



Hydro-meteorological and agricultural trends in water-scarce Karha Basin, western India: current and future scenario

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Abstract

The scientific understanding of hydro-meteorological and agricultural changes in the water-scarce region is crucial to formulate a plan for sustainable management of water resources and cropping pattern under the scenario of climate change. The present investigation, therefore, has attempted to detect the trends in the monsoon rainfall, runoff, dam storage, post-monsoon groundwater (PMGW) levels, and agricultural data in the Karha Basin, located in the rain shadow zone of the Western Ghat. Additionally, trends in projected monsoon rainfall and average annual temperature were also analyzed. The study indicates no significant increase in monsoon rainfall over the basin during past (1981–2013) and future (2015–2050). The noteworthy decline in monsoon runoff has mainly resulted due to the effective implementation of surface water harvesting in the basin, which has a significant positive change in PMGW table in the basin. The study also provides evidence of the shift in agricultural pattern, where the rainfed crops are getting replaced by the high water-requiring/cash crops. It may increase the future agricultural water demand and pressurize the limited water resources in the basin. On the other hand, significant increase in near-term future (up to 2050) temperature can augment the water demand along with the adverse impacts on the agricultural productivity. The Karha Basin is already suffering from water deficiency. The man-induced increase in agricultural water demand and the adverse climatic changes in the Karha Basin are very likely to aggravate the future drought conditions and further add to an already difficult water management challenge in the basin.

Keywords Semi-arid region · Monsoon rainfall-runoff · Groundwater · Temperature · Agricultural crops · Climate change

Introduction

The rainfed agriculture in the semi-arid region of Maharashtra in western India is the predominant economic activity which is strongly influenced by water availability and change in economic motives. Highly variable and deficient rainfall is the chief characteristic of the semi-arid region of Maharashtra (IMD 2005; Guhathakurta and Saji 2013) which increases stress on the agrarian economy. This water-deficit zone receives less than 700-mm rainfall during the monsoon period. The dry spells in the monsoon season and spatio-temporal variability in rainfall further aggravate the situation (Todmal and Kale 2016). Guhathakurta and Saji (2013) have observed an increasing trend in rainfall and seasonality over the districts in the vicinity of Western Ghat (including the present study area). However, declining trends in rainfall and streamflows in the semi-arid region of Maharashtra were observed during the recent decades by Kale et al. (2014). Ironically, during the same period, the area under food grain

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crops was replaced by cash crops such as sugarcane, maize, and onion (Deosthali 2002). The cropped area under maize and sugarcane is expanding at the annual rate of 11 and 3%, respectively (World Bank 2008). In order to avail the surface irrigation for cultivation of cash crops in the water-scarce region, a number of water storage structures were constructed in the upper reaches, which resulted in decline of annual runoff volume in the Upper Bhima Basin by 0.78 km³ (Biggs et al. 2007). Due to insufficient rainfall and surface irrigation facilities in the water-scarce area, more than 50% of the cultivable area depends on the groundwater resource (Pathak et al. 1999; GoM 2014b). The unrestricted extraction of groundwater (via deep dug/bore wells) resulted into decline in pre- and post-monsoon groundwater table, particularly in the drought-prone area of Maharashtra (GSDA 2014).

In the Fifth Assessment Report, IPCC has estimated intensification of water deficiency and food shortage problems in South Asia due to human-induced global warming (CDKN 2014). The climate change projection models estimated an increase in precipitation and temperature over the state of Maharashtra, which may adversely affect the productivity of some crops (TERI 2014). Apart from this, in the Krishna Basin (including water scarcity zone of Maharashtra), the rainfall and water yield are expected to reduce in the future by 20 and 30–50%, respectively (Gosain et al. 2006; Jain and Kumar 2012). The significant rise in temperature (by 1.5 to 2 °C) is estimated over the Maharashtra State (TERI 2014), which can increase the annual water deficiency and adversely affect the productivity of agricultural crops (World Bank 2003) particularly in the semi-arid regions. To understand the impacts of future climate change on the groundwater resource in the Upper Bhima Basin (including the study area), Surinaidu et al. (2013) have developed regional groundwater flow models. Considering the current rate of groundwater extraction, these models have suggested a significant fall in the groundwater table by about 6 m during the next 30 years. Under such circumstances, the agricultural pattern in the semi-arid region of Maharashtra is rapidly shifting from drought-resistant crops to the water-intensive cash crops (Kalamkar 2011; Todmal and Kale 2016). Furthermore, Maharashtra Water and Irrigation Commission (1999) has estimated about double requirement of food grains in 2032, which may lead to aggravating of the food shortage problem for the state of Maharashtra in the future. It is, therefore, a great challenge for water resource managers and agronomists to fulfill the agricultural water demand with limited water resources under the climate change scenario.

In order to understand the recent trends in hydro-meteorological and agricultural changes in the semi-arid region of Maharashtra, rainfall, runoff, dam storage, and groundwater in the Karha River Basin were analyzed. An attempt has also been made to verify whether the rainfed crops in the study basin are getting replaced by cash crops. Additionally, with

the use of projected data, near-term future (up to 2050) rainfall and temperature changes and their potential impacts on the rainfed agriculture in the basin are discussed.

