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SPATIO-TEMPORAL VARIABILITY AND AVAILABILITY OF RAINFALL IN KARHA BASIN DURING THE TWENTIETH CENTURY

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ABSTRACT

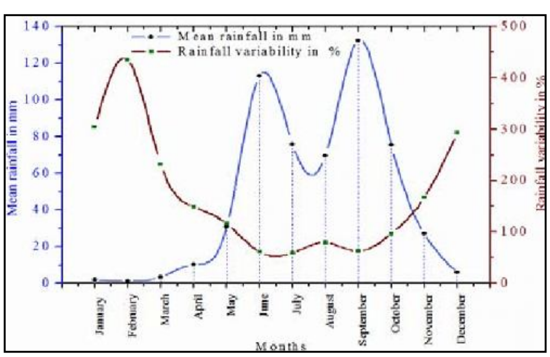
Understanding of spatio-temporal variability and availability of water from monsoon rainfall is essential in semi-arid region for planners to formulate the year plan of water uses comprising domestic, industrial water supply and irrigation. In the present work, the available water from monsoon rainfall in Karha Basin and at dam site is estimated. Yearly rainfall (station wise and average catchment rainfall) were constructed to identify the spatial and temporal variations in rainfall. By using daily rainfall data of three stations, the average catchment rainfall was estimated which has been used to define 75 percentile assured rainfall in a catchment. The study reveals there is a huge spatial variability in rainfall. It is increasing from East to West in a Nazare Dam Catchment. Sasvad raingauge station predominantly determines the dam storage volume. During the monsoon period, in dam catchment about 432 mm of assured rainfall and about 670 MCFT assured water volumes at dam site can be available.

KEY WORDS:*Semi-arid, variability, assured rainfall, dam storage, moving average.*

INTRODUCTION

In India, grate social disputes has been resulting for water resources. As it affects all the biotic components, economic activities and the social quality of life at national, regional and the local level also. All the socio-economic activities are directly or indirectly depend on the water availability. Acute water shortage affects all human activities in general and agriculture in particular (Pandey et al., 2007). Slight fluctuations in annual water availability may affect widely in populated arid and semi-arid areas those cover more than 1/4th land area of the world (Wang et al., 2007). Hence, in such kind of sensitive areas the annual plan for water availability and demand are of vital importance.

In Maharashtra rainy days varies between 30-118, that resulting variations in availability of water resource. In a semi-arid region (Western Maharashtra) of the state, 30-50 rainy days are observed. It is because of Western Ghats which shaping the climate of the state by producing the orographic effect, due to which the western Maharashtra receives less than 700 mm rainfall (Choudhary, 1992; Gadgil, 2002). During the lean period, the water level in dams, tanks, ponds, dug wells and stream sharply decreases. In such a drought prone areas, the spatio-temporal assessment of water availability is for most important to formulate the water usage plan for various activities.



Since, rainfall is one of a meteorological element that is non-continuous and highly varies with space and time, due to this statistical description of rainfall is quite multifaceted (Kavvas & Delleur, 1975). Variability in rainfall data may provide information about uncertainty in water availability in a region. Therefore, in natural sciences spatio-temporal variability has substantial interest (Winkler *et al.,* 1988).Finkelstein and Truppi (1991). Markham (1970) studied the spatial variations in seasonality pattern in United States. Guhathakurtaand Saji (2013) have evaluated the spatio-temporal variability in rainfall during the last century over Maharashtra state. More research is necessary on the spatial variability and distribution of precipitation, the amount of precipitationper occurrence, the variations between periods of dry, wet or normal weather.

Being a part of drought prone or rainshadow region of Maharashtra, Nazare Dam Catchment experiencing acute water shortage in every year. Even a miner fluctuation in monsoon rainfall amount can result disastrous effects on agricultural practices and socio-economical life. Millions of people and their various activities in this catchment totally depend on the monsoon rainfall. considering their importance, this paper attempts to understand and evaluate the spatio-temporal variations and water availability through monsoon rainfall and dam storage.

