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IMPACT OF EL NIÑO SOUTHERN OSCILLATION ON SUMMER MONSOON RAINFALL IN BHIMA BASIN, CENTRAL INDIA

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The study of the effects of ENSO on summer monsoon rainfall (SMR) was carried in the Bhima River basin located in Central India. Gridded $1^{\circ} \times 1^{\circ}$ resolution daily rainfall data (1901-2004) and ENSO indices data (SOI, MEI and Niño 3.4) were used in this study. Analysis show that the SMR is significantly correlated with monsoonal ENSO indices at most of the grids. SMR is positively correlated with SOI index whereas negatively correlated with MEI and N3.4 indices. ENSO phase wise analysis shows that a strong/weak SMR is associated with La Niña phase/El Niño phase except for the grids that are located on higher elevation in Western Ghats. Overall on an average 15.02% more rainfall has been received during La Niña phases and 9.50% less in El Niño phases in the basin during summer monsoon season.

KEYWORD: ENSO, El Niño, La Niña, SOI, MEI and N3.4, Monsoon Rainfall

INTRODUCTION

The El Niño Southern Oscillation (ENSO) phenomenon is a natural part of global climate system resulting from the interaction between large-scale oceans atmospheric circulation processes in the equatorial Pacific [1]. ENSO refers to variations in the temperature of the surface of the tropical eastern Pacific Ocean (El Niño and La Niña) and in air surface pressure in the tropical western Pacific Ocean. The two variations are coupled: the warm oceanic phase, El Niño, accompanies high air surface pressure in the western pacific, while the cold phase and La Niña accompanies low air surface pressure in the western pacific.

In the 1920s, Sir Gilbert Walker first thought of the significance of the Southern Oscillation when he described, ‘A swaying of pressure backwards and forwards between the Pacific Ocean and Indian Ocean.’ The story of the understanding of El Niño begins in India, where Sir Gilbert Walker studies the variability in the monsoon rainfall. By correlating surface pressures over the Pacific with those in India, Walker discovers a pattern which he calls the Southern Oscillation. The mean surface winds over the equatorial Pacific, the trade winds, blow from east to west and are driven by an area of average high pressure in the eastern part of the Pacific and a low pressure area over Indonesia. The Southern Oscillation consists of an irregular strengthening and weakening of the trade winds, related to the changes in surface pressure.

El Niño and La Niña occurrences are commonly known to be linked with extreme climate around the globe [2] [3] [4] [5] [6]. The extremes of this climate pattern's oscillations cause extreme weather (such as floods and droughts) in many regions of the world. Severe floods and droughts associated with ENSO occur in different parts of the world

negatively affecting important economic activities of many countries such as, agriculture, hydrology, and tourism. During La Niña years, the formation of tropical cyclones, along with the subtropical ridge position, shifts westward across the western Pacific ocean, which increases the landfall threat to China. In March 2008, La Niña caused a drop in sea surface temperatures over Southeast Asia by 2°C. It also caused heavy rains over Malaysia, the Philippines, and Indonesia. The ENSO phenomenon is the dominant feature of inter-annual variability in the climate system [7]. One of its most important effects is those related with changes in precipitation patterns. Seasonal prediction of the Asian Summer monsoon is a key goal of weather and climate forecasters, the phenomenon being of great importance to agrarian societies.

Indian rainfall variability is the end product of a series of complex interaction between ocean and atmospheric phenomenon. Currently, a strong emphasis is on to study the association between Indian climate and ENSO especially considering India as an agrarian economy [8]. Indian monsoon rainfall negatively correlated with ENSO in which a weak (strong) monsoon is related to a warm (cold) event [9]. These signals have weakened rapidly since the late 1970s 1992 [10]. The inter-annual variability (IAV) of Indian summer monsoon (ISM) is anti-correlated with ENSO [11] [12]. The aim of the study was investigate if any is there a correlation in between summer monsoon rainfall (SMR) and ENSO and to analyze the impact of ENSO phases on occurrence of SMR on the basin scale in the Central India.

MATERIAL AND METHODS

Study Area and Data

The Bhima River is a major river in southern India. It flows for 861 km through Maharashtra, Karnataka, and Andhra Pradesh states, before joining the Krishna River. Bhima River is the second largest sub-catchment in the Krishna basin and lies in between 73° 18' 26.64''E to 77° 56' 22.825'' E longitude and 16° 24' 55.619''N to 19° 25' 26.64''N latitude, covering an area of 70,614 km² (Figure 1). Running north-south on the western side of Maharashtra is the Sahyadri Range (known as the “Western Ghats”) with an average elevation of 1,000 m. This range quickly transitions through the Mawal area before it flattens out into the Deccan Plateau. Stream-flows in the catchment are generated predominantly in the Western Ghats.

