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Studies on hydrologic extremities over India – Monsoon Period

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ABSTRACT
In the present investigation, an attempt has been made to study and understand some of the aspects of hydrologic extremities in terms of prevalence of varied degrees of drought, humidness and climate shifts of All India on a weekly basis, through the revised water balance model during the monsoon period from 1951 to 1998. Weekly aridity, humidness and climate shifts of the south west monsoon period are studied for All India and compared to march of Southern Oscillation Index and Sea Surface temperature of Nino 3 region during the period 1981 to 1991, 1992 to 1998.

INTRODUCTION

It has been reported in many studies that the abnormal or subnormal increase of sea surface temperatures of eastern tropical Pacific (El Nino/La Nina), from time to time in conjunction with the negative or positive phase of southern oscillation has a strong bearing on Indian summer monsoon, otherwise known as southwest monsoon. The El Nino Southern Oscillation (ENSO) event modifies the monsoon circulation pattern over India and its neighbours and as a result, there may be a delay in the onset of monsoon, shorter duration, breaks in the monsoon rains will take place. A strong ENSO signal may cause severe drought, on the other hand, an LNSO event may intensify and strengthen the monsoon circulation pattern and cause the opposite pattern with low pressures and cyclonic activity, which results in a heavy downpour and a flood situation may arise across the country.

The past and current anthropogenic land use changes have lead the way for the significant variations of land surface dynamic parameters such as surface albedo, surface resistance, vegetation index and vegetation fractional coverage and in turn resulted in large changes in surface energy and water balance, which in turn may modulate atmospheric circulation over the region, which is very important in understanding the atmospheric and climatic changes.

The activity of summer monsoon rainfall has a strong bearing on many climate teleconnections. Various aspects of Indian summer monsoon activity – ENSO and LNSO relationship have been investigated by several research workers. Alexander et.al, (1978), Banerjee, Sen & Ramana (1978), Rasmusson & Carpenter (1983), Bhalme, Mooley & Jadhav (1983), Shukla & Paolino (1983), Krishnamurthy (1985), Parthasarathy & Pant (1985), Mooley, Parthasarathy & Pant (1986) to name a few.

Bjerknes (1969) reported that the maxima of the sea temperature in the eastern and central equatorial Pacific occur as a result of anomalous weakening of the trade winds of the Southern Hemisphere with inherent weakening of the equatorial upwelling that are closely tied to the “Southern Oscillation”.

Trenberth (1975) reported about the quasi biennial standing wave in southern hemisphere and its inter relations with sea surface temperatures.

Quinn & Burf (1978) has shown that droughts in Indonesia coincide with El Nino episodes. Droughts in Australia have been observed in association with these warm temperature events Angell (1981). Bhalme (1984), Chaudhary & Mhasawade (1991) have investigated association between El Nino and rainfall and droughts in India.

Barnett (1984) has studied the interannual variability of the monsoon and trade wind systems using complex empirical orthogonal function analysis.

Webster (1981, 1983, 1994 and 1995) has extensively studied about the mechanisms of atmospheric response to sea surface temperatures, monsoon low frequency variability and surface hydrological effect, and role of hydrological processes in ocean atmospheric interaction and cycling rates in predicting the ocean atmospheric interactions.

The hydrometeorological aspects of monsoon droughts and floods and the associated problems are reported by Sikka (1999, 2000). The intensified hydrological aspects due to ENSO and LNSO over

Indian summer monsoon have been reported by Sarma & Srinivas (2005).

In the present investigation, some of the aspects of the extreme climate variability which is as a consequence of global warming are reported here through water balance model with reference to All India on a weekly basis in terms of humidness, droughts, and climate shifts.

