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Present hydro-meteorological and agricultural trends in Karha Basin, western India

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Abstract:

The Intergovernmental Panel on Climate Change (IPCC) has highlighted that agriculture in the semi-arid regions of South Asia is particularly vulnerable to the adverse effects of climate change. In this context, a scientific understanding of hydro-meteorological and agricultural changes in water-scarce areas is essential for developing effective strategies for water resource management and crop planning under changing climate conditions. This study focuses on the Karha Basin, located in the rain shadow region of the Western Ghats, and aims to identify trends in monsoon rainfall, surface runoff, dam storage, post-monsoon groundwater (PMGW) levels, and agricultural practices. It also includes an analysis of projected trends in monsoon rainfall and average annual temperature. The findings reveal no significant increase in monsoon rainfall over the basin during the historical period (1981–2013). However, a notable decline in monsoon runoff has been observed, primarily due to the effective implementation of surface water harvesting measures. These interventions have led to a significant improvement in post-monsoon groundwater levels. The study also identifies a shift in cropping patterns, with traditional rainfed crops increasingly being replaced by high water-demanding and cash crops. This transition may escalate future agricultural water demand, placing further pressure on the region's already limited water resources. Given that the Karha Basin is already experiencing water scarcity, the combination of human-driven increases in agricultural water use and adverse climatic changes is expected to intensify drought conditions and further complicate water management efforts in the region.

Key words: Groundwater, Temperature, Agricultural crops, Climate change, Trend analysis.

Introduction:

Rainfed agriculture is the primary livelihood in the semi-arid region of Maharashtra, where rainfall is both low (typically under 700 mm during the monsoon) and highly variable (IMD, 2005; Todmal and Kale, 2016). This variability places immense stress on the agrarian economy. Despite localized increases in rainfall near the Western Ghats (Guhathakurta and Saji, 2013); recent decades have shown declining trends in rainfall and stream flow across Madhya Maharashtra (Kale et al., 2014). During this time, a major shift from food grains to high water-demanding cash crops like sugarcane and maize has occurred (Deosthali, 2002; World Bank, 2008), supported by new water storage structures that reduced runoff in the Upper Bhima Basin by 0.78 km³ (Biggs et al., 2007). Due to insufficient surface water, over half the cultivable land depends on groundwater, but unregulated extraction has caused a significant drop in both pre- and post-monsoon groundwater levels (GSDA, 2014).

Climate projections indicate worsening conditions, with rising temperatures (1–1.5°C by 2050) and potential declines in rainfall and water yield in regions like the Krishna Basin (Gosain et al., 2006; TERI, 2014). This could reduce crop productivity and intensify water scarcity, particularly in semi-arid areas (World Bank, 2003). Groundwater models for the Upper Bhima Basin suggest a 6-

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meter decline in water tables over the next 30 years if current extraction continues (Surinaidu et al., 2013). Combined with a shift toward water-intensive crops (Kalamkar, 2011), this trend poses serious challenges for future food and water security. To assess these impacts, the present study analyzes trends in rainfall, runoff, dam storage, groundwater, and cropping patterns in the Karha River Basin, along with future rainfall and temperature projections and their implications for rainfed agriculture.

The Karha Basin:

The Karha River Basin, covering an area of about 1140 km² with a river length of 103 km, is a severely drought-prone region in Maharashtra and forms part of the Krishna Basin as a left-bank tributary of the Nira River. It encompasses parts of Purandar, Baramati, Haveli, and Daund Talukas of Pune District, with over 75% of its area lying in Purandar (Upper Karha) and Baramati (Lower Karha) Talukas. The basin receives 85–95% of its annual rainfall, less than 500 mm, during the monsoon period (June to October), which exhibits high spatial variability (350–750 mm) due to its proximity to the Western Ghats. Since the 1970s, rainfall variability has notably increased, with a bimodal distribution peaking in September (130 mm) and June (110 mm). The Karha River remains mostly dry in the non-monsoon season due to minimal rainfall, resulting in a soil moisture deficit of 800–1100 mm and a high drought frequency (once every three years). To mitigate water scarcity, numerous minor irrigation structures and KT weirs were built in the 1990s, especially in Baramati (4 minor projects and 27 weirs) and Purandar (8 minor projects and 6 weirs). With low surface and sub-surface water availability, drought-resistant crops like sorghum, pearl millet, gram, and pulses dominate (covering 55% of cropped area), while water-intensive crops such as sugarcane, maize, and wheat account for about 12%. A medium-sized dam, Nazare Dam, located near Jejuri Town, has a total capacity of 22.31 MCM and supports irrigation of approximately 3200 hectares. The dam's upstream catchment spans 400 km² (35% of the basin), and its regulation of surface runoff often leaves the downstream Karha River dry, even during monsoon.