The Karha Basin

The Karha River Basin drains about 1140 km² area with a length of 103 km and falls in the severe to chronic drought-prone area of Maharashtra. It is a left-bank tributary of the Nira River and eventually forms a part of the Krishna Basin (Fig. 1a). It drains part of Purandar, Baramati, Haveli, and Dound talukas (administrative sub-divisions of a district) of the Pune District. More than 75% of the basin area falls in the Purandar (Upper Karha Basin) and Baramati (Lower Karha Basin) talukas (Fig. 1b). About 85 to 95% of annual rainfall in the basin is received during the monsoon months (June to October), which is less than 500 mm. On account of being located in the vicinity of the Western Ghat, the rainfall is characterized by high inter-basin variation in monsoon rainfall (350 to 750 mm). The basin has experienced a notable increase in rainfall variability after the 1970s (Todmal and Kale 2016). The basin rainfall during the monsoon season depicts bimodal distribution, where the maximum rainfall is received in the month of September (130 mm), followed by June (110 mm) (Todmal and Kale 2016). During the non-monsoon season (November to May) due to nil to marginal rainfall, the Karha River channel remains mostly dry. On account of low monsoon rainfall, the basin suffers from annual soil moisture deficiency of about 800 to 1100 mm (Dikshit 1983). As a result, the basin experiences very high frequency of drought condition (once in 3 years) (Deosthali 2002). In order to overcome the water scarcity in the basin, a large number of minor water storage structures and KT (Kolhapur type) weirs were constructed in Baramati (4 and 27, respectively) and Purandar (8 and 6, respectively) talukas during the 1990s (GoM 1999).

As the basin receives very scanty amount of rainfall, the surface and sub-surface water availability is notably low, particularly during the pre-monsoon season. Therefore, the drought-resistant crops such as sorghum, pearl millet, gram, and pulses are dominant in the rainshadow zone of Maharashtra. However, in the areas where the surface irrigation facilities are available, the water-intensive cash crops such as sugarcane, wheat, maize, and onion are preferred. More than 55% of the total cropped area in the basin is under sorghum (jowar) and pearl millet (bajra). The area under sugarcane, maize, and wheat crops is about 12% of the net sown area (GoM 1999). A medium irrigation project is situated on the Karha River at Nazare near Jejuri Town (Fig. 1b). Additionally, in order to impound the surface water in the basin, about half a dozen of minor irrigation projects and about 25 weirs are constructed during the post-1990s. The Nazare

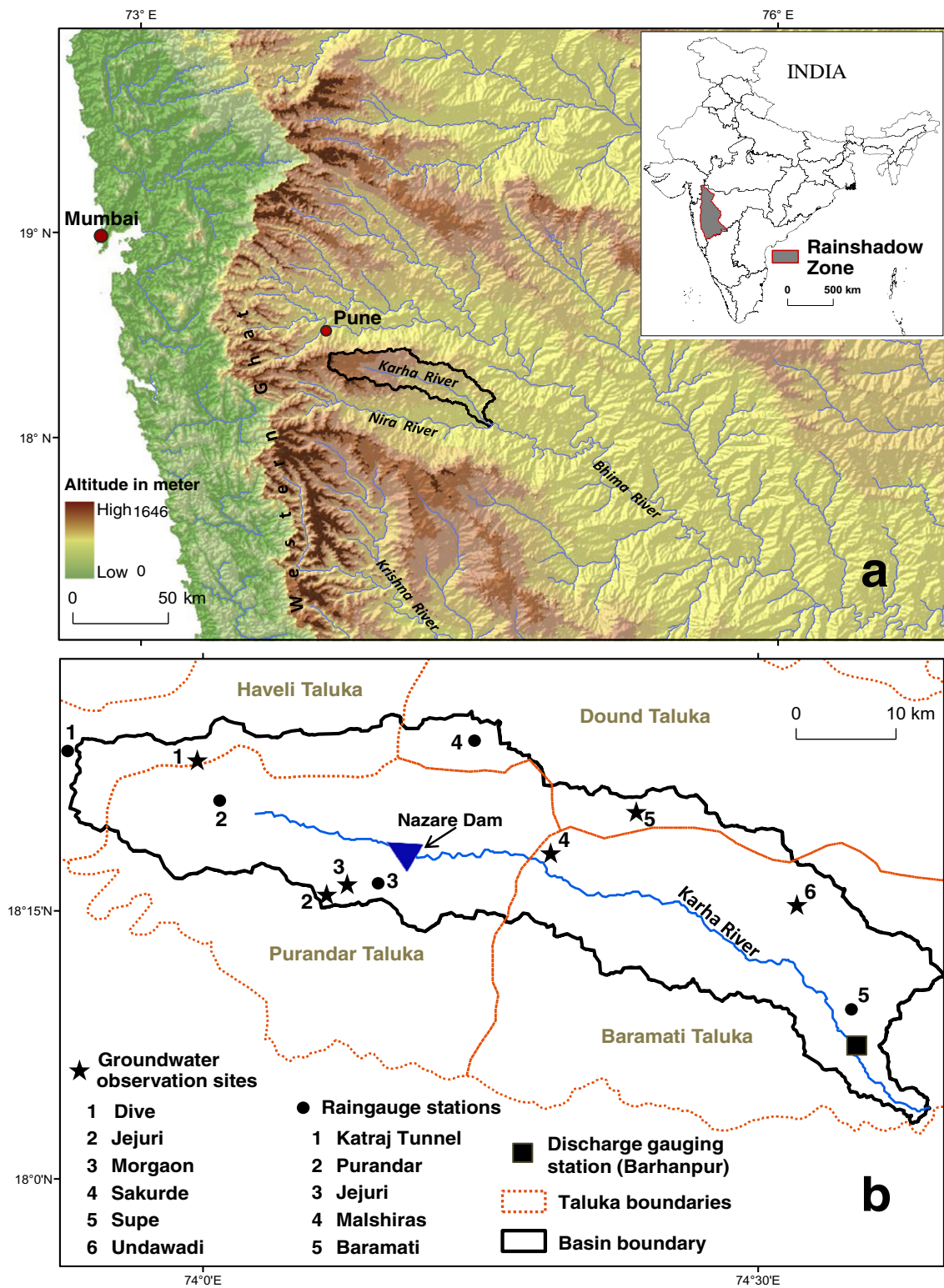


Fig. 1 Location of a the Karha Basin and b rainfall, groundwater, and discharge gauging stations

Dam has been designed with dead and total storage capacities of 5.68 and 22.31 million cubic meters (MCM), respectively. It has 400-km² (35% of the total basin area) upstream catchment area. The stored water in the dam is mainly used to irrigate the

agricultural land (about 3200 ha) in the study basin. As the Nazare Dam restricts considerable surface runoff volume in the Upper Karha Basin, the downstream reach of the river channel is frequently dry even during the monsoon season.