MATERIALS AND METHODOLOGY

The revised water balance concept of Thornthwaite & Mather (1955) is followed in computing the basic climate water budget elements for the 90 stations that are drawn from the varied geographical settings of India based on the Normals of Agroclimatic Observatories India (IMD) and the data supplied by the IMD, PUNE on a weekly basis for the standard monsoon period (22^{nd} week to 39^{th} week) (Gore & Thapliyal, 1999). The weekly climatic indices such as humidity, aridity, moisture indices are derived from the basic water budget elements. Weekly humidity and aridity indices of All India will reflect the weekly affectivity of moisture, which are chosen for the study of prevalence of humid and drought events respectively. To determine the severity of humid and drought events of the country as a whole, percentage departures from the mean are obtained and are normalized with mean. To obtain the varied categories of humid and drought events, standard deviation (σ) is used and the scheme of Sarma, Padmakumari & Srinivas (1999 a and b) is modified to suit to the weekly climate analysis.

The statistical results of the present investigation in terms of occurrence of All India weekly droughts, humid events and climate shifts are segregated not only for the period of 1951-1980 but also for the period of 1981 – 1991, 1992-1998, ENSO year (1987) and LNSO year (1988) with a view to study the variations in occurrence of these extremities during the monsoon period.

Moist Climates		**Dry Climates**	
Limit	**Category**	**Limit**	**Category**
$0 < \sigma$	Moderate humid week	0 to σ	Moderate drought week
$\sigma - 2\sigma$	Very humid week	σ to 2σ	Severe drought week
$> 2\sigma$	High humid week	$> 2\sigma$	Very severe drought week

In determining the moisture status of India as a whole, the revised expression of moisture index (Carter & Mather 1966) is followed and is obtained on weekly climate concept.

RESULTS AND DISCUSSION

Weekly Water Balances of All India – Extremities:

The variations in All India hydrologic regime during the monsoon period in the extreme situations are studied through water balance model. The principal inputs of the water balance are precipitation and potential evapotranspiration on a weekly basis are obtained from the selected stations that spread in length and breadth wise in the climatic spectrum of India.

It is evident from the present investigation that the normal (1951-1980) hydrologic regime of All India is first humid climate (B_1), with a mean weekly precipitation of 57 mm and potential evapotranspiration of 36 mm that could result in a moderate water surplus of 14 mm with a water deficit of 1 mm (Table 1).

Table 1. Mean weekly Water Budget Elements – Monsoon period

All India

Period	P (mm)	PE (mm)	AE (mm)	S (mm)	D (mm)	I_{wh} (%)	I_{wa} (%)	I_{wm} (%)
1951 – 1980	57	36	35	14	1	40	1	39 (B_1)
1981 - 1991	73	35	34	30	1	88	1	87 (B_4)
1992 – 1998	66	33	33	25	0	76	2	74 (B_3)
1987 (ENSO year)	44	35	34	04	1	12	4	8 (C_2)
1988 (LNSO year)	74	36	36	30	0	84	0	83 (B_4)

During the study period of 1981 – 1991, there is an increase in the rainfall and water surplus by 16 mm each, with depreciation in the water need by 1 mm, which improved the moisture status of India and pushed upward to fourth humid climate (B_4) type (Table 1). There is an increase in the mean weekly affectivity of moisture by 120% from the respective normalcy.

During the period 1992-1998, climate status of India has improved to third humid type (B_3) due to an increase in rainfall and water surplus by 9 mm and 11 mm respectively, accompanied by depreciation in the water need by 3 mm from the corresponding formals (Table.1). The weekly affectivity of moisture has showed a rise by 90% from the respective normal. In the ENSO year (1987), a depreciation in the rainfall, water surplus and water need by 13 mm (23%), 10 mm (71%) and 1 mm (2%) from the respective normal have pushed down the moisture status to moist sub humid (C_2) (Table 1). The weekly affectivity of moisture has diminished by 70%from the corresponding normalcy. It is observed from Table.1 that there was an increase in the mean weekly rainfall, water surplus by 17 mm (33%), 16 mm (114%) with a decrease in the water deficit by 1 mm (100%) from the respective normal during the monsoon period of an LNSO year (1988), which forced the climate to shift into fourth humid climate (B_4) type, with a rise in the weekly affectivity of moisture by 110% from the normal.