The catchment has a highly diverse climate mainly caused by the interaction between the monsoon and the Western Ghats mountain range. The mean annual rainfall of the catchment is 642 mm and is unevenly distributed. It is an important catchment in the context of serving inter-sectorial demands including drinking and agricultural water supply, where agriculture has been a mainstay in Maharashtra’s economy, and hydropower generation (363 MW).

The high-resolution 1×1 degree latitude/longitude gridded daily rainfall data (1901-2004) of India is obtained from Indian Meteorological Department (IMD). Bhima basin is covered in 14 grids (Figure 1). Three ENSO indices data namely; Southern Oscillation Index (SOI), Multivariate ENSO Index (MEI), and Niño 3.4 (N3.4) are extracted from National Oceanic and Atmospheric Administration (NOAA).

SOI is the standardized anomaly of monthly Mean Sea Level Pressure (MSLP) differences; measured at Papeete, Tahiti (149.6W, 17.5S) and Darwin, Australia (139.9E, 12.4S). MEI is based on six parameters observed over the tropical pacific. These six parameters are: sea-level pressure (P), zonal (U), and meridional (V) component of the surface wind, sea surface temperature (S), surface air temperature (A) and the total cloudiness fraction of the sky

(C). Niño 3.4 representing the averaged Sea Surface Temperature (SST) anomalies over the equatorial central Pacific box (5N-5S, 120W-170W).

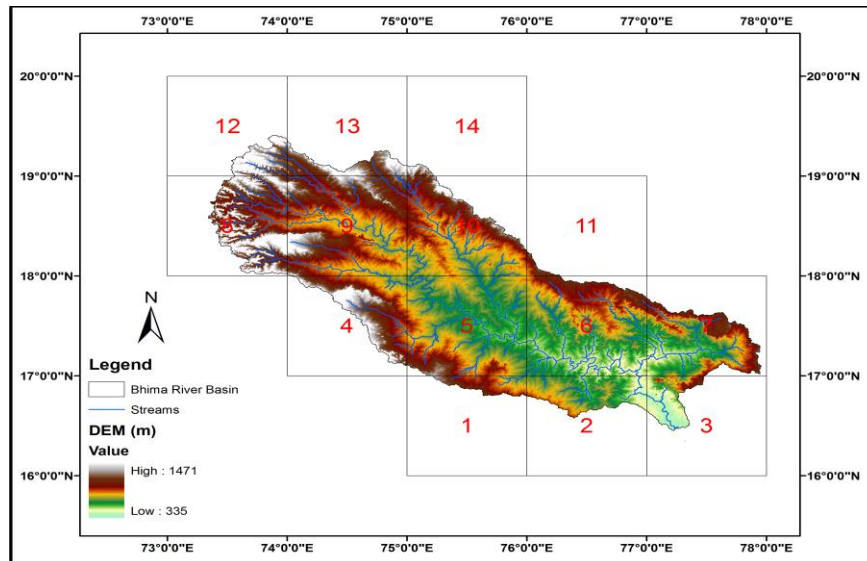


Figure 1. Location of Grids on Bhima River Basin

METHODOLOGY

Step-by step methodology used to carry out the analysis is given below:

1. The daily rainfall data for 14 grids ($1^0 \times 1^0$) which covers the whole Bhima Basin was extracted for the period of 1901-2004 from gridded rainfall data of India.
2. Monthly SMR (June, July, August and September) series were derived from daily rainfall data to match the time scale of ENSO indices. The rainfall series were then normalized using the mean and standard deviation of the series, because the ENSO indices are in normalized data. Also area weighted method was used to prepare the SMR for the whole basin.
3. Seasonal mean indices namely; summer (FMAM), monsoon (JJAS) and winter (ONDI) were computed using ENSO indices data.
4. Pearson's correlation coefficients, r , were computed using normalized SMR and seasonal ENSO indices (SOI, MEI and N3.4) data to study the relationships between summer monsoon rainfall and ENSO. The t-statistics was used to find the statistical significance of 'r' at 5% significance level..
5. Each of the three SMR, as described above, was further divided into three sub series corresponding to La Niña, Neutral and El Niño events to investigate changes in SMR during these phases on the basis of SOI index.
6. The parametric ANOVA ($H_0: \mu_{La\ Niña} = \mu_{Neutral} = \mu_{El\ Niño}$ i.e. population means are homogeneous; $H_1: \mu_{La\ Niña} \neq \mu_{Neutral} \neq \mu_{El\ Niño}$ i.e. population means are heterogeneous) was used to test the hypothesis if there is any difference among the monsoon rainfalls occurred during the three different ENSO phases.
7. Percentage change in SMR occurred in La Niña/ El Niño phase was calculated with respect to the SMR of neutral/normal phase.