Data and methodology

In the present study, seven types of data including rainfall, temperature, streamflow, dam storage, and groundwater and data regarding agricultural crop productivity and area under principal crops were considered. Details of data used in the present study are given in Table 1. The daily rainfall and annual mean temperature (AMT) data were collected from India Meteorological Department (IMD). Among the selected sites, Katraj Tunnel (rain gauge) and Pune (temperature gauging site) are located outside the catchment. It should be noted that no temperature gauging station is available within the study basin. The missing values in the rainfall data were filled by linear regression equation. For this, statistically significant relationship with nearby stations is considered. The daily discharge data were obtained from Hydrological Data Users Group (HDUG). The discharge gives the volume of water passing through a point in a given unit of time at a cross-section (Muthreja 1986). Therefore, in the present study, the daily runoff is calculated as a product of daily discharge and the number of seconds in a day.

In order to consider the surface storage in the Karha Basin, daily storage and spillway data for Nazare Dam were obtained from the Irrigation Department of Maharashtra State (IDMS) for about three decades. The total volume of water available at Nazare Dam Site for each year was estimated by adding the maximum dam water storage and the spillway discharges of the respective years. The obtained value of the water available at dam site for each year is considered runoff volume over the dam catchment area. The data regarding post-monsoon groundwater levels (usually recorded in the month of May)

were acquired from the Groundwater Survey and Development Agency (GSDA). The missing values in the groundwater level data were filled by using linear regression equation. As the groundwater levels are directly associated with the monsoon rainfall, significant linear relationships with nearby rainfall stations were considered for this estimation.

One of the major objectives of this study is to understand the recent changes in agriculture and water availability in the semi-arid Karha Basin. Agriculture in the study basin is characterized by a combination of drought-resistant and irrigated (high water requiring) crops. Sorghum (jowar), pearl millet (bajra), gram, pulses, edible oil seeds, and pigeon pea are drought-resistant crops, whereas sugarcane, maize, wheat, and onion are the high water-requiring crops. In the present investigation, all the abovementioned crops are taken into consideration. The agricultural cropped area and productivity data for the Purandar, Baramati, Haveli, and Daund Talukas for about three decades (1980–2010) were collected from the Agriculture Department of Maharashtra State (ADMS). The missing values in the cropped area and productivity data were filled by averaging the preceding and succeeding years' records.

Another objective of this study was to identify the future changes in climatic variables over the Karha Basin, particularly rainfall and temperature. For this, the projected Coordinated Regional Downscaling Experiment (CORDEX) data were acquired from the Indian Institute of Tropical Meteorology (IITM), Pune. CORDEX South Asia data include simulations performed by the Swedish Meteorological and Hydrological Institute (SMHI), Rossby Centre RCM Rossby Center Atmospheric Model version 4 (RCA4). The yearly projected mean temperature and monsoon rainfall values for the period

Table 1 Details of data used in the present study

Variables	Selected stations/crops/pixels	Length of records	Station/crop name
Monsoon rainfall	5	1970–2013 (43 years)	Katraj Tunnel, Saswad, Jejuri, Malshiras, and Baramati
Annual mean temperature	1	1975–2014 (40 years)	Pune
Monsoon discharge	1	1981–2006 (26 years)	Barhanpur
Dam storage	1	1983–2014 (32 years)	Nazare Dam site
Post-monsoon groundwater level	6 (post-monsoon)	1981–2014 (34 years)	Dive, Jejuri, Morgaon, Sakurde, Supe, and Undawadi Kadepathar
Agriculture data for four basin-covering talukas	8 crops (cropped area)	1980–2010 (30 years)	Sorghum, pearl millet, gram, pulses, wheat, sugarcane, maize, and onion
	8 crops (productivity)	1980–2014 (35 years)	
CORDEX RCA4 projected data	8 pixels (0.25° × 0.25° each) (monsoon rainfall)	2015–2050 (35 years)	8 pixels which covered the entire basin
	8 pixels (0.25° × 0.25° each) (annual mean temperature)	2015–2050 (35 years)	

between 2015 and 2050 were obtained by averaging the monsoon rainfall values of pixels (of $0.25^\circ \times 0.25^\circ$ size) which covered the Karha Basin.

The Thiessen polygon method was used to calculate the average basin rainfall over the Karha Basin and Nazare Dam catchment (Upper Karha Basin). To understand the dependency of agricultural crops on water resources, coefficients of correlation between the productivity of crops (rainfed and irrigated) and hydrological variables (rainfall and post-monsoon groundwater (PMGW) level) were calculated (Table 2). The annual mean temperature data were used as an input to estimate yearly potential evapotranspiration values (PET) by the Thornthwaite method. In order to identify the changes in monsoon rainfall, runoff, water available at the dam site, PMGW level, annual mean temperature, PET, crop productivity, and agricultural cropped area, trend analysis was carried out by applying standard parametric and non-parametric statistical methods. Linear regression method was used to detect linear trends and the obtained results were verified by using non-parametric Mann-Kendall statistics. An attempt was also made to determine the point of initiation of step change in the abovementioned hydro-meteorological and agricultural data series. For this, the CUSUM, cumulative deviation, and Worsley likelihood ratio tests were applied. The obtained results of the year of step change were verified by Student's t and rank sum tests. In the same way, trends in projected monsoon rainfall and annual mean temperature were detected.