STUDY AREA:

The Karha River Basin is extended in between 18º 3' and 18º 27' N latitude and between 73º 52' and 74º 40' E longitude. Geologically, the basin underlain by Deccan Trap Basalts of Cretaceous Eocene age (Kale, 2002). It is a left bank tributary of Nira River, and eventually a part of Krisha River system. It originates in Sahydri Hills near Garade Village at an altitude of 1081 mt. ASL and drains 1141km^2 catchment with the 103 km length, which partially covers an area of Haveli, Purandhar, Daund and Baramati Tehsils of Pune Districts (Fig. 1).

The Nazare medium project is situated on the Karha River near to Jejuri village (Pune). The elevation of dam from the mean sea level is about 660 meters. The Nazare Dam has 788 MCFT water storage capacities that consist of 200 MCFT and 588 MCFT as dead and live water storage respectively. The catchment area behind the dam is about 398 km^2 that entirely falls in semi-arid and drought prone area of Maharashtra. The same dam serves irrigation facility for Purandhar and Baramati Tehsils of Pune District.

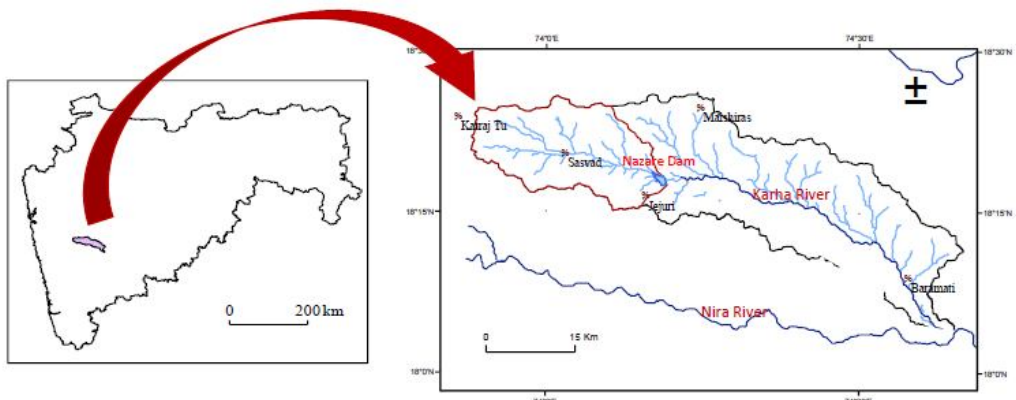


Fig.1 Index map of Nazare Dam Catchment in Karha River Basin.

Hydro-Meteorological Characteristics:

The Western Ghat, which predominantly determined the rainfall distribution over the state (Gadgil, 2002). Because of its orographic effect, towards east from the leeward side of Western Ghat, the annual rainfall markedly reduces up to 300 mm. Therefore, this rainfall deficiency zone recognized as a *rainshadow zone*. However, the rainfall is the principal source of water, all the rivers depicts monsoon-fed character.

Since, Karha River Basin entirely falls in this zone, monsoonal climate and physiography are the predominant physical factors controlling spatio-temporal variations in rainfall and discharge.

Being a part of Upland plateau region of Maharashtra, Karha Basin receives about 85 to 95 % of annual rainfall during monsoon and post-monsoon season, which is a dominant water source for streamflow (Gupta and Chakrapani, 2005). It receives annual rainfall between 350 and 750 mm with 30 to 45 rainy days (Gadgil, 2002) which is a scanty rainfall in a state. In addition to this, the basin suffers from the annual soil moisture deficiency between 800 and 1100 mm (Dikshit, 2002). Since, Karha River has intermittent nature, it remain dry during the non-monsoon season. After the construction of Nazare Dam, the river flow did not remain natural therefore, some of the time, it may observe dry in monsoon season also. The drought events are very frequently (once in three years) and severely observed in the basin (Chawdhury and Abhyankar, 1984; Deosthali, 2002; Gadgil, 2002), which may cause due to rainfall variability and critical rainfall regime.