RESULTS

Correlation analysis between SMR and Seasonal ENSO Indices

The results of the correlation analysis (Pearson's Correlation Coefficient) between SMR and seasonal ENSO indices; SOI, MEI and N3.4 are shown in Figure 2 (a-c), respectively. Correlation of ENSO indices increases from winter season to monsoon season of indices. That means the correlation weakens the prior and after the onset of summer monsoon season. Only the SMR of most of the grids shows significant correlation with monsoon season of indices (Table 1) at 5% significance level. Only grid eight is not-significantly correlated with monsoonal SOI index. Also grids #4, #8 and #9 are not showing significant correlation with MEI and N3.4. SMR is positively correlated to SOI and negatively MEI, N3.4. Overall, SMR of basin shows the significant correlation with all indices at 5% significance level. The higher percentage of SMR variability is explained by SOI (21.41 at grid 10) followed by N3.4 (21.36 at grid #11) and MEI (17.49 at grid #7).

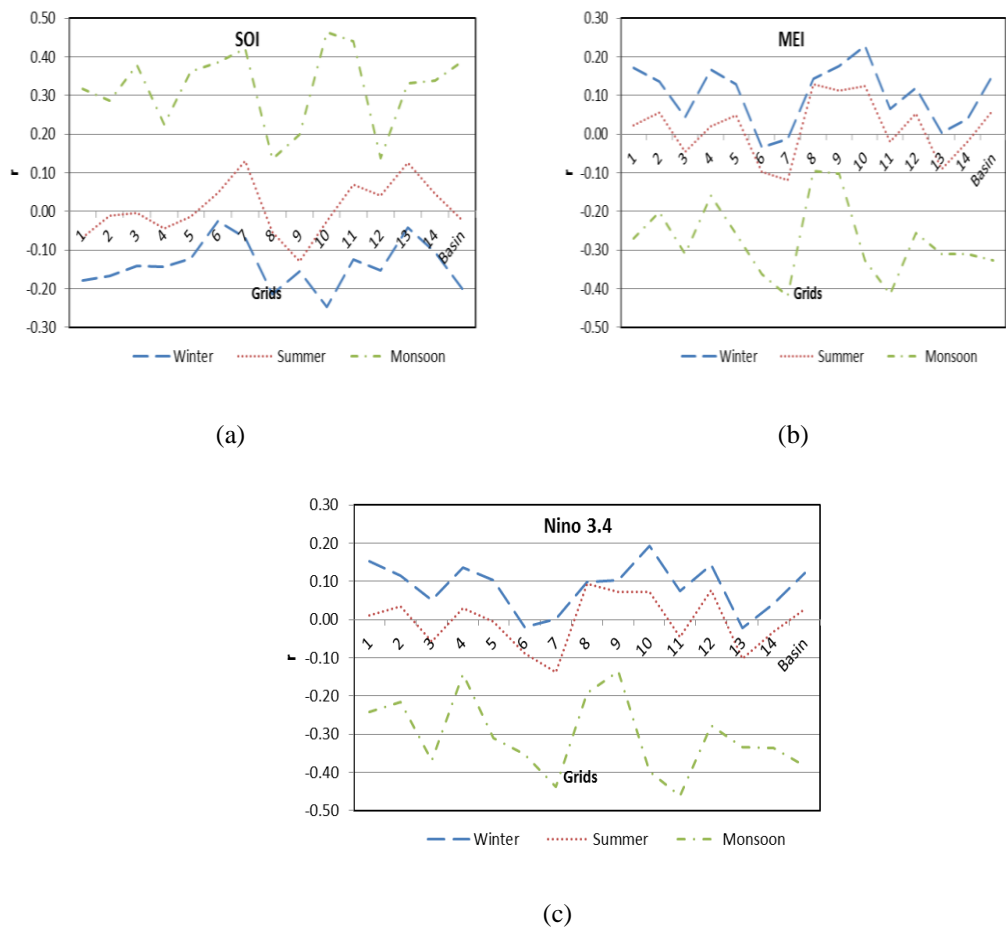


Figure 2: Pearson's Correlation Coefficients between SMR and Seasonal ENSO indices at each grid and at whole Bhima basin