Results

Monsoon rainfall and groundwater level vis-à-vis agricultural productivity

In the Upper Bhima Basin (including the Karha Basin), about 16 and 21% of the agricultural area depends on the surface irrigation and monsoon rainfall, respectively (Udmale et al. 2014). On account of limited monsoon rainfall and surface water availability, the groundwater resource in the Karha Basin plays a crucial role to determine the agricultural productivity. Among all the selected crops, the productivity of rainfed crops displays notable association with monsoon rainfall ($r^2 \sim 0.20$) and groundwater irrigation (r^2 between 0.28 and 0.37)

(Table 2). The crops such as sorghum and gram are the post-monsoon (*Rabbi*) crops and cannot be grown without a supplement of groundwater irrigation. Pearl millet and pulse crops are cultivated during the monsoon period; however, due to higher monsoon rainfall variability in the study basin (Todmal and Kale 2016), they are highly reliant on groundwater irrigation to a great extent. Therefore, it can be stated that the PMGW availability chiefly determines yield of rainfed crops in the basin. On the other hand, the productivity of high water-requiring crops (wheat and sugarcane) exhibits marginal dependency ($r^2 < 0.20$) on rainfall and groundwater resources (Table 2). It is pertinent to mention here that the water-intensive crops are mainly based on the perennial source of water and, hence, grown in the areas of adequate availability of surface irrigation. During the summer season, due to limited availability of surface water for irrigation, wheat and sugarcane crops are irrigated with groundwater. The significant relationship between groundwater and high water-requiring crop productivity evidences the same fact (Table 2).

Trends in monsoon rainfall, temperature, and PET

Table 3 summarizes the results of trend and step-change analyses. Trends in monsoon rainfall display spatial consistency in the Karha Basin, as all the stations in the Karha Basin reveal increasing trend. Among them, Malshiras is the only station that exhibits a statistically significant increase in monsoon rainfall at the annual rate of 8.9 mm. The average basin rainfall over the Karha Basin and Nazare Dam catchment shows an increase in monsoon rainfall, which is not statistically significant. It can be stated that the overall stationwise increasing trend in the monsoon rainfall is well reflected in the average basin rainfall. However, very likely due to inadequate data, these increasing trends are not statistically significant. Although the majority of rain gauge stations do not exhibit a significant increasing trend, the results of step-change analysis advocate a considerable increase in monsoon rainfall, particularly after 2003. Exceptionally, at Baramati and Purandar stations, a step increase in monsoon rainfall is observed after 1994 and 1986, respectively. The year of step increase in rainfall over the entire Karha Basin and the Dam catchment is comparable (after 2003). However, the shift increase in

Table 2 Coefficient of linear regression (r^2) between water resources and agricultural productivity in the Karha Basin

Particulars	Irrigated crops		Rainfed crops		
	Wheat	Sugarcane	Sorghum	Gram	Pearl millet
Monsoon rainfall	0.05	0.04	<i>0.20</i>	<i>0.19</i>	<i>0.21</i>
Post-monsoon groundwater level	<i>0.19</i>	<i>0.15</i>	<i>0.37</i>	<i>0.28</i>	<i>0.33</i>

Italic values indicate statistically significant relationship at 95% confidence level

Table 3 Trends in hydrological variables and agricultural crops in the Karha Basin

Particulars		Trend (<i>b</i> value)	Step-jump year	Crops	Trend (<i>b</i> value)	Step-jump year
Monsoon rainfall (in mm)	Baramati	↑	1994	Area under crops in Purandar taluka	Sorghum	↓* (-892) 1991*
	Jejuri	↑	2004*		Pearl millet	↓ 1996*
	Malshiras	↑* (8.9)	2003*		Gram	↑ 1995
	Purandar	↑	1986*		Pulses	↓* (-315) 1997*
	Katraj	↑	2003*		Wheat	↑ 1987*
	Karha Basin	↑	2003		Onion	↑* (34) 1994*
	Dam catchment	↑	2003*		Maize	↑* (20) 1995*
Karha Basin runoff	↓* (-6.1)	1996	Sugarcane	↑ 1994*		
Dam catchment runoff	↑	2004*	Area under crops in Baramati taluka	Sorghum	↓* (-1372) 1997*	
Post-monsoon groundwater levels (in meters)	Dive	↓* (-0.3)		2004*	Pearl millet	↓ 1991*
	Sakurde	↑		2000	Gram	↓ 2001
	Jejuri	↓* (-0.3)		2003*	Pulses	↓* (-235) 1996*
	Morgaon	↓* (-0.1)		2003*	Wheat	↑* (158) 1990*
	Supé	↓		2004*	Onion	↑ 1993*
	Undawadi Kadepathar	↓* (-0.1)		2003*	Maize	↑* (71) 1991*
	Karha Basin	↓* (-0.1)	2003*	Sugarcane	↑* (115) 1993*	

Upward arrows indicate increasing trends and vice versa; increasing trend in groundwater implies fall in water table and vice versa; *b* values for cropped area are in hectares and runoff volume in MCM (million cubic meters)

*Significant trends at 95% confidence level

rainfall over the Karha Basin during the post-2003 period is not statistically significant (Fig. 2a).

To understand direction and magnitude of temperature over the study basin, the trend in temperature at Pune Station was estimated. The AMT shows an increasing trend between 1975 and 2014, which is statistically significant. During the last four decades, the study basin experienced 0.16 °C/decade rise in AMT. Obviously, it has amplified the annual rate of PET. Therefore, annual PET during the same period exhibits a significant increase (Fig. 2d). It has increased by 56 mm during 1975–2014 (14 mm/decade). The swift rise in PET can be noticed after 2002. In other words, the rise in temperature has increased hydrological losses over the Karha Basin.

