

Studies on hydrological extremes—ENSO signal

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Abstract The Krishna River basin is one of the major river systems of south India. Its hydrological regime is studied using a season climate concept based on a water balance model. Proneness to humid and drought events along with frequency distributions of climate types for selected stations of the river basin are reported. The statistical correlation of the river discharge with the Southern Oscillation Index (SOI) and Sea Surface Temperature (SST) of the Niño3 region of the equatorial Pacific Ocean is also analysed.

INTRODUCTION

Aberrations of the hydrological regime of landscapes of the world in response to the ENSO (El Niño Southern Oscillation) short term climate signal should be appraised. It is worth mention here that the work of Simpson & Cane (1993) on ENSO related impacts on annual river discharge in southeast Australia. The ENSO might be modulating the equatorial regions, tropical as well as extra-tropical, with impacts on economy and society. It is a widely accepted theory that the present global warming phase is modulating the ENSO signal, which in turn is influencing the timing, intensity and frequency of extreme hydrological events such as floods and droughts (Shukla, 1991, 1998). Fingerprints are already traced globally on societies. An attempt has been made in the present investigation to understand the variations in river flows of the Krishna River basin at Vijayawada in relation to the ENSO signal. The seasonal effectivity of moisture in its climate spectrum during the principal rainy season (southwest monsoon period) is studied following the revised water balance concept of Thornthwaite & Mather (1955). In determining the climate type of the stations and in delineating the climate zonation of the Krishna River basin, the revised expression of the moisture index and the revised climate limits of Carter & Mather (1966) are followed. The spatial variation in the hydrological regime during the southwest monsoon period is analysed by selecting two stations from the perhumid zone (Mahabaleswar and Belgaum), five from the dry subhumid zone (Pune, Hyderabad, Raichur, Kurnool and Chitradurg) and one from the semiarid zone (Bellary), according to the moisture zonation of the river basin. The humidity and aridity indices on a seasonal basis are obtained from the revised water budgeting procedure as suggested by Sarma (1982) and Sarma & Ravindranath (1986) in an attempt to study the fluctuations in the seasonal effectivity of moisture in the moist and dry climates of the river basin. The simple reason is that the magnitude and the variation of water deficit and water surplus are very small in the respective moist and dry climates.

MATERIALS AND METHODS

Percentage departures from the respective median value of the humidity and aridity indices for the monsoon period on a yearly basis are obtained to describe the severity of humid and drought events. In determining the various categories of humid and drought events, the standard deviation (σ) of yearly indices is used as follows:

Classification of humid years		Classification of drought years	
$<\sigma$	Moderate humid year	$<1/2\sigma$	Slight drought
$>\sigma$	Very humid year	$1/2\sigma$ to σ	Moderate drought
$>2\sigma$	High humid year	σ to 2σ	Severe drought
		$>2\sigma$	Very severe drought

Proneness to humid and drought events of varied intensity at a station is obtained by expressing the corresponding number of the category of events as a percentage of the total study period.

The frequency distribution of climate types is also obtained by expressing the number of occasions of a particular type recorded by the station as a percentage of the total number of years studied.

The Krishna River discharge at Vijayawada is correlated with the mean annual Southern Oscillation Index (SOI) and Equatorial SST anomaly time series of the Niño3 region using Wright index values for September, October and November (Wright, 1989), and corresponding regression equations are subsequently obtained.

DISCUSSION AND RESULTS

Prevalence of humid and drought events

Figures 1 and 2 depict the occurrence of seasonal events of humidity and aridity, respectively, during the principal rainy period in the moist and dry climate provinces of the Krishna River basin. The fluctuations in humidity index at Belgaum (Fig. 1(b)) are small compared to Mahabaleswar (Fig. 1(a)), while the variations in aridity are maximum at Hyderabad compared to Bellary (Fig. 2).