Data Source and Methodology:

Data used:

Being a water scarcity zone, different government agencies attracted an attention to gauge the hydrological data in drought prone areas of Maharashtra. Therefore, station wise daily rainfall data in Karha Basin were available from IMD (Indian Meteorological Department) and Agriculture Department of Maharashtra for five raingauge stations (Table.1). Because of moderate sized basin, there is only one gauge discharge station available. Hence, in order to understand the inter basin variability in water availability, dam storage data were considered. In addition to this, the spillway discharge data were also taken into account. Monthly and annual dam storage data for about three decades were made available from Irrigation Department of Maharashtra State. The duration of precipitation data were selected with accordance to the dam storage and discharge data availability.

Data validation and testing:

In order to validate the raw precipitation and dam storage data, established methods in meteorology were used. The missing values in the daily precipitation series were filled by using correlation and regression method. Since, only five raingauge stations available in a river catchment, the data of each individual station had to be subjected to homogeneity test with nearby stations to ensure their quality (Mutreja, 1986). For the confirmation of consistency in inter annual variations in rainfall data, double mass curves were plotted. Statistically significant correlation (at 95 % confidence level) and high explained variance in double mass curve supports acceptable quality of precipitation data for long-term trend analysis.

Table 1. Details of daily rain gauge sites and catchment.

Sr. No	Rain gauge stations	Location	Length of rainfall records (Years)	Mean monsoon rainfall in mm	Thiesson polygon area (in km^2)
1.	Baramati		112 (1901-2012)	431.48	247
2.	Jejuri	18˚ 16' N 74˚ 09' E	105 (1902-2006)	397.55	248
3.	Malshiras		26 (1981-2006)	298.15	335

4.	Sasvad	20˚ 50' N 74˚ 17' E	105 (1902-2006)	522.33	254
5.	Katraj	18˚ 24' N 73˚ 51' E	41 (1966-2006)	835.49	57

Estimation of area weighted rainfall:

The Thiessen polygon method is widely used in climatology and hydrology to estimate area-weighted average rainfall from point rainfall data (Muthreja, 1990). This method attempts to allow for non-uniform distribution of gauges by providing a weighting factor for each gauge (Raghunath, 2005). Following the same standard procedure, the area of Karha Basin upstream of the discharge gauge station was divided into number of polygons of corresponding rain gauge stations.

METHODOLOGY

In order to investigate the monsoon rainfall variability, the descriptive statistics analysis was carried out. With the use of parameters of central tendency and dispersion, the coefficients of variability for individual station were derived. For better understanding of spatial variations in average rainfall and rainfall variability, maps were prepared in Arc-GIS software. Apart from this, the *student t test* and *Mann-whitney* tests were applied to understand the unevenness in spatial distribution of rainfall. In order to compare the monsoon rainfall between the selected stations, the precipitation data were standardized by the simple *Z-score* technique(Pant and Rupa Kumar, 1997; Bhutiyani et al., 2007).

