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Studies On Aberrations In Climate Impacts – Water Balance Model

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ABSTRACT
Global climate has been already perturbed due to variations in orbital forcing and man made factors and the footprints of it are traceable in the world climate spectrum (IPCC 1995). It is also evidenced world-wide that man made factors are aggravating the global effects of climate change in terms of triggering extreme weather events. The present paper address critically not only the spatiotemporal variations of moisture and thermal regimes of India through water balance model but also the occurrence of varied degrees of humidness and droughts in moist and dry climates respectively for selected stations that are drawn from its climate spectrum by selecting not less than two stations representing north and south of each of its climate zones. The paper then proceeds in analyzing proneness to varied degrees of droughts on All India basis. Climate stability and the basic water budget elements in extreme climate shifts for the selected stations are also studied. The investigation presents the modulation of basic water budget elements of All India during extreme climate shifts of wetness and dryness in the context of LNSO and ENSO signals and their climate implications are discussed. Finally, trends in All India moisture regime in the context of LNSO and ENSO signals are also reported.

INTRODUCTION

Global climate has already perturbed due to variations in orbital forcing but it is the increased concentrations of GHGs that led to a positive radiative forcing of world climate that tended to warm the surface, which in turn triggered other changes of climate (IPCC 1995). Climate change resulted in the intensification of Global hydrological cycle. General Circulation Models (GCMs) under greenhouse warming scenario predicted shorter durations of winter and precipitation seasons that ultimately manifested in terms of varied degrees of humid and drought events with an overall enhanced and protracted hydrologic variability and pointing to potentially worsening conditions for flood control, water store and water supply. Further, climate change also complicates the conjunctive utilization of surface and ground waters because the time available for ground water recharge is reduced under these conditions (Loaiciga et al. 1996).

Apart from the climate change due to global warming, the prevalence and the modulated quasi permanent systems of the world under changed scenario govern and teleconnect the performance of circulation patterns of major rain bearing systems of the selected weather systems of the world and Indian Ocean monsoons is a case in- point in the context of ENSO and LNSO signals (Shukla 1998).

In the present investigation the authors have addressed hydroclimatic anomalies in space and time over India in the context of perturbation in the regional hydrological cycle of India. The annual precipitation in space and time over India is the source of water and is about 4000 cubic km and out of this, the seasonal rainfall contribution is 3000