The yearly fluctuations in seasonal effectivity of moisture are higher in dry climate zones (Fig. 2) compared to moist ones (Fig. 1) (for space considerations the diagrams for the remaining stations are not presented). Tables 1 and 2 represent the statistic of proneness of humid and drought years at selected stations in the Krishna River basin. The percentage frequency of the occurrence of moderate humid years is high at perhumid climate compared to very humid and high humid years (Table 1). The total frequency of humid years is 50% at Mahabaleswar, whereas it is 48.2% at Belgaum (Table 1). Chitradurg that enjoys the dry subhumid status during the principal rainy season has recorded a frequency of 17.5% for moderate droughts, while Bellary represents semiarid status during June to September has experienced the maximum frequency (21.2%) of slight droughts. Pune, Raichur, and Kurnool have recorded very severe droughts with a frequency of 4%.

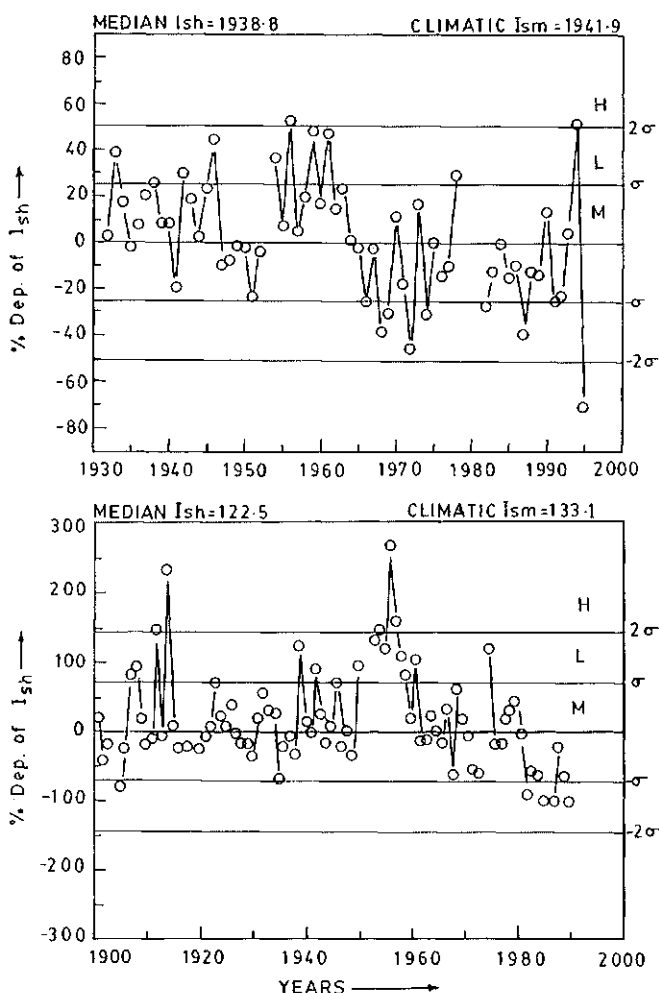


Fig. 1 Seasonal humidity index—perhumid zone: (a) Mahabaleswar, and (b) Belgaum.

Stability of hydrological regime

Among the eight stations that are selected from the varied geographical settings of Krishna River basin, Mahabaleswar is the only one that maintained the perhumid status all the time during the principal rainy season (Table 3). A station's regime is considered stable if it experiences a particular climatic type with a frequency equal to or greater than 70%. None of the remaining stations could register a stable nature in their moisture regime. The other selected stations have recorded more than one climate type. The frequency distribution of climate types from perhumid to arid is mainly dependent on the spatio-temporal aspects of the monsoon-like weather which, apart from other factors, in turn might be influenced by the climate related teleconnections of the world climate system. Belgaum season climate is subdominant in perhumid with a frequency of 68.2%. At Hyderabad and Bellary, C₁ (dry subhumid) and D (semiarid) climate types are subdominant with a frequency of 62.5 and 62.6%, respectively.