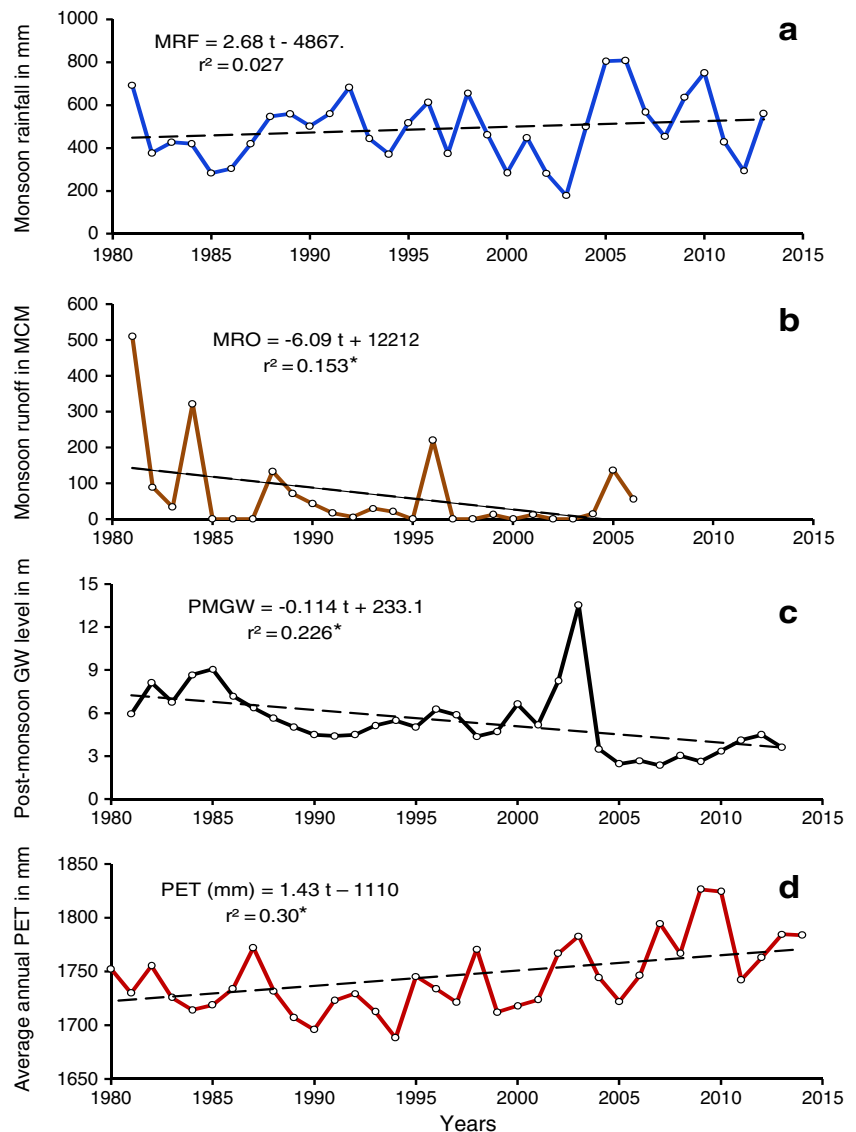
Trends in monsoon runoff, dam storage, and groundwater levels

As the semi-arid hydrology of Maharashtra is rainfall dependent, it is expected to reflect the trends in monsoon rainfall in runoff, dam storage, and PMGW levels. However, a statistically significant declining trend in the monsoon runoff over Karha Basin is observed (Table 3 and Fig. 2). It is observed to be declining at the rate of 6.1 MCM/year. Kale et al. (2014) have also observed the comparable trend for the study basin. The declining runoff at the lower reach of the Karha River does not display inherent decline due to climatic change. Notable inter-basin variation in trends in monsoon runoff can be noticed in the

Karha Basin (Table 3), as the upper domain of the basin (Nazare Dam catchment) exhibits an increasing trend in monsoon runoff, although it is not significant. The inherent link between monsoon rainfall and runoff can be noticed in the Upper Karha Basin. The monsoon rainfall over the Nazare Dam catchment shows significant positive shift after 2003, which may have led to rapid increase in monsoon runoff over the dam catchment after 2004 (Table 3).

On the other hand, all the selected dug well sites in the present study reveal a decreasing trend (i.e., rise in water table), with Sakurde being the solitary exception. Among them, statistically significant rise in post-monsoon groundwater (GW) level is observed at Dive, Jejuri, Morgaon, and Undawadi Kadepathar (Table 3). The rate of rise in groundwater table is very marginal (0.1 m/year) at Supé and Undawadi Kadepathar, whereas it is registered to be slightly higher (0.3 m/year) at Jejuri and Morgaon sites. As the average basin post-monsoon GW level is derived from stationwise data, it exhibits a significant rise in water table at the annual rate of 0.1 m (Fig. 3). Another interesting observation made from Table 3 is that majority of stations display shift increase and decrease in monsoon rainfall and post-monsoon GW level (i.e., rise in water table), respectively, after 2003. It suggests a good agreement between PMGW level and rainfall in the Karha Basin. Apart from this, increased surface storages in the basin during the last two decades can be another plausible reason for a significant rise in groundwater table in the basin.

