below-average rainfall were associated with higher variability and *vice-versa*. It is interesting to note that there is a remarkable shift in this pattern within the last 2-3 decades. During these decades, the periods of above-average rainfall are associated with higher variability and *vice-versa*, particularly, in the middle and lower parts of the basin (represented by Jejuri and Baramati stations, respectively).

3.2. Trends in cropped area

The results of trend analysis for the area under different crops namely Jowar (sorghum) and bajra (pearl millet), wheat, onion and sugarcane in the Karha Basin are given in Table 2. In the Purandar Taluka, except jowar (sorghum) and bajra (pearl millet), all the selected crops show an increasing trend. Among them, the area under onion and sugarcane reveal significant increasing trend particularly after 1994 and 1997, respectively. The area under rainfed crops such as Jowar (sorghum) and bajra (pearl millet) in Purandar Taluka shows a notable decline

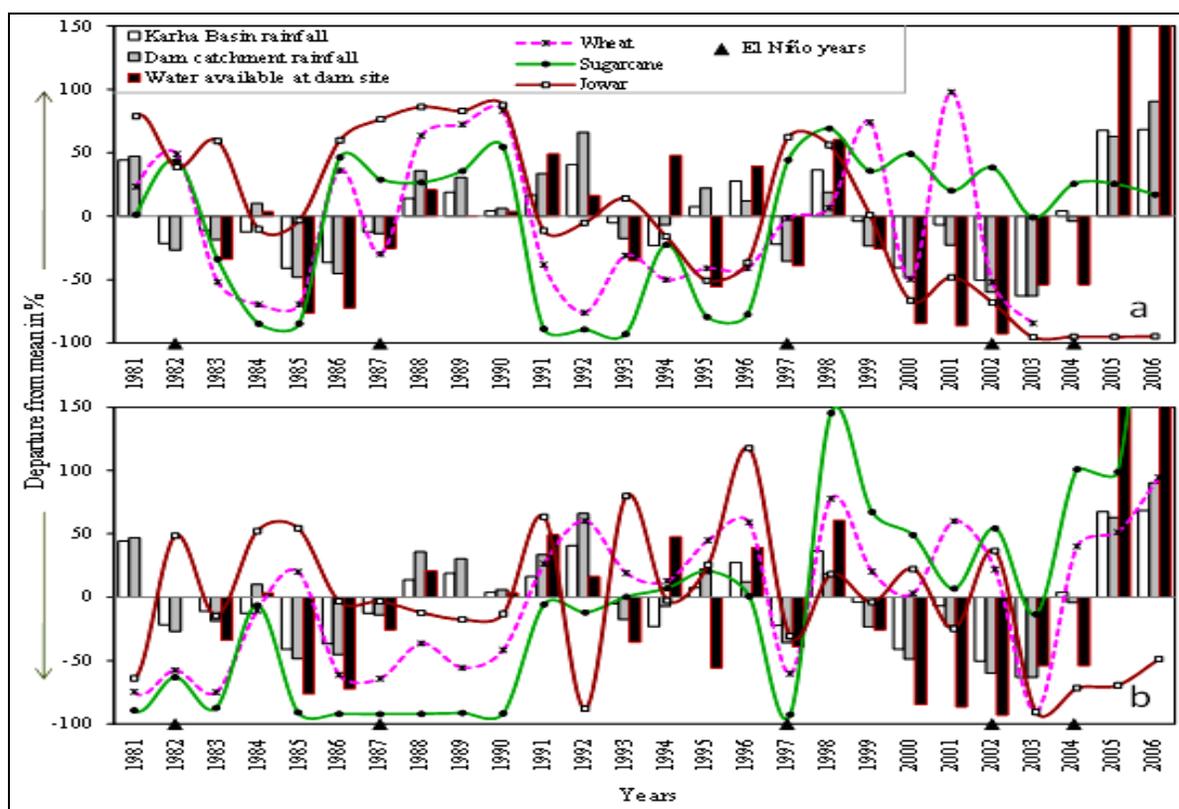


Figs. 5(a&b). Exceedence probabilities (a) average monsoon rainfall and (b) water volume at Nazare Dam