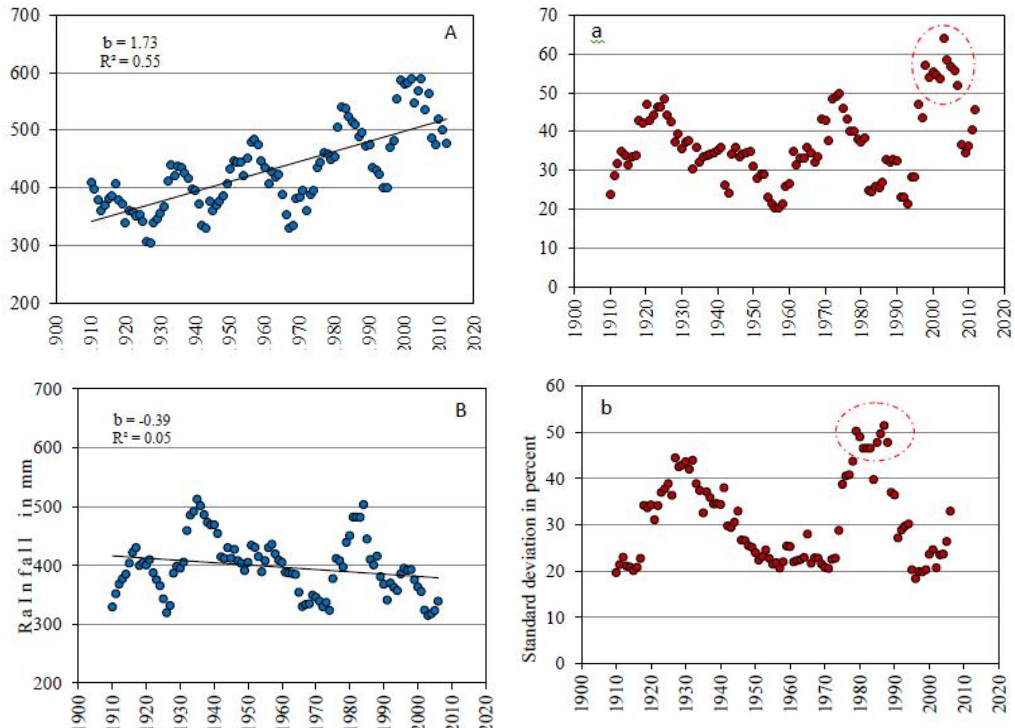
Parametric and non-parametric statistical methods such as linear regression, Mann-Kandall and Spearman's Rho were used for trend analysis. To evaluate the stationwise change in rainfall during last century, the slope parameter (rate of change) of linear regression and/or Sen's slope estimator were multiplied by 100. Inter decadal rate of change in rainfall at Baramati, Sasvad and Jejuri were computed with linear regression method. Since, from late 1970s, may be due to global warming, rainfall and other climatic variables fluctuates significantly (Dai and Trenberth, 1998; 2004; Nagrajan, 2009), hence, to identify the year of change (step change) in precipitation during 20th century, the parametric and non-parametric techniques such as Distribution-free CUSUM, Cumulative deviation, Worsley Likelihood Ratio were used. For the confirmation of the same results, the Rank Sum and the Student's t test were applied.

In order to estimate the assured availability of monsoon rainfall and Nazare dam storage, the Gamma (with two parameters) and Weibull probability distribution were fitted to the rainfall and dam storage data respectively. In this viewpoint, both the hydro-meteorological variables at 75-percent probability of exceedence were considered as assured amount.

Table 2. Results of trend analysis for rainfall and dam storage in the Karha Basin.

Test Name	Baramati	Jejuri	Malshiras	Sasvad	Katraj	Karha Basin	Dam Catchment	Dam storage
	Linear trend							
Mann-Kendall	+*	—	+	+*	+	+	—	+
Spearman's Rho	+*	—	+	+*	+	+	—	+
Linear regression	+*	—	+*	+*	+	+	+	+

change during 100 years (in mm)	157*	-27	278*	249*	60	271	105	
	Year of change							
Cusum	1972	1926	1988	1949*	1987	1987	2003	2004
Cumulative deviation	1972*	1981	2003	1986*	2004	2003	2004	2004
Worsley likelihood	1972*	1981	2003	2004	2004	2004	2003*	2004*
	Verified year of change							
Step-jump year	1972*	1981	1987*	1986*	1988	1987	2003*	2004*
Rank Sum	+*	–	+*	+*	+	+	+	+
Student's t	+*	–	+*	+*	+	+	+	+



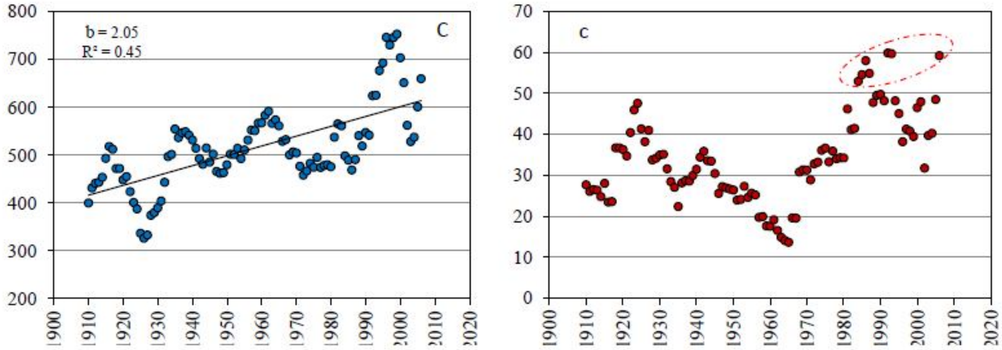


Fig. 2 A, B and C temporal variations in ten-year moving average rainfall at Baramati, Jejuri and Sasvad. a, b and c ten-year moving standard deviation of rainfall at Baramati, Jejuri and Sasvad.