Fig. 2 Trends in **a** monsoon rainfall, **b** monsoon runoff, **c** PMGW level, and **d** PET (Pune). Runoff data after 2006 were not available. Declining trend in PMGW level implies rise in water table. Asterisk (*) indicates significant trend at 95% confidence level



Trends in agricultural cropped area and productivity

About 75% area of the Karha Basin falls in Purandar and Baramati talukas. Therefore, the results of trends in the agricultural cropped area (in Table 3) are given for these two talukas. Trends in the cropped area under high water-requiring crops and rainfed crops are almost incomparable over the Karha Basin. In the Purandar taluka (Upper Karha Basin), the area under all the rainfed crops exhibits a declining trend, except gram. Among them, the cropped area under sorghum and pulses shows a significant decrease, particularly after 1991 and 1997, respectively. Cropped areas under these two crops are decreasing at the annual rate of 892 and 315 ha, respectively. Although a declining trend in pearl millet cultivation is not significant in the Purandar taluka, it has registered notable decline after 1996. On the contrary, cropped areas under irrigated crops in the Purandar taluka such as

sugarcane, wheat, maize, and onion reveal an increasing trend. Particularly, cropped areas under onion and maize crops are increasing significantly at the rate of 20 to 35 ha per year. The cropped areas under sugarcane and wheat show an increasing trend, which is not statistically significant. Briefly, the cultivation of irrigated crops (except wheat crop) in the Upper Karha Basin has rapidly increased during the post-1994 period (Table 3).

The trends in agricultural cropped areas in the Upper (Purandar taluka) and Lower (Baramati taluka) Karha Basin are in good agreement. The cultivation of sorghum and pulses in the lower basin is significantly declining (at the rate of 1372 and 235 ha/year, respectively), particularly during the post-1996 period (Table 3). Similarly, a decrease in areas under pearl millet and gram is observed, but it is not statistically significant. In the case of high water-requiring crops, with the exception of onion, all the selected crops reveal a

significant increase in cropped area, which is notably observed after the period 1991 to 1993. Perhaps due to an increase in water harvesting structures in the Baramati taluka, the area under sugarcane (highest water requiring crop) is significantly increasing at the rate of 115 ha/year in the lower domain of the basin. Similarly, areas under wheat and maize are expanding at the annual rate of 158 and 71 ha, respectively.

Apart from this, similar trends in areas under abovementioned crops are observed in the Haveli and Dound talukas which cover the remaining $\sim 25\%$ of the Karha Basin. Briefly, the cultivation of drought-resistant crops (sorghum, gram, pulses, and pearl millet) is declining in the Karha Basin, whereas preference for the high water-requiring crops has grown rapidly during the last two decades. The remarkable reduction in the cropped area under sorghum which is the predominant drought-resistant crop suggests shift in cropping pattern over the Karha Basin. The obtained agricultural trends in the present study compare well with those of a district-level study carried out by Kalamkar (2011). Trend analysis of productivity of rainfed crops (sorghum, pearl millet, and gram) and water-intensive crops (wheat and sugarcane) in the Karha Basin displays an increasing trend. This increase in productivity is registered particularly during the post-1990 period.

Near-term future trends in the rainfall and temperature over the Karha Basin

Figure 3 displays the near-term future (up to 2050) trends in projected monsoon rainfall and annual mean temperature over the Karha River Basin. The linear regression analysis of monsoon rainfall reveals an increasing trend over the study basin until 2050, which is not statistically significant. In other words, it suggests no considerable change in water availability in the Karha Basin during the next three decades. Besides this, the below-average monsoon rainfall during the 2030s denotes likely occurrence of severe water scarcity in the study basin (Fig. 3a). The projected mean temperature records exhibit a statistically significant increasing trend over the basin (Fig. 3b). The rate of increase in mean temperature is found to be $0.03\text{ }^{\circ}\text{C}$ per year (or $0.3\text{ }^{\circ}\text{C}$ per decade). Therefore, by mid-century (2050), the mean temperature over the study area is expected to rise by $1.02\text{ }^{\circ}\text{C}$. Another observation that can be made from this figure is that the rise in mean temperature is likely to intensify after 2035 (Fig. 3b). The projected monsoon rainfall and mean temperature over the study basin are characterized by a considerably moderate coefficient of variation (less than 33%). Below-average monsoon rainfall and swift increase in mean temperature in the late 2030s suggest a potential decline in soil moisture, which can adversely affect all the agricultural crops in general and rainfed crops in particular.