From the foregoing account it can be inferred that due to the subnormal rainfall during the monsoon period of ENSO year (1987), the moisture status of the country as a whole has taken a shift into moist sub humid (C_2) climate and in the rest of extremities the moisture status improved on a weekly basis.

Occurrence of humid and drought events:

Among the three climate indices chosen to study the climate status of All India, humidity index has experienced maximum mean and standard deviation followed by moisture index and aridity index during the south west monsoon period of 1981-1991. During the south west monsoon period of 1951 – 1980, the country as a whole has experienced a total of 6 high humid events (Table 2a). Though the total number of humid events in summer monsoon of 1981-1991 is 6, there is an increase in the number of very humid events accompanied by a decrease in high humid events, compared to the normal (1951-1980). For the period of 1992-1998, the country as a whole experienced a maximum total of 9 humid events consisting of 5- moderate and 2- very and high humid events each. In the ENSO year (1987), the country as a whole has witnessed a minimum total of 2 humid events which are high humid, where as in the LNSO year (1988) the sum of the humid events is 8, that comprises of 4 – moderate, 2- very and high humid events each. It is observed that the totality of humid events has improved during the monsoon periods of 1992-1998, LNSO year (1988) and diminished in the ENSO year (1987) compared to normal due to the variations the strength and depth of the monsoon.

The country as a whole has experienced only one severe drought during the monsoon period of 1951-1980, 1981-1991, 1992-1998 and LNSO year (1988) but for the ENSO year (1987) this number has shot up to 4, which might be due to the affect of ENSO on Indian summer monsoon (Table 2b). The mean and standard deviation of aridity indices of ENSO year (1987) have increased by 2 and 3 respectively from the corresponding normalcy.

The mean and standard deviation of All India moisture index for the period 1951-1980 is 38 and 6 respectively. During this period the hydrological regime of India has witnessed a total of 7 - climate shifts, that comprises 6 – high and one moderate. The mean and standard deviations of All India moisture indices have showed an increasing trend through out the period 1981-1991, 1992-1998 and LNSO year (1988), but decreased in the ENSO year (1987) and as a result, All India has showed an upward trend in moderated and large climate shifts accompanied by a downward trend in high climate shifts from the normalcy. It is evident from the Table 2c, that the high and large climate shifts are more consistent than the moderate climate shifts.

It is observed from the above analysis, that during south west monsoon period of the ENSO year, all India hydrological regime has experienced an increased number of very severe droughts along with the decreased number of climate shifts compared to normal, 1981-1991, 1992-1998. During LNSO period as well as in 1992-1998, India has witnessed an increased number of climate shifts in contrast with corresponding normal. The increased and decreased number of climate shifts during the period of 1987 and 1988 might be related to the frequent subnormal depth and intensity of monsoon currents over India in relation to the short term climate signal of ElNino-Southern Oscillation from southern tropical Pacific. The prevalence of low pressure systems and their tracks, the location of monsoon trough throughout the monsoon period will also influence the weekly monsoon activity.

Table 2a. Climate statistics of All India humid events – Monsoon period.

S.No.	Period	Mean	Standard Deviation	Humid Events High	Very	Moderate	Total
1.	1951-1980	40	46	6	0	0	6
2.	1981-1991	90	92	1	5	0	6
3.	1992-1998	76	68	2	2	5	9
4.	1987 (ENSO)	14	40	2	0	0	2
5.	1988 (LNSO)	85	78	2	2	4	8

Table 2b. Climate statistics of All India drought events – Monsoon period.

S.No.	Period	Mean	Standard Deviation Severe	Drought Events Very	Severe	Moderate	Total
1.	1951-1980	2	6	1	0	0	1
2.	1981-1991	1	3	1	0	0	1
3.	1992-1998	2	6	1	0	0	1
4.	1987 (ENSO)	4	9	4	0	0	4
5.	1988 (LNSO)	0	2	1	0	0	1

Table 2c. Climate statistics of All India climate shifts – Monsoon period.