DISCUSSION OF RESULTS:

Although Pune District as whole has rainfall variability about 25 percent, at micro scale of Karha Basin, it is observed in between 30 and 50 percent (Fig. 3). Even though, the rainfall amount is decreasing from source to mouth in river basin, there is an absence of systematic pattern in rainfall variability. Interestingly, since, Katraj with 835 mm and Jejuri with 398 mm monsoon rainfall reveal least (about 35 %) rainfall variability, the rainfall amount does not have influence on the variability. May be due to proximity to the Western-Ghat, Katraj station receives highest amount of monsoon rainfall. The rainfall variability at Baramati and Sasvad is observed in between 42 and 46 percent. The highest rainfall variability is observed at Malshiras station, which is about 51 percent. In addition to this, Table 1 shows that within a moderate area of Karha Basin, the degree of association weakening with the distance between the stations, which indicate high spatial variability in rainfall. Apart from this, the same outcome is supported from the results of student t test, all the stations except Jejuri reveals significant difference in a monsoon rainfall data. Figure 4 demonstrates that within a river basin, rainfall and dam storage at the upper rich (Nazare Dam catchment) mimics the rainfall variability pattern of the entire Karha Basin.

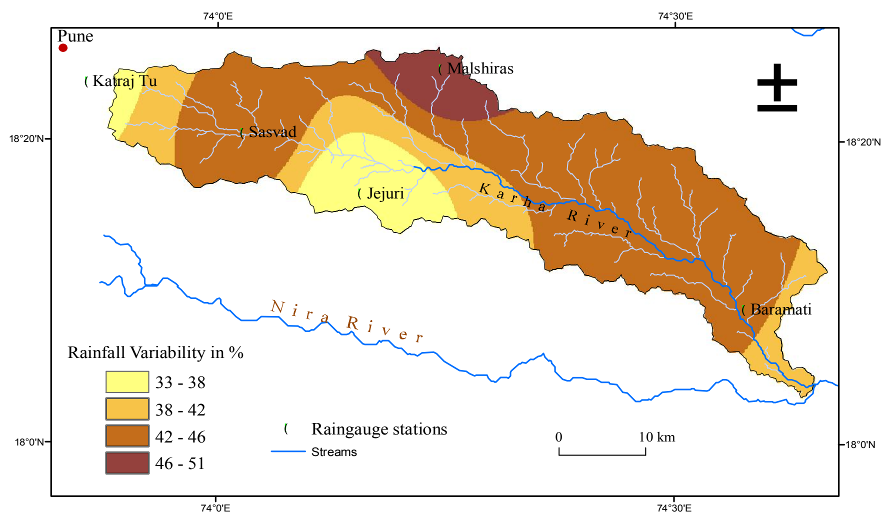


Fig.3 Spatial variability in monsoon rainfall in Karha Basin

The monthly variability and month wise rainfall regime in Karha Basin. About 85 percent of annual rainfall is received during monsoon season. Since the variability of rainfall during monsoon period is marginal (less than 100 %), the assurance of rainfall is more during this period of year. During the pre-monsoon season (January to May), the rainfall amount is very scanty and uncertain. Hence, the rainfall variability in these months is very high which ranges between 100 and 400 percent. Month of September is contributing highest amount of rainfall which is about 130 mm. followed by June (110 mm). In case of rainfall variability, February month showing the maximum variability which is >400 percent followed by January, December and March those have rainfall variability 304, 293 and 231 percent respectively. Since, Sasvad gauging station covers large area of Nazare Dam catchment, it predominantly determines the variations in dam storage volume. The dam storage in the years like 1985, 1986, 2000, 2002 and 2003 exhibit the noteworthy harmony with El~Nino events, therefore for the same years all the stations reveals a decrease in a rainfall amount.