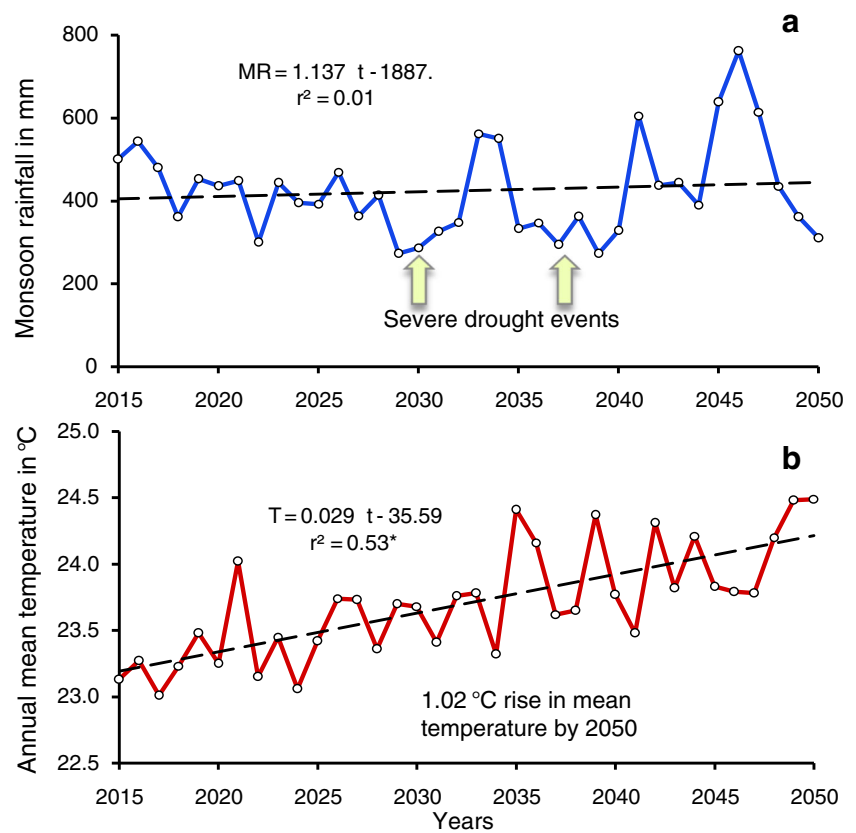
Discussion

From the result given in the preceding section, it is clear that the agricultural practices in the Karha Basin heavily depend on the ground water resource, followed by the monsoon rainfall. The distribution of rainfall within a monsoon period is highly variable (seasonality index > 1.1) in the Pune District (Guhathakurta and Saji 2013), including the Karha Basin. Perhaps due to this, the availability of groundwater resource in the study area ensures productivity of crops. The areas under surface irrigation in the Baramati and Purandar talukas are about 13.5 and 6.6%, respectively, of the net sown area (DSA 2014), which is below the state average ($\sim 18\%$) (Kalamkar 2011; GoM 2014a). Under such circumstances, ground water irrigation plays a crucial role to determine the productivity of the high water-requiring crops.

The present study makes it clear the notable consistency in increasing trend in monsoon rainfall over the Karha Basin, although it is not statistically significant. Among the selected stations, Malshiras reveals a significant increase in monsoon rainfall. The previous studies (Guhathakurta and Saji 2013; Todmal and Kale 2016) have also observed an increasing trend in rainfall over parts of western Maharashtra. About 60% of rain gauge stations (three out of five) in the study basin as well as the upper domain of the Karha Basin are observed with a notable increase in monsoon rainfall after 2003 (Table 3). However, there is strong possibility that due to the averaging effect or shorter data duration, the average monsoon rainfall over the Karha Basin does not show a significant increase (Fig. 2). It signifies no substantial increase in water availability during the last three decades (1980–2014). Moreover, Fig. 3 shows an increasing trend in projected monsoon rainfall (for the period between 2015 and 2050), but it is not statistically significant. In a nutshell, the water availability over the Karha Basin has neither increased during last three decades (1980–2014) nor it is expected to increase in the near-term future (2015–2050). It is pertinent to mention here that the surface and sub-surface water resources in the Karha Basin predominantly depend on the monsoon rainfall, which may pressurize by increasing demand of water in the future. In view of future water resource management, it should be noted that the below-average rainfall estimation during the 2030s indicates a possibility of occurrence of severe droughts over the basin (Fig. 3). Additionally, the future temperature rise over the Karha Basin very likely to amplifies rate of annual PET, which will lead to increase in crop water requirement and severity of droughts.

The rainfall, runoff, and post-monsoon GW level relationship can be inferred from Table 2. The inconsistent trends in monsoon rainfall (increasing) and monsoon runoff (declining) are observed over the area under investigation. The decrease in monsoon runoff recorded at the lower reaches of the river indicates a notable role of anthropogenic activities in the basin during the recent decades. Previous studies carried out by

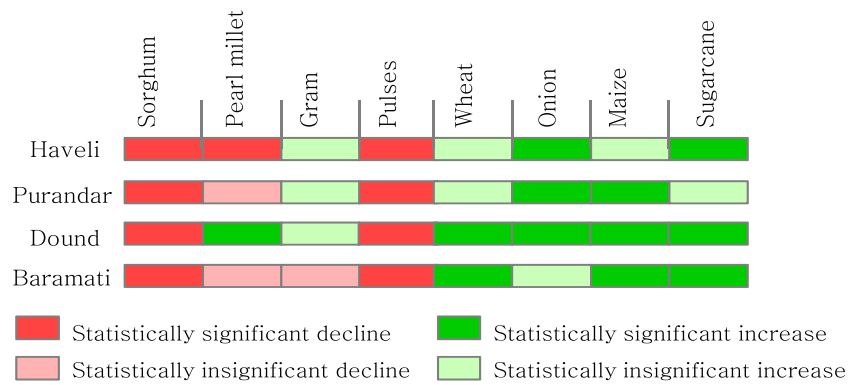
Fig. 3 Trends in projected **a** monsoon rainfall and **b** annual mean temperature over the Karha Basin. MR monsoon rainfall, t time, T annual mean temperature. Asterisk (*) indicates significant relationship (trend) at 95% confidence level



Biggs et al. (2007) and Samal and Gedam (2012) have concluded that the increase in water storage structures in the Upper Bhima (including study area) is mainly responsible for the significant decline in runoff volume at downstream. Across the Karha River and its tributaries, one medium irrigation project (with 22.31 MCM water storage), 25 KT weirs (Kolhapur-type weirs) (Kale et al. 2014), and seven minor projects (with irrigated area < 2000 ha) were constructed during the last three decades. Therefore, a considerable increase in water harvesting in the Karha Basin is primarily responsible for the statistically significant decline in monsoon runoff. Apart from this, a rise in PET has resulted in an increase in hydrological losses during the gauge period. This can be a partial reason for the decline in monsoon runoff in the study basin. On the other hand, an outcome of adaptation of water conservation measures in the Karha Basin is evident from a significant rise in the post-monsoon groundwater table (declining trend implies rise in water table) in the basin. Surinaidu et al. (2013) have estimated GW level decline in the Upper Bhima Basin (including Karha Basin) by 6 m during the near-term future. However, in the future, the Karha Basin may stand alone as an exception, as it exhibits a significant rise in post-monsoon GW level (by 10 cm/year). Apart from this, the consistent period of step increase (after 2003) in monsoon rainfall and PMGW table indicates an inherent natural relationship between both.