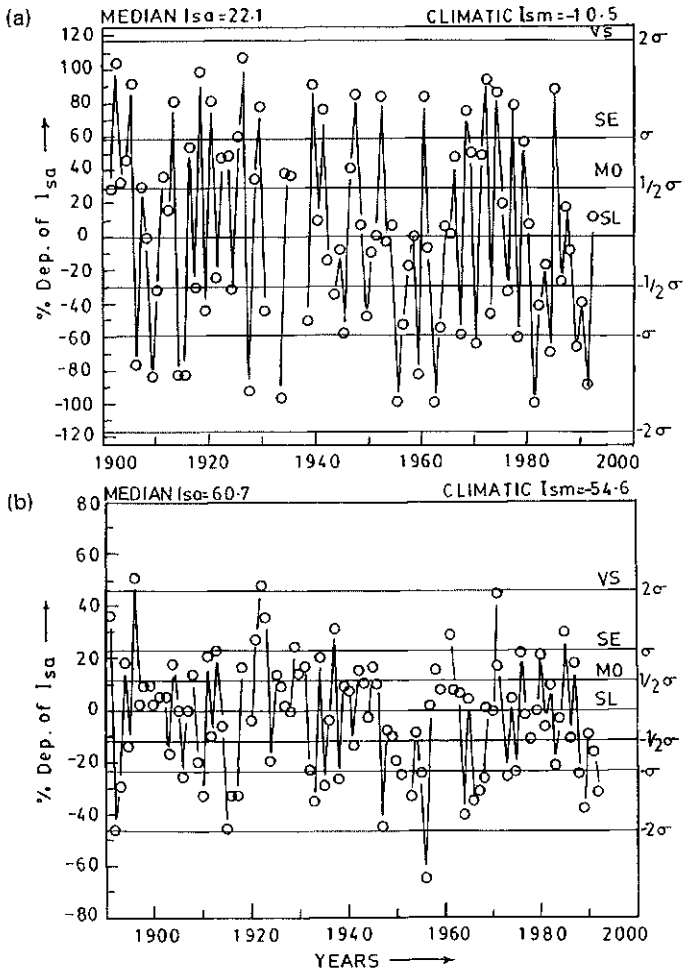


Fig. 2 Seasonal aridity index—dry subhumid zone: (a) Hyderabad, and (b) Bellary.

Table 1 Proneness to humid years in percentage—southwest monsoon season.

Station	Moisture status	Moderate	Very humid	High	Total
Mahabaleswar	A	33.3	13.3	3.3	50
Belgaum	A	28.2	14.1	5.8	48.2

Table 3 clearly shows that the hydrological regime of the Krishna River basin is not constant at most of the stations but oscillates. The presence of perhumid status at Raichur and Chitradurg indicates that even subhumid zone (Table 3) can lodge them under extremely good conditions of southwest monsoon.

In Table 4 the basic water budget elements at some of the selected stations are presented for extreme shifts of the southwest monsoon compared to normal situations. The perhumid climate zone of Krishna River basin recorded during extreme wet years

Table 2 Proneness to droughts in percentage—southwest monsoon season.

Station	Moisture status	Slight	Moderate	Severe	Very severe	Total
Pune	C ₁	19.2	14.4	12.5	3.8	50
Hyderabad	C ₁	12.5	17.0	20.4	-	50
Raichur	C ₁	12.0	15.3	16.4	4.3	48.3
Kurnool	C ₁	15.5	08.8	21.1	4.4	50
Chitradurg	C ₁	18.6	17.5	12.0	1.0	49.4
Bellary	D	21.2	17.1	08.1	2.0	48.4

Table 3 Frequency distribution of climate types for the Krishna River basin—monsoon period.

Station	A	B ₄	B ₃	B ₂	B ₁	C ₂	C ₁	D	E
Mahabaleswar	100	-	-	-	-	-	-	-	-
Belgaum	68.2	14.1	2.3	7	1.1	2.3	4.7	-	-
Punc	-	-	0.9	1.9	6.7	15.3	57.6	17.3	-
Hyderabad	-	-	-	3.4	4.5	9.0	62.5	20.4	-
Kurnool	-	-	-	-	2.2	2.2	45.5	47.7	2.2
Raichur	1.0	-	-	-	-	10.9	49.4	36.2	2.1
Chitradurg	1.0	-	-	-	-	1.0	36.2	58.2	3.2
Bellary	-	-	-	-	-	-	5.0	62.6	32.3

(A) Perhumid; (B₄) Fourth humid; (B₃) Third humid; (B₂) Second humid; (B₁) First humid; (C₂) Moist subhumid; (C₁) Dry subhumid; (D) Semiarid; (E) Arid.