S.No.	Period	Mean	Standard Deviation	Climate Shifts High	Large	Moderate	Total
1.	1951-1980	38	6	6	0	1	7
2.	1981-1991	89	92	1	5	0	6
3.	1992-1998	74	70	2	2	5	9
4.	1987 (ENSO)	10	42	2	0	0	2
5.	**1988 (LNSO)**	**85**	**78**	**2**	**2**	**4**	**8**

Trend Analysis of aridity, humid and climate shifts with SOI and SST of Nino 3:

A multiple correlation and regression analysis between SST of Nino 3, SOI and hydro meteorological parameters such as aridity, humidity and moisture indices are obtained during the south west monsoon period of 1992-1998.

The all India mean weekly affectivity of moisture has showed an increasing trend with rising SOI accompanied by falling SST in the first half of each monsoon period and decreasing trend from the rest of the period (Fig.1a & 1b). There are fluctuations in the affectivity of moisture and might be due to variations in the monsoon circulation pattern that are effected by the SOI and SST of Nino 3. The joint correlation coefficient of mean weekly humidity index during the monsoon period with SOI and SST is 0.4049 (Table.3).

It is observed that the All India mean weekly aridity indices have showed an increasing and decreasing trends with falling and rising SOI respectively, where as the aridity pattern is marching along with the variations in SST of Nino 3 during the selected monsoon period of 1992-1998 (Fig.2a & 2b). The explainability of mean weekly aridity index for the

Table 3. Correlation Coefficients of All India weekly climate statistics with SOI and SST of Nino 3 – Monsoon period

S.No.	Climate Statistic	Correlation with SOI & SST of Nino 3
1.	Aridity Index (I_{wa}%)	0.462
2.	Humidity Index (I_{wh}%)	0.405
3.	Moisture Index (I_{wm}%)	0.433

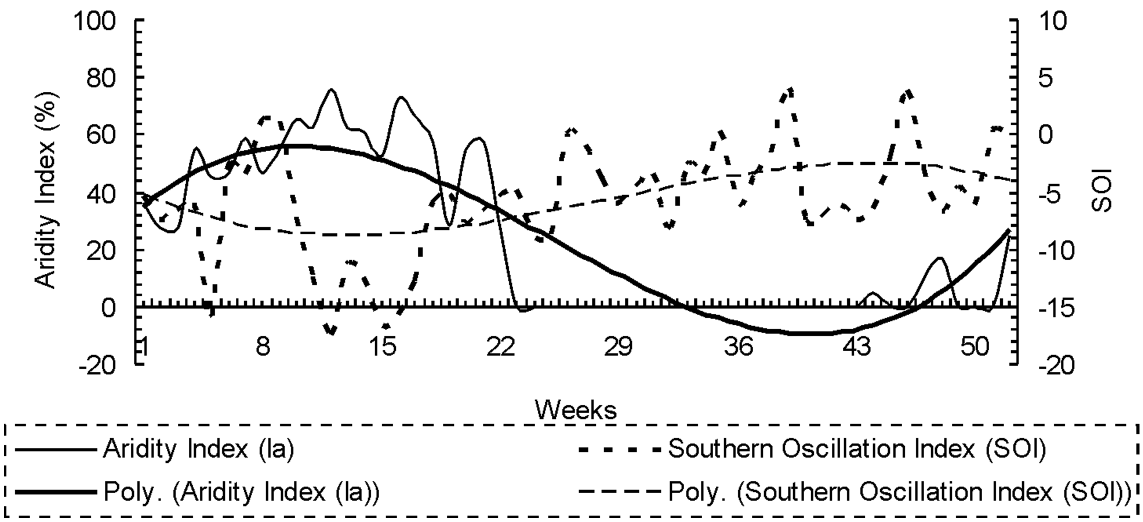

Figure 1a. March of All India mean weekly aridity index (%) and SOI for the period 1992-1998.