Table 1. Pearson's Correlation and variance explained by ENSO indices

Indices	SOI			MEI			N3.4		
	r	t	Var	r	t	Var	r	t	Var
1	0.32	3.38	10.08	-0.27	2.83	7.27	-0.24	2.42	5.80
2	0.29	3.02	8.23	-0.20	2.07	4.02	-0.22	2.16	4.67
3	0.38	4.13	14.31	-0.31	3.28	9.55	-0.37	3.88	13.65
4	0.23	2.34	5.09	-0.16	1.62*	2.51	-0.14	1.41*	2.05
5	0.36	3.93	13.15	-0.26	2.71	6.72	-0.31	3.17	9.55
6	0.39	4.22	14.87	-0.36	3.91	13.05	-0.35	3.68	12.49
7	0.42	4.70	17.80	-0.42	4.65	17.49	-0.44	4.73	19.07
8	0.14	1.39*	1.86	-0.10	0.97*	0.92	-0.19	1.91*	3.70
9	0.20	2.05	3.95	-0.10	1.04*	1.06	-0.13	1.32*	1.80
10	0.46	5.27	21.41	-0.33	3.49	10.66	-0.40	4.21	15.72
11	0.44	4.96	19.43	-0.41	4.61	17.22	-0.46	5.08	21.36
12	0.14	1.41*	1.91	-0.26	2.66	6.51	-0.28	2.82	7.70
13	0.33	3.54	10.92	-0.31	3.30	9.63	-0.33	3.46	11.20
14	0.34	3.63	11.45	-0.31	3.28	9.57	-0.34	3.47	11.23
Basin	0.39	4.26	15.09	-0.33	3.49	10.65	-0.38	4.04	14.64
*indicates the non-significance of r at 5% significance level									

Impact of ENSO Phases on SMR

The SMR series of each grid and basin were divided into three sub-series according to ENSO phases (La Niña phase, Neutral phase and El Niño phase) and the mean of the SMR of each phase was calculated for each grid and for the whole basin (Figure 3). The analysis shows that the rainfall occurred during the La Niña/El Niño phase is above/below the normal SMR at each grid points and basin too. It implies that the SMR occurred in La Niña phase is more than the SMR occurred in El Niño phase. Figure 4 shows SMR occurred in three different ENSO phases with indication of ENSO events at Grid #1.

Homogeneity analysis of means of SMR during ENSO phases was carried out using ANOVA. The F statistics of ANOVA test are given in Table 2. Alternate hypothesis is accepted at 5% significance level for all grids and basin too except grids #8 and #12. Percentage change in mean of SMR was calculated during La Niña and El Niño phases with respect to mean of SMR and shown in Figure 5. It shows that the percentage change in SMR during La Niña is greater than the SMR of El Niño phase. That means the rainfall occurred in the cold phase/warm is increases/decreases than the neutral SMR. It is clearly seen that overall on an average 15.02% more rainfall has been received in La Niña phase and 9.50% less in El Niño phase in the basin during summer monsoon season

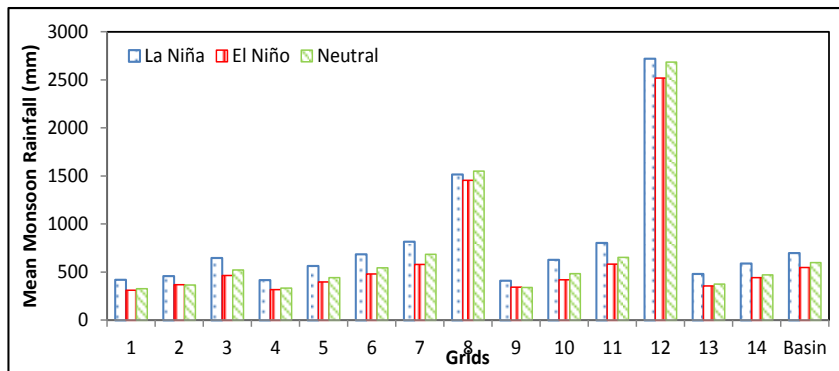


Figure 3. Mean Monsoon Rainfall in La Niña and El Niño phases at Each Grid

Table 2. Homogeneity analysis of means of SMR during ENSO phases using ANOVA

Grids	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Basin
F-statistics	8.77	7.304	13.599	5.62	10.153	10.937	11.619	0.606*	2.939	12.605	11.786	1.161*	7.344	7.704	11.592