during the post-1991 period. Reduction in the area under jowar (sorghum) and bajra (pearl millet) is also observed in the Baramati Taluka, which covers the lower part of the Karha Basin. The area under pearl millet (bajra) crop exhibits significant reduction during the recent decades, particular after 1991. On the other hand, the areas under predominantly high-water requiring crops such as onion and sugarcane are increasing significantly, and show significant positive change, particularly after 1990.

3.3. Assured availability of water

In rain-deficient areas, availability of assured water is crucial from the point of view of agricultural production and the socio-economic conditions of the local population. In the Indian context, the rainfall at 75 per cent probability



Figs. 6(a&b). Departures cropped area in Purandar (a) and Baramati (b) Talukas vis-à-vis monsoon rainfall and dam storage

is generally considered as assured or dependent rainfall for determining the general cropping pattern of an area, and rainfall at 50 per cent probability is considered as the medium limit for taking risk. The Gamma probability distribution based estimated assured or dependable monsoon rainfall at 75% and 50% probability level for the Karha Basin is 360 and 460 mm, respectively [Fig. 5(a)]. Similarly, for the Nazare Dam catchment the corresponding values are 450 and 620 mm [Fig. 5(a)].

Based on the dam storage and spillway data for the period 1983 to 2011 and the Weibull probability distribution, the dependable water volume at dam site (75% probability level) and medium limit for taking risk (50% probability level) at Nazare Dam site was estimated to be 18 and 34 MCM, respectively. At the dam site, the annual available water volume was observed below the median and assured volumes for 14 (48%) and 24 (83%) times, respectively, within the gauge period (29 years). In addition to this, except the years between 1988 and 1992, only once the dam recorded above-average storage consecutively for two years (in 2005 and 2006). As the average dam catchment rainfall determines the water volume available at the dam site, exceptionally high

monsoon rainfall amounts in 2005 and 2006 (1070 and 1251 mm, respectively) contributed to the high water volume availability (105 and 180 MCM, respectively) for these two years. The assured water volume available at the dam site is 18 MCM, which is less than the total storage capacity (22.31 MCM) of the dam. Based on the exceedence probability for dam full storage (67%) depicted in Fig. 5(b), it can be inferred that the Nazare Dam overflows twice in three years.

3.4. Monsoon rainfall and water availability vis-à-vis area under principal crops

An attempt was made to correlate the monsoon rainfall and dam storage changes vis-à-vis the area under three principal crops. As the dam storage and cropped area data are available for all the years from 1983 to 2006, an attempt was made to understand their relationship with the monsoon rainfall over the basin for the same period. The principal crops grown in the Karha Basin are jowar and bajra, wheat, sugarcane and onion. These crops contribute >50% cropped area to the total net sown area in Purandar and Baramati Talukas. Jowar covers between 30 and 45%, sugarcane - about 7%, bajra (pearl millet) - 7 to 15%,

wheat - between 5 and 7% and onion - about 2% of the total net sown area. Amongst the rainfed crops and high-water requiring crops, jowar (sorghum) and sugarcane, respectively, cover maximum area in the basin. Therefore, these two crops along with wheat were considered for further analysis. As September contributes the highest amount of rainfall in the basin (Fig. 2), the total amount of monsoon rainfall received in the final months of monsoon season should also be reflected by the changes in the area under wheat crop, which is the main winter (*rabi*) crop after jowar (sorghum) and is a good indicator of the soil moisture conditions during the post-monsoon season. Hence, the area under wheat was also considered.