produced increased water surplus by nearly one and a half times or three times compared to normal (Table 4). Some of these stations, during weak or poor monsoonish weather conditions, experienced diminished water surplus by nearly three and half times in the case of Mahabaleswar and even to zero at Belgaum. During extreme wet years the water surplus of the dry subhumid zone of the basin showed increased values from zero to a couple of hundreds or to a maximum of 1067 mm in the case of Chitradurg. Bellary with a semiarid status could register an increased water surplus of 24 mm from normal zero during an extreme shift of the southwest monsoon to the moister side. On the other hand, when monsoonish weather is tilting to the dry side, the water deficit of the stations are elevated from their normal level to a couple or several hundreds of mm (Table 4), and thereby the main moisture regime is changed to extreme dryness.

Regional hydrological regime in relation to ENSO signal

The historic mean flow of the Krishna River at Vijayawada point is $1533 \text{ m}^3 \text{ s}^{-1}$. The mean of the 1901–1946 period is $1698 \text{ m}^3 \text{ s}^{-1}$, while the mean for the 1947–1995 period is $1370 \text{ m}^3 \text{ s}^{-1}$ and the trend is negative with a slope of $165 \text{ m}^3 \text{ s}^{-1} \text{ year}^{-1}$. The mean flow of the second half of the period is less than, not only the historic, but also the first half, and this indicates a decreased flow in the latter half of the period that might be due to decreased monsoonish activity which in turn is modulated by the increased frequency of warm phase ENSO events.

Table 4 Water budget elements (mm) in extreme shifts for the Krishna River basin.

Station	Category of the year	Rainfall	Water need	Water deficit	Water surplus	Main climate
Mahabaleswar	Normal	5493	262	0	5088	1941.9 (A)
	Wet 1956	7307	239	0	7068	2957.3 (A)
	Dry 1995	1986	276	0	1569	568.4 (A)
Belgaum	Normal	1054	389	0	518	133.1 (A)
	Wet 1956	2122	359	0	1618	450.7 (A)
	Dry 1987	454	442	56	0	-12.6 (C ₁)
Pune	Normal	535	511	42	0	-8.2 (C ₁)
	Wet 1907	995	483	29	392	75.1 (B ₃)
	Dry 1904	230	527	297	0	-56.3 (D)
Hyderabad	Normal	576	596	63	0	-10.5 (C ₁)
	Wet 1955	968	539	0	280	51.9 (B ₂)
	Dry 1926	432	641	292	0	-45.5 (D)
Kurnool	Normal	460	653	193	0	-29.5 (C ₁)
	Wet 1964	881	631	78	254	27.8 (B ₁)
	Dry 1922	152	668	516	0	-77.2 (E)
Raichur	Normal	516	623	39	0	-6.2 (C ₁)
	Wet 1981	1392	618	100	725	101 (A)
	Dry 1918	142	644	502	0	-77.9 (E)
Chitradurga	Normal	329	461	142	0	-30.0 (C ₁)
	Wet 1962	1453	463	225	1067	181.8 (A)
	Dry 1918	119	504	379	0	-75.2 (E)
Bellary	Normal	287	633	346	0	-54.6 (D)
	Wet 1956	630	581	124	24	-17.2 (C ₁)
	Dry 1896	54	652	598	0	-91.7 (E)

The abnormal or subnormal increase of sea surface temperature of the eastern tropical Pacific Ocean from time to time, in conjunction with the negative or positive phase of the Southern Oscillation, gives rise to subnormal or abnormal circulation patterns in space and time. Such phenomena might be responsible for causing deficit or excess amounts of rainfall in the selected regions of the world as manifested in the failure of active seasonal rains of the southwest monsoon over India and neighbourhood. An attempt is made here to compare the nature of ENSO with that of river flows of the Krishna basin in south India. Figures 3 and 4 depict the annual variation of discharge of the Krishna River with, respectively, SOI and SST of the Niño3 region (5°N–5°S; 150–90°W) of equatorial Pacific Ocean. The Sea Surface Temperature (SST) anomaly time series used here are those of mean Wright index values for September, October and November (Wright, 1989). It is clear from Figs 3 and 4 that in general the higher discharges are in agreement with the positive phase of SOI and negative SST of the eastern Equatorial Pacific and *vice versa*. The ENSO has two phases, namely cold and warm, and when the southwest monsoon is locked with the cold phase of the ENSO, India and its neighbourhood receive excessive rainfall, while the southwest monsoon generally fails to sustain the normal hydrological regime to India and its neighbourhood, when locked with the warm phase of ENSO (Verma, 1990).