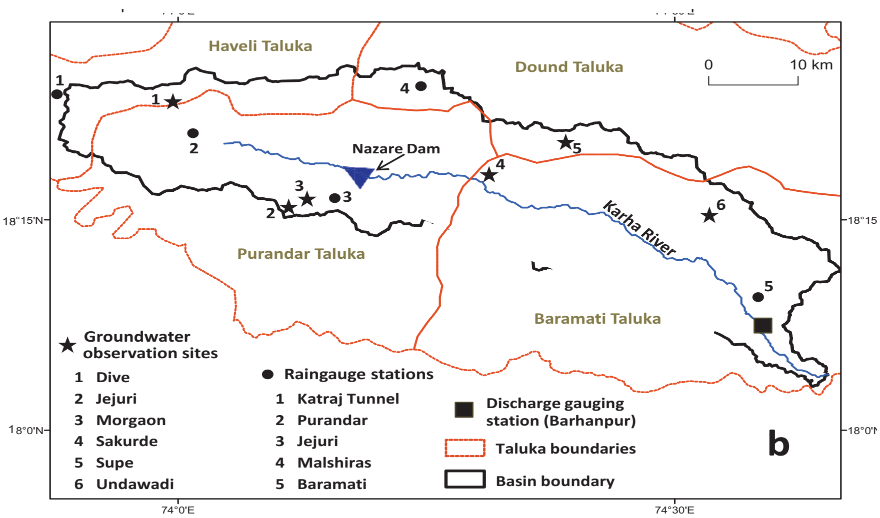

Figure 1 Location map of Karha Basin with rainfall, groundwater and discharge gauging stations

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2. Data and Methodology:

In this study, six types of data were analyzed, including rainfall, stream flow, dam storage, groundwater levels, agricultural crop productivity, and area under principal crops. The daily rainfall and discharge data were obtained from the India Meteorological Department (IMD) and the Hydrological Data Users Group (HDUG), respectively. Among the five selected rain gauge stations, Katraj Tunnel is located outside the basin. Missing rainfall values were estimated using linear regression based on significant relationships with nearby stations. Daily storage and spillway discharge data for Nazare Dam, spanning about three decades, were provided by the Maharashtra State Irrigation Department (IDMS). Annual water availability at the dam was calculated by summing the maximum storage and annual spillway discharge. Groundwater level data, recorded pre- and post-monsoon (May and October) and obtained from the Groundwater Survey and Development Agency (GSDA), also had missing values filled using linear regression, leveraging their strong correlation with monsoon rainfall. To assess agricultural and water resource changes in the semi-arid Karha Basin, the study included both drought-resistant crops (sorghum, pearl millet, gram, pulses, edible oil seeds, pigeon pea) and high water-requiring crops (sugarcane, maize, wheat, onion). Crop area and productivity data for Purandar, Baramati, Haveli, and Daund Talukas (1980–2010) were collected from the Agriculture Department of Maharashtra State (ADMS), with missing data filled by averaging adjacent years.

In the Upper Bhima Basin, including the Karha Basin, about 16% of agricultural area relies on surface irrigation and 21% on monsoon rainfall (Udmale et al., 2014). Due to limited rainfall and surface water, groundwater plays a crucial role in determining agricultural productivity. Rainfed crops like sorghum, gram, pearl millet, and pulses show significant dependence on monsoon rainfall ($r^2 \sim 0.20$) and groundwater (r^2 between 0.28 and 0.37), with sorghum and gram requiring groundwater for post-monsoon cultivation. High rainfall variability increases reliance on groundwater. High water-requiring crops such as wheat and sugarcane are mostly irrigated from perennial surface water, but in summer depend on groundwater, as reflected by their significant, though weaker, correlation with groundwater levels ($r^2 < 0.20$).

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
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 (34years)	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)	

Table 2 Coefficient of linear regression (r^2) between hydrological variables and agricultural productivity in the Karha Basin.

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

Numbers in bold indicate statistically significant relationship at 0.05 level

3. Results

3.1 Trends in monsoon runoff, dam storage and groundwater levels

In the semi-arid Karha Basin, where hydrology is largely rain-dependent, a statistically significant declining trend in monsoon runoff is observed at a rate of 6.1 MCM/year (Table 3), consistent with Kale et al. (2014). This decline is not attributed to climatic change, as the Upper Karha Basin (Nazare Dam catchment) shows a non-significant increasing runoff trend, linked to a significant positive shift in monsoon rainfall after 2003, likely driving increased runoff post-2004 (Table 3). Conversely, most dug well sites show a decreasing groundwater trend (i.e., rising water table), with significant post-monsoon groundwater rise at Dive, Jejuri, Morgaon, and Undawadi Kadepathar (Table 3). The average post-monsoon groundwater level across the basin rises significantly at 0.1 meters per year. The majority of stations reflect a step increase in monsoon rainfall and corresponding rise in groundwater levels after 2003, indicating strong rainfall-PMGW linkage. Additionally, the expansion of surface water storage over the past two decades likely contributes to the groundwater rise.