It is evident from Figs. 6(a&b) that negative departures of the average monsoon rainfall are associated with higher negative departure in the dam storage. This was observed in 1983, 1985-86, 1993, 1997, 1999-2002. In general, from 1982 to 1987 and from 1999 to 2004 the monsoon rainfall and the dam storage were significantly less. The above-average phase was observed between 1988 and 1992. Further, the dam storage and basin average monsoon rainfall exhibit negative departures in El Niño years between 1981 and 2006 [Figs. 6(a&b)].

Another fact that is evident from the plots in Figs. 6(a&b) is that, by and large, the cropped area has varied according to the temporal distribution of monsoon rainfall and the dam storage. Although the correlation is not strong and varies from crop to crop, it is reasonable to infer that the periods of lower monsoon rainfall (negative departure) were generally characterized by a decline in the area under the crops and vice versa. However, this pattern gets more erratic and confusing in the most recent decades.

4. Discussion

From the results presented in the preceding section it is clear that the water-scarce Karha Basin is characterized by significant temporal variations in the monsoon rainfall and the basin has experienced distinct periods of excess (above-average) and deficient (below-average) monsoon rainfall since the beginning of the 20th century. About two-third of the El Niño events since 1901 were associated with negative departures in the monsoon rainfall over the basin, even though the relationship between El Niño events and the Indian monsoon rainfall has become weaker at the all-India level in recent decades (Kumar *et al.*, 1999; Shewale & Kumar, 2005). Therefore, it is reasonable to conclude that a stronger relationship between the two still exists for the Karha Basin and El Niño generally retards the monsoon over the basin. Kale *et al.* (2014) also observed a good association

between the low discharge years and the El Niño years in five semi-arid rivers in Madhya Maharashtra.

Another important observation that emerges from the present analysis is that there is a noteworthy shift in the trend in the monsoon rainfall as well as in the duration, beginning and end of the excess/deficient monsoon epochs in the recent decades. The post-1970 period also shows a remarkable increase in the magnitude of the rainfall variability (increase by about 30 to 50%). Considering the pattern of monsoon rainfall during the first five to six decades of the last century, the noteworthy fluctuations in the monsoon rainfall in recent decades do not appear to represent the inherent natural variability. Under such circumstances, the only plausible explanation is that increased variability could be linked to human-induced global warming and climate change. Several recent studies have indicated significant warming and increase in the rainfall extremes at the all-India level during the last few decades (Dash & Hunt, 2007; Jain & Kumar, 2012; Subash & Sikka, 2014).

Two rain gauge stations with longer records (Purandar and Baramati) show statistically significant positive trend in monsoon rainfall. Guhathakurta and Saji (2013) have also inferred increasing trend in monsoon rainfall in the western districts of Maharashtra, including the study area. However, they show that the seasonality index, a measure of the distribution of monthly rainfall, has registered an increase in about two-third districts of the state. Figs. 3 and 4 also show that the most recent period is featured by significant increase in the rainfall variability. The increase in seasonality and variability of rainfall is a matter of great concern, as well distributed monsoon rainfall (low seasonality) and low variability are extremely important from the standpoint of rainfed agriculture in rainfall-deficient areas (Kale *et al.*, 2014).

The plots given in Figs. 6(a&b) indicate that the pattern of variations in the area under jowar (sorghum), wheat and sugarcane, to a large extent, are dictated by the average monsoon rainfall over the basin. However, the relationships are not perfect, particularly for the recent decades. Apart from antecedent moisture conditions and local variations in monsoon rainfall [Fig. 1(b)], other factors might have also contributed to the modest to significant deviations as well as lags and leads in the area under rainfed and irrigated crops. First, the Nazare Dam irrigates about 3200 ha of land by way of canal irrigation and lift (reservoir and river) irrigation during the monsoon as well as post-monsoon season. The irrigated area varies (2000-4000 ha) according to the dam water storage and timing of monsoon rainfall (late or early monsoon). In addition to Nazare Dam (a medium irrigation project), there are seven minor irrigation projects in the basin, each