* indicates acceptance of null hypothesis at 5% significance level

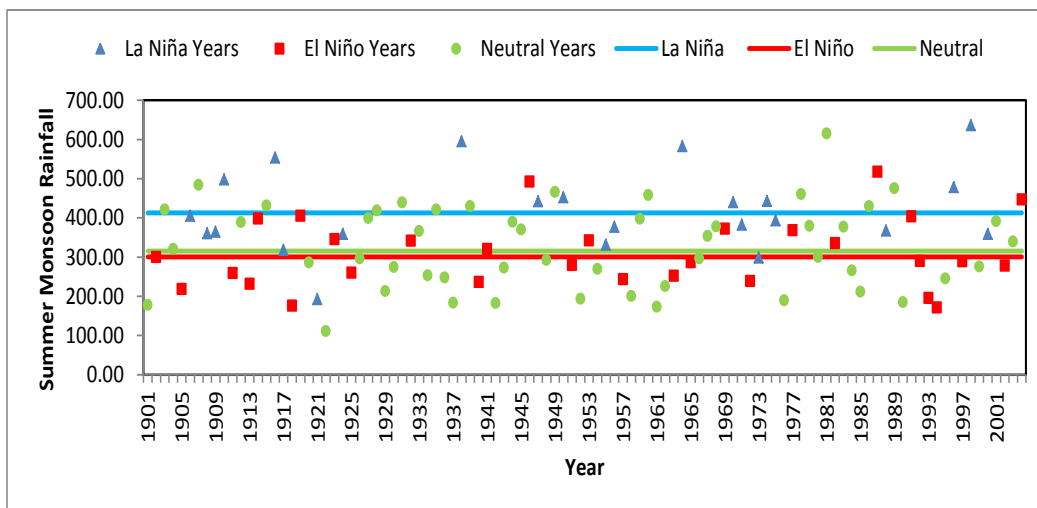


Figure 4. SMR during La Niña, neutral and El Niño phases at Grid 1.

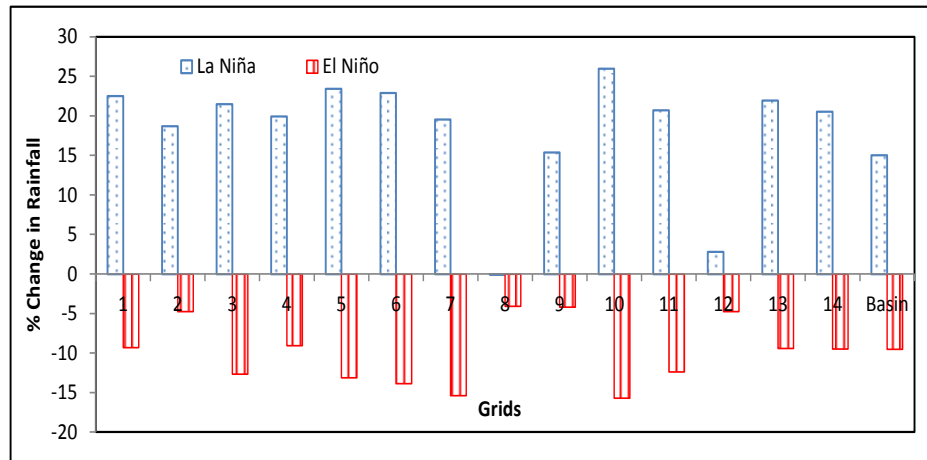


Figure 5. Percentage change in mean SRM during La Niña and El Niño phases

CONCLUSIONS

The major conclusions of this study drawn from the analysis of summer monsoon rainfall and ENSO indices are enumerated below:

- 1) The only SMR shows significant correlation with the monsoonal ENSO indices at most of the grid points. That is the correlation weakens the prior and after the onset of summer monsoon season.
- 2) Overall, SMR of basin shows the significant correlation with all indices at 5% significance level.
- 3) The SMR shows significant positive correlation with the monsoonal SOI and negative with N3.4 and MEI.
- 4) The higher percentage of SMR variability is explained by SOI (21.41 at grid #10) followed by N3.4 (21.36 at grid #11) and MEI (17.49 at grid #7).
- 5) The ANOVA tests implies that the mean of SRM during the three ENSO phases are significantly different from each other at most of the grids and for whole basin too except grid #8 and #12.
- 6) SMR occurred during the La Niña/El Niño phase is usually higher/lower than the neutral phase.
- 7) It is clearly seen that overall on an average 15.02% more rainfall has been received in La Niña phase and 9.50% less in El Niño phase in the basin during summer monsoon season.
- 8) Overall the strong/weak SMR is associated with La Niña/ El Niño respectively.

Overall, the analysis shows that ENSO has bearing on summer monsoon rainfall in the basin. It underline the need that ENSO which a natural climate variability in the global climate system, should be considered duly in the climate change studies attributing to human activities. The paper also put forward the need to study stream flows during ENSO phases from irrigation water availability point of view.

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