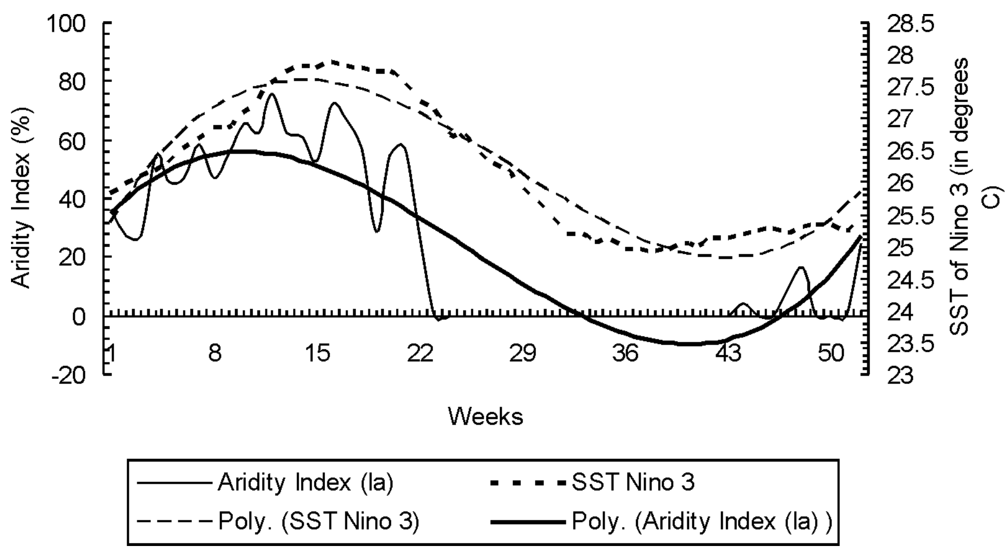

Figure 1b. March of All India mean weekly aridity index (%) and SST of Nino 3 for the period 1992-1998.

monsoon period with SOI and SST was 0.462 (Table.3). It is noticed that the SOI coupled with SST of Nino3 is showing much effect on All India aridity pattern.

There is an increasing trend in the mean weekly moisture index of All India in the first half and a downward trend in the second half of the selected monsoon periods due to the prevailed signal from the coupled ocean atmospheric interaction (Fig.3a & 3b). It is also observed that the prevalence of decreasing and increasing trends in moisture indices with the rise and fall of SST of Nino 3 respectively. The explainability of moisture status with SOI and SST was 0.4327 jointly (Table.3).

From the aforesaid observations it can be concluded that the joint or combined affectivity of SOI and SST on the mean weekly-derived water budget elements such as weekly humidity index (I_{wh}), weekly aridity index (I_{wa}) and weekly moisture index (I_{wm}) is moderate.