of which irrigates up to 2000 ha area. It should also be noted that a canal from the Veer Dam on the Nira River runs through the southern part of the Baramati Taluka and accounts of significant area under sugarcane and other irrigated crops in the taluka. Further, although year wise information regarding the area under irrigation in the two talukas is not available, field observations indicate a dramatic increase in the area under dug well/bore-well irrigation in the last 1-2 decades. Furthermore, over two dozen KT weirs (Kolhapur-Type weirs) have been built across the Karha River and its tributaries to impound water and recharge the groundwater during the monsoon season. In addition, water conservation measures are also being adopted in many parts of the basin in recent years. There is evidence of increase in the water table in some observation wells in the Karha Basin during the post-monsoon season (Kale *et al.*, 2014). As a result, the area under rainfed crops (such as jowar and bajra) is being gradually replaced by irrigated cash crops (such as sugarcane and vegetables). This change is particularly evident after 1990 (Table 2). It is most likely due to these various reasons that the change in the area under different crops does not strictly vary according to the monsoon rainfall in a given year.

However, there are some anomalies in the interrelationship between the cropped area and the basin rainfall [Figs. 6(a&b)] that cannot be fully explained. Although 1998 was a wetter year, the increase in the area under jowar (sorghum), wheat and sugarcane is not commensurate with the increase in rainfall. Further, there is no apparent explanation for the remarkably lower area in the Purandar Taluka under different crops during the two consecutive wettest years of the last decade, *i.e.*, 2005 and 2006. No satisfactory answers were provided during personal interviews with the concern officials of the Maharashtra State Agriculture Department and Shri Someshwar Cooperative Sugar Factory, Someshwarnagar.

5. Conclusions

This study has given some insights on the connection between monsoon rainfall and dam storage on one hand and the changes in the cropping pattern on the other, in a rainfall-deficient basin situated in the rain shadow zone of the Western Ghat. The monsoon rainfall displays a high degree of inter-annual variability (30-50%) and distinct episodes of above-average (excess) and below-average (deficient) monsoon rainfall. There is enough evidence for enhanced monsoon variability during the recent warmer period (post-1970). An important observation that emerges is that although the teleconnections between the Indian monsoon rainfall and El Niño events have become weaker at the all-India level in recent decades (Kumar *et al.*, 1999; Shewale and Kumar, 2005),

El Niño retards the monsoon in the study area. This in other words implies that the forecast of the monsoon rainfall over the basin depends to some extent on the predictability of El Niño events.

The study also provides evidence of changes in the area under major crops with the multi-year fluctuations in monsoon rainfall and dam water storage [Figs. 6(a&b)]. On account of increasing dependence on irrigation (well or canal), there is a shift in the cropping pattern from rainfed crops to irrigated crops in the most recent decades.

Several recent studies on projections of climate change have indicated an increase in the amount of rainfall in the drought-prone areas in Maharashtra under warmer conditions (World Bank, 2008; TERI, 2014). However, these studies also indicate that the increase in precipitation will be accompanied by an increase in the rainfall variability. This is already evident in recent decades (Figs. 3 and 4). Studies on crop responses to climate change reveal that while the yields of rainfed crops, such as jowar (sorghum) and bajra (pearl millet) crops are likely to increase, the yield of water-intensive cash crops, such as sugarcane, are expected to decline considerably (World Bank, 2008).

Given the erratic behaviour of the monsoons, the dominance of hard rock terrain in the catchment and the high plateau-setting of the basin in the rain shadow zone of the Western Ghat, the Karha Basin is already suffering from severe water scarcity. Large-scale unsustainable drawdown of basalt aquifers is likely to lead to rapid depletion of groundwater in near future, threatening agriculture and food security. In water scarce regions of Maharashtra, droughts have a severe adverse economic impact on the agrarian households (Udmal *et al.*, 2014). Climate change related impacts, such as increase in rainfall variability both within and between years, are likely to further add to already difficult water management challenges in the basin. Needless to say, it is necessary to shed current water resource management approaches and to plan for new challenges under climate change scenarios.

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