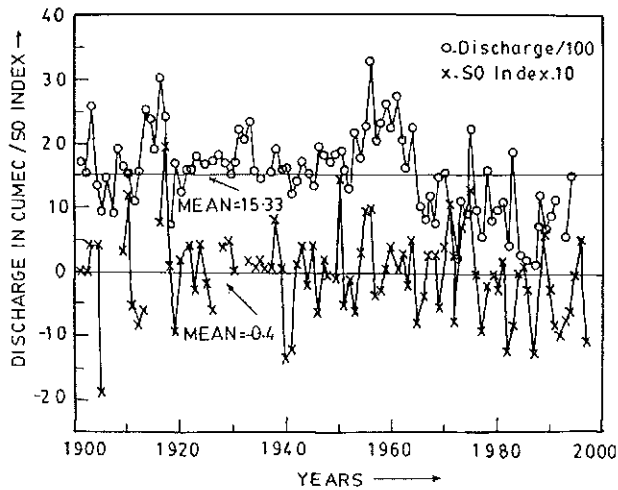


Fig. 3 River flows of Krishna at Vijayawada point and SO index.

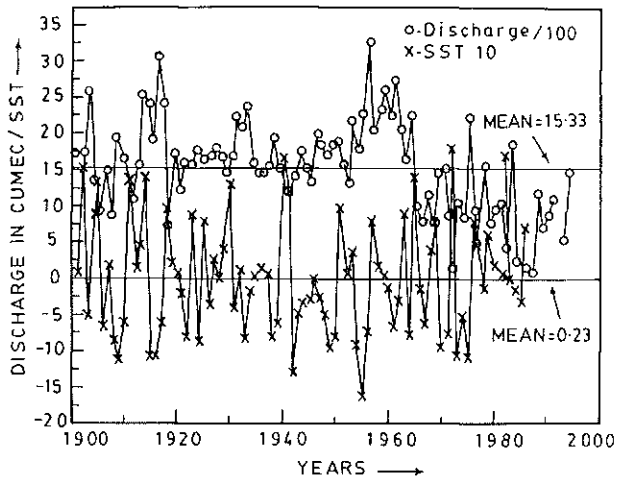


Fig. 4 River flows of Krishna at Vijayawada point and SST.

Statistical correlation of river discharge with atmospheric SOI and SST indices

The correlation coefficient of mean annual river discharge of Krishna River basin at Vijayawada with the SOI and the eastern equatorial sea surface temperature are 0.32 and -0.40 respectively. A multiple regression analysis of annual river flow with SOI and SSTSON (actual mean SST of September, October and November) yielded clearer results indicating coupled ocean-atmosphere impacts on teleconnected phenomena (Table 5) resulting in either increased or decreased river flow.

Table 5 Linear regression analysis of rainfall with SOI and SST.

Variables	<i>r</i>	Regression equation
$\bar{Q}/100, \text{SOI} \times 10$	0.3208	Discharge = 15.5742 + 0.3136 × SOI.10
$\bar{Q}/100, \text{SSTSON} \times 10$	0.4087	Discharge = 15.7633 – 0.3258 × SSTSON.10
$\bar{Q}/100, \text{SOI} \times 10, \text{SSTSON} \times 10$	0.4136	Discharge = 15.7335 + 0.0829 × SOI – 0.2805 × SSTSON.10

Discharge = Mean annual discharge (\bar{Q})/100

SOI × 10 = Actual mean annual SOI × 10

SSTSON × 10 = Actual mean SST of September, October, November × 10.

CONCLUSIONS

A general decrease of humid and drought events is observed during 1961–1990 compared to the first half of the twentieth century. The hydrologic regime of the Krishna River basin is unstable except for elevated stations like Mahabaleswar. The extreme wet or dry shift of the southwest monsoon might be responsible in improving or diminishing the hydrologic regime of the river basin. It is observed that a general decrease or increase of river flow compared to historic during the warm or cold phases of the ENSO events.

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