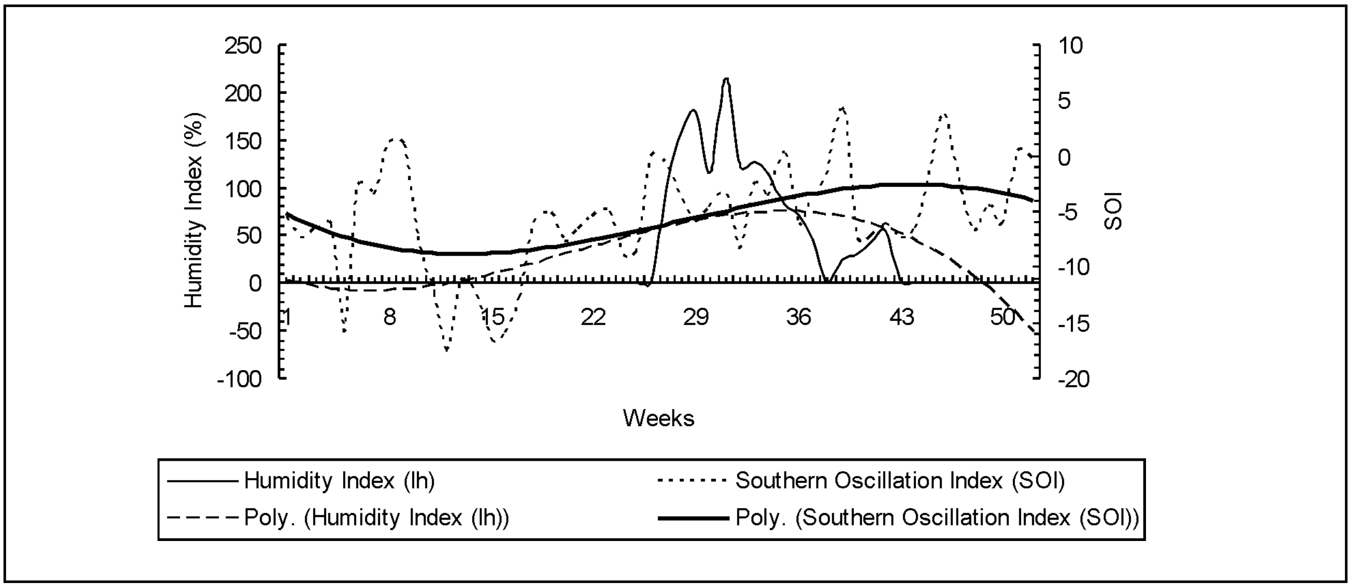

Figure 2a. March of All India mean weekly humidity index (%) and SOI for the period 1992-1998.