Table 3. Details of daily rain gauge sites and catchment.

	Baramati	Malshiras	Jejuri	Sasvad	Katraj Tunnel
Baramati		0.00	0.12	0.21*	0.14
Malshiras	3.56*		0.23*	0.44*	0.33*
Jejuri	1.55	3.25*		0.07	0.00
Sasvad	-1.93*	5.47*	-3.78*		0.20*
Katraj Tunnel	-10.81*	9.32*	-12.79*	-8.87*	

Figure above and below the diagonal axis are the results of correlation and student's t test respectively, * = statistically significant result at 0.05 level.

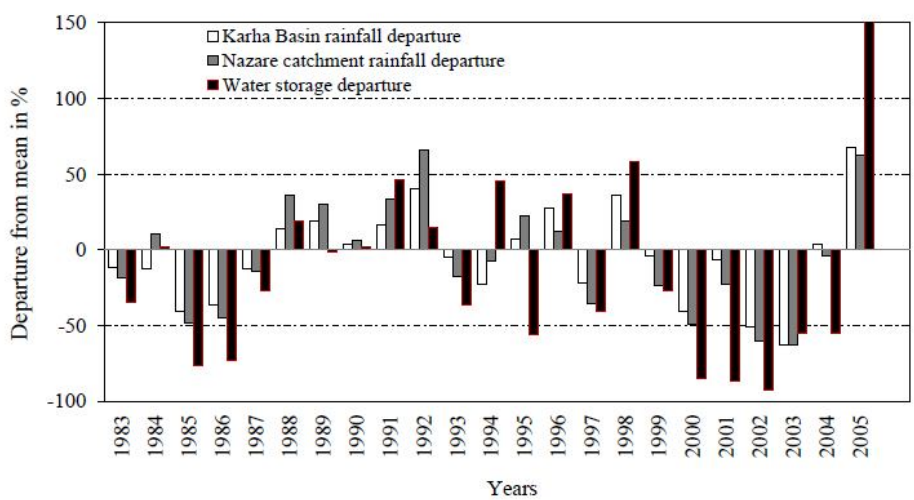


Fig. 4 Percentage departure of monsoon rainfall and dam storage from corresponding mean.

on catchment monsoon rainfall, there is significant connection between the both. Interestingly negative departure of monsoon average catchment rainfall resulting even higher negative departure in dam storage, the same fact was observed in 1983,1985, 1986, 1993, 1997, 1999, 2000, 2001, 2002 and 2004. It may be caused due to increase in hydrological losses with decrease in rainfall. It is seen that during 1985, 1986, 1987 and from 1999 to 2004 both the catchment average rainfall and the dam storage were significantly less than the corresponding mean. It is clear from the flow duration curve for the dam storage and average monsoon rainfall that although > 3000 MCFT (million cubic feet) water can be available at Nazare Dam it has very less probability that is < 10 percent. With the 50 percent probability that is median value, about 1200 MCFT water can be available at dam site. Since 75 percentile is considered as an assured, it is observed about 670 MCFT, which is less than the storage capacity of a dam by about 100 MCFT. In case of monsoon rainfall, 530 mm is observed to be a central value. In a Nazare Dam Catchment, about 432 mm rainfall with 75 percentile is observed as an assured monsoon rainfall.

CONCLUSIONS:

The following conclusions can be drawn from this study:

1. In Nazare Dam Catchment, about 85 percent of annual rainfall is received during June to October.
2. In the catchment from West to East monsoon rainfall amount and variability are decreasing toward Jejuri.
3. Although there is an absence of systematic temporal pattern in monsoon rainfall, it has good connection with El-Nino events.
4. Decrease in monsoon rainfall resulting more decrease in dam storage than expected proportional decline.
5. Assured water can be available at Nazare Dam site is about 678 MCFT and from assured monsoon rainfall, the same catchment can receive about 432 mm rainfall.

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