3.2 Trends in agricultural cropped area and productivity

About 75% of the Karha Basin lies in Purandar and Baramati Talukas, and therefore, the trends in agricultural cropped area are presented specifically for these two regions (Table 3). In Purandar Taluka (Upper Karha Basin), rainfed crops show a general declining trend, except for gram. Notably, the area under sorghum and pulses has significantly decreased at annual rates of 892 and 315 hectares, respectively, especially after 1991 and 1997. Pearl millet also shows a decline after 1996, though not statistically significant. In contrast, irrigated crops such as sugarcane, wheat, maize, and onion show increasing trends, with onion and maize rising significantly by 20 to 35 hectares per year. The expansion of irrigated crops, particularly post-1994, reflects a clear shift in cropping practices in the Upper Karha Basin (Table 3).

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Similar patterns are observed in the Lower Karha Basin (Baramati Taluka), where sorghum and pulses exhibit significant declines at rates of 1372 and 235 hectares per year, especially after 1996 (Table 3). Areas under pearl millet and gram also decreased but without statistical significance. In contrast, high-water requiring crops, except onion, have expanded significantly since 1991–1993. The most striking change is in sugarcane cultivation, which increased by 115 hectares annually, likely due to improved water harvesting infrastructure in Baramati. Wheat and maize expanded at rates of 158 and 71 hectares per year, respectively. Similar trends are seen in Haveli and Daund Talukas, covering the remaining 25% of the basin. Overall, there has been a clear shift from drought-resistant to high-water requiring crops over the last two decades, with sorghum showing the most significant reduction, indicating a major change in cropping pattern. These agricultural trends align with the district-level findings of Kalamkar (2011), and productivity trends for both rainfed and irrigated crops show a significant increase, particularly after 1990 (Table 3).

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

	Particulars	Trend (b value)	Step-jump year
Monsoon rainfall (in mm)	Baramati	↑	+1994
	Jejuri	↑	+2004*
	Malshiras	↑ * (+8.9)	+2003*
	Purandar	↑	+1986*
	Katraj	↑	+2003*
	Karha Basin	↑	+2003
	Dam catchment	↑	+2003*
	Karha Basin runoff	↓ *(-6.1)	-1996
	Dam catchment runoff	↑	+2004*
Post-monsoon groundwater levels (in meters)	Dive	↓ * (-0.3)	-2004*
	Sakurde	↑	+2000
	Jejuri	↓ * (-0.3)	-2003*
	Morgaon	↓ * (-0.1)	-2003*
	Supe	↓	-2004*
	Undawadi Kadepathar	↓ * (-0.1)	-2003*
	Karha Basin	↓ * (-0.1)	-2003*

	Crops	Trend (b value)	Step-jump year
Area under crops in Purandar Taluka	Sorghum	* ↓ 892)	-1991*
	Pearl millet	↓	-1996*
	Gram	↑	+1995
	Pulses	* ↓ 315)	-1997*
	Wheat	↑	+1987*
	Onion	* ↑ 34)	+1994*
	Maize	* ↑ 20)	+1995*
	Sugarcane	↑	+1994*
Area under crops in Baramati Taluka	Sorghum	* ↓ 1372)	-1997*
	Pearl millet	↓	-1991*
	Gram	↓	-2001
	Pulses	* ↓ 235)	-1996*
	Wheat	* ↑ 58)	+1990*
	Onion	↑	+1993*
	Maize	* ↑ 1)	+1991*
	Sugarcane	* ↑ 15)	+1993*

Increasing trend in groundwater implies fall in water table and vice-versa, b values for cropped area are in hectares. Runoff volume in MCM (million cubic meters).

Conclusion:

The present study provides valuable insights into changes in monsoon rainfall, runoff, groundwater levels, agricultural productivity, and cropping patterns in the water-scarce Karha Basin, located in the drought-prone region of Maharashtra State. While the increasing commercial interest in agriculture has driven the expansion of cash crop cultivation (Kalamkar, 2011), crop productivity in the Karha Basin remains heavily dependent on groundwater and monsoon rainfall. The significant rise in watershed management structures, especially in the lower basin, explains the observed decline in monsoon runoff, leading to a notable increase in the pre-monsoon groundwater table due to effective surface water harvesting. However, in the upper basin, there is considerable scope for further surface water impoundment, which may exacerbate future water shortages for cash crop cultivation in the lower Karha Basin.

Despite no significant increase in monsoon rainfall, cash crop cultivation has expanded considerably, driving up agricultural water demand. Anthropogenic activities, particularly the shift in cropping patterns, are already stressing the limited water resources of the Karha Basin, and future climate changes are likely to compound this challenge. Therefore, effective water resource management under changing climate conditions is critical. Policy measures should mandate and subsidize water-saving agricultural practices, while agronomists can contribute by promoting low-water requiring varieties of cash crops to tackle this agro-climatic challenge.

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