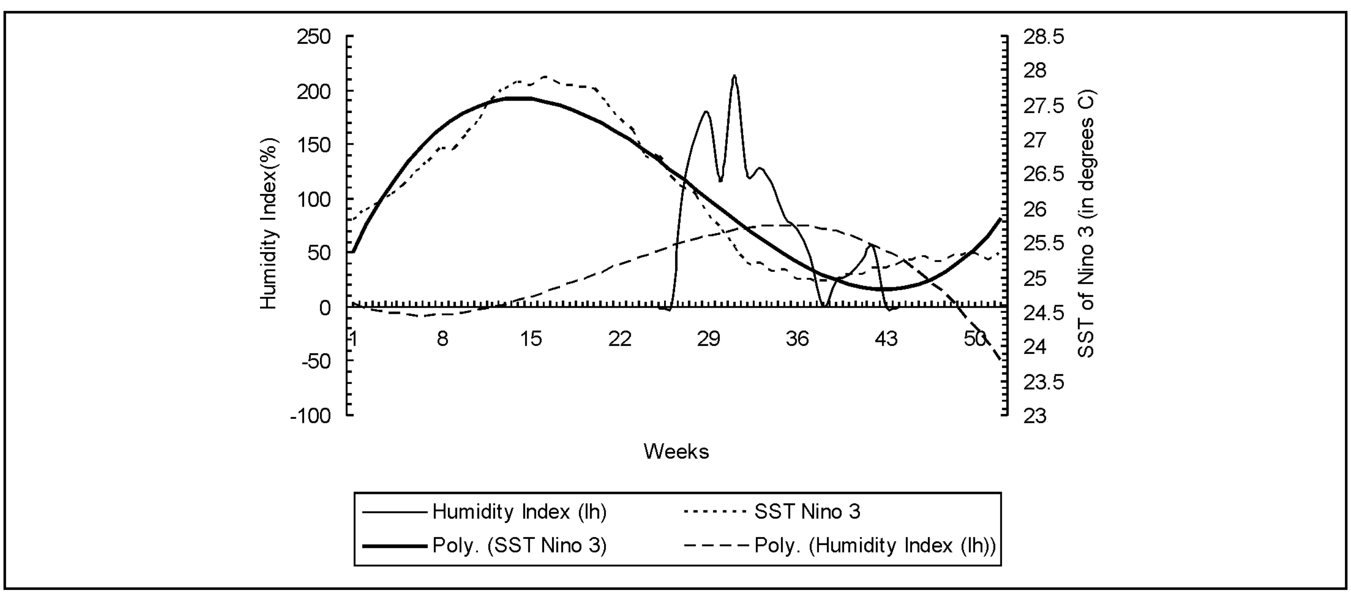

Figure 2b. March of All India mean weekly humidity index (%) and SST of Nino 3 for the period 1992-1998.

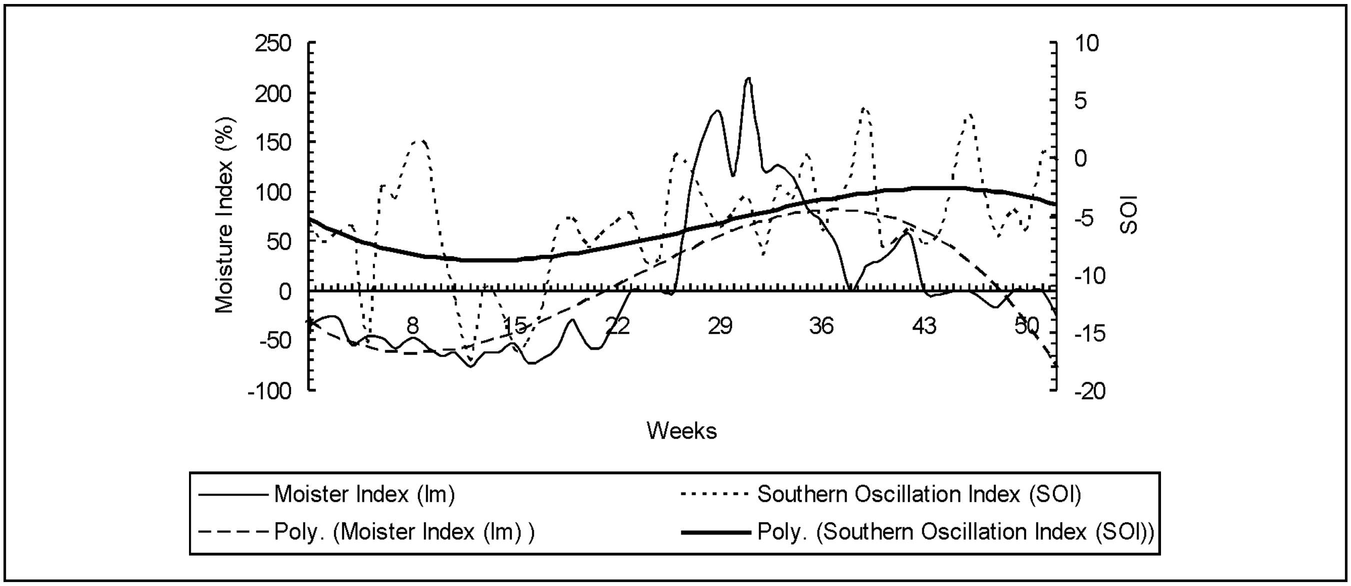

Figure 3a. March of All India mean weekly moisture index (%) and SOI for the period 1992-1998.

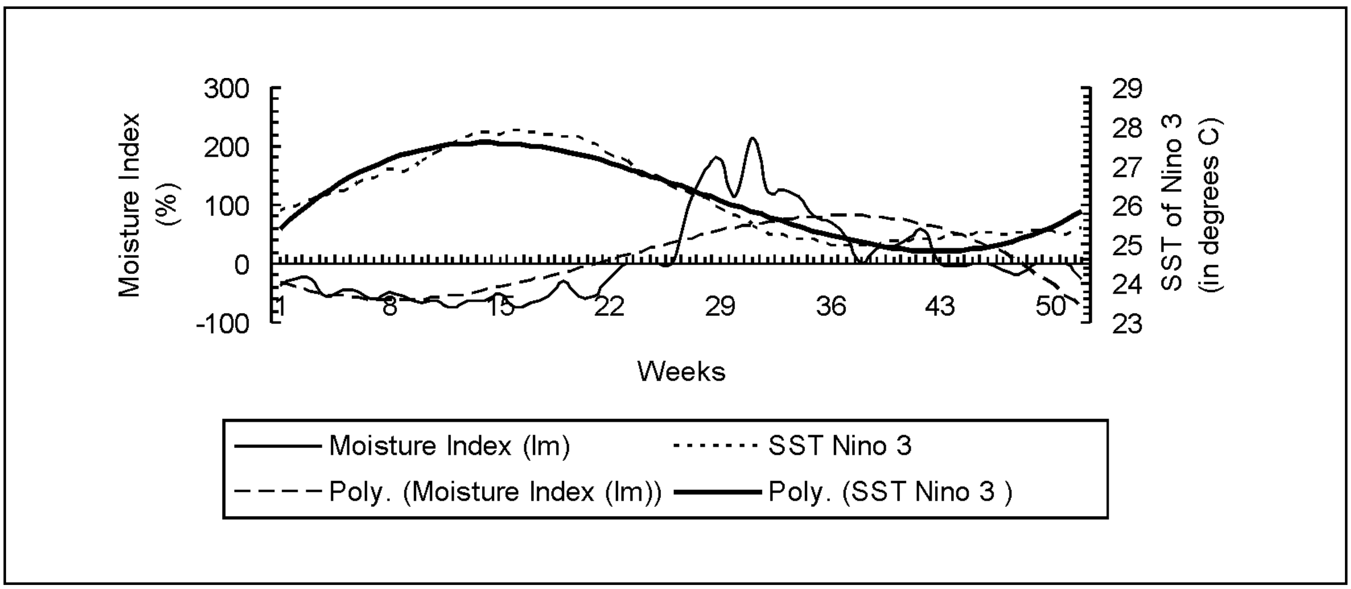

Figure 3b. March of All India mean weekly moisutre index (%) and SST of Nino3 for the period 1992-1998.

SUMMARY AND CONCLUSIONS

The weekly hydrological regime of the country as a whole during the south west monsoon period was first humid type (B_1), which improved to fourth (B_4) humid in the south west monsoon periods of 1981-1991 as well as in the LNSO year (1988) and deteriorated to moist subhumid (C_2) in the ENSO year (1987). This shows the climatic instability of the country. The increase and decrease in the climate shifts during combined El Nino and La Nina scenarios might be due to the subnormal and abnormal performance of the south west monsoon.

In the trend analysis through the third degree polynomial fit, it is observed that the All India weekly aridity is increasing with increase and decrease trends in SST of Nino 3 region and SOI respectively, while the humidity and climate status have improved with the lower SOI and SST of Nino 3.

The joint correlation coefficients of mean weekly aridity, humidity and moisture indices with SOI and SST of Nino 3 are 0.462, 0.4049 and 0.4327, which will explain the impact of SOI and SST of Nino 3 on the south west monsoon circulation pattern.

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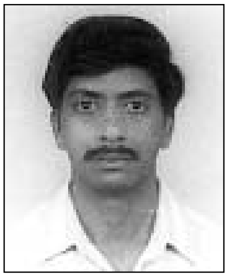

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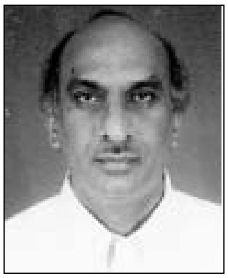

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ii) Vegetation Phenology from satellite measurements.
iii) Physioclimate spectrum of India, induced bioclimate changes and the effects of psycho-physiological sensations and
iv) Floods and Droughts identification, mapping and monitoring from water balance model.