Figure 4 provides a better picture of agricultural trends over the Karha Basin and the surrounding area (four talukas which cover the entire basin). The agricultural cropped area under rainfed crops (particularly, sorghum and pulses) is observed to be declining significantly over the study basin. The district-level study carried out by Kalamkar (2011) also inferred a significant decreasing trend in the area under food grain and cereal crops in the Pune District, including the study area. The present study has evidenced growth in the area under cash crops such as sugarcane, wheat, maize, and onion over the Karha Basin and the surrounding area during the last three decades (1980–2010) (Fig. 4). In such circumstances, it can be stated that the area under high water-requiring crops (cash crops) in the Karha Basin is increasing at the cost of rainfed crops. It is pertinent to mention that in the present study basin, a majority of surface water storage structures in the study basin (five small projects, 86 Kolhapur-type weirs, and 307 percolation tanks) are concentrated in the Baramati taluka (Lower Karha Basin). Moreover, the canals from Nazare and Veer dams irrigate western and southern parts of the Baramati taluka, respectively. This may have attributed to significant increase in cultivation of sugarcane, maize and wheat in the Lower Karha Basin during recent decades. Perhaps due to limited availability of perennial irrigation facility, the upper domain of the study basin registered marginal increase in area under sugarcane and wheat. Whereas, cultivation of maize and

Fig. 4 Talukawise trends in cropped area under selected crops



onion crops which are the short duration crops and require comparatively less water, is notably increased (Fig. 4). It should be noted that in the Purandar taluka, surface water resources perennially irrigate only about 7% of the cropped area. Therefore, instead of sugarcane and wheat cultivation, farmers in the Upper Karha Basin may have preferred the maize and onion crops.

However, the anomalous increase in the cropped area under gram in Haveli, Purandar, and Dound talukas (area under pearl millet also) (Fig. 4) cannot be fully explained. In this connection, no satisfactory explanations were obtained during personal interviews with the concern officials of the Agriculture Department of Maharashtra State.

In spite of increased rainfall variability (by about 30–50%) over the Karha Basin during the last four decades (Todmal and Kale 2016), a majority of selected crops display a significant increase in productivity, particularly after 1990. Kalamkar (2011) has also inferred an increasing trend in agricultural productivity over the districts of western Maharashtra (including study area). It denotes important role of factors (fertilizers, pesticides, insecticides, groundwater availability, irrigation techniques, and antecedent moisture) other than monsoon rainfall to determine the changes in agricultural productivity in the study basin.

A notable shift in temperature and other climatic parameters over Indian region is observed approximately after 1970 (Dash and Hunt 2007; Jain and Kumar 2012; Subash and Sikka 2014). Particularly, the western India (including the Karha Basin) experienced an increase in temperature at the rate of 0.3 °C per decade since 1973 (Nayak and Manda Nayak and Mandal 2012). Temperature increase is a major concern from the stand point of agriculture, as it can adversely affect the productivity of food grain, cereals, and cash crops (Bhoomiraj et al. 2011; Hebbar et al. 2013; Kumar and Parikh 2001; TERI 2014; World Bank 2003) particularly in the rainfed agriculture. The present investigation estimated a significant increase in average annual temperature (by 0.29 °C per decade) over the Karha Basin during the near-term future (2015–2050) (Fig. 3). Considering this rate of increase, temperature over the study area is expected to rise

by 1.02 °C up to 2050. This warming may lead to decline in productivity of sorghum (by 6 to 18%) (Bhoomiraj et al. 2011) and sugarcane (by 6 to 22%) (World Bank 2003), which are the major rainfed and irrigated crops, respectively, in the study basin. Moreover, rise in temperature (> 34 °C) sharply declines germination of pearl millet (Ong and Monteith 1985). Besides this, rise in temperature very likely intensifies the rate of evaporation which in turn increases the soil moisture deficiency in the basin. Eventually, it increases water requirement of rainfed as well as irrigated crops. Warming in the Karha Basin can indirectly pressurize the available water resource (which is estimated to be constant in the future) and create a serious threat to the rainfed agriculture.

Conclusion

The present investigation has given insight into changes in monsoon rainfall, runoff, groundwater level, agricultural productivity, and cropping pattern in the water-scarce Karha Basin, situated in the drought-prone area of the Maharashtra State. Although the growing commercial perspective among the farmers towards agriculture is responsible for the increase in cultivation of cash crops (Kalamkar 2011) in the Karha Basin, the crop productivity (particularly rainfed crops) heavily depends on the groundwater and monsoon rainfall. The notable increase in water shed management structures during the recent years (particularly in the lower domain of the basin) explains the decline in the monsoon runoff over the Karha Basin. Therefore, the significant increase in PMGW table is reflected as an outcome of the effective implementation of surface water harvesting. However, in the upper domain of the Karha Basin, there is scope for surface water impoundment, which perhaps creates water deficiency in the future for the cultivation of cash crops in the Lower Karha Basin.

Without a considerable increase in monsoon rainfall over the Karha Basin, cultivation of cash crops increased significantly (Fig. 4). Obviously, it leads to augment the agricultural water requirement. Near-term future (up to 2050) water

availability in the study basin will be more or less the same (Fig. 3a), which may not be sufficient to fulfill the increased agricultural water demand in the future. On the other hand, a significant increase in average temperature over the Karha Basin can adversely affect the agricultural productivity and amplify the agricultural water demand. In a nutshell, the anthropogenic activities (shift in the agriculture pattern) adding pressure on available water resources in the Karha Basin and the future climatic changes are likely to further add to already difficult water management challenge. Needless to say, it is necessary to effectively manage the available water resources in the basin under the climate change scenario. For this, the government should compel and heavily subsidize the use of water-saving techniques in agriculture. Apart from this, the agronomist can play a crucial role in such agro-climatic challenge by introducing low water-requiring varieties of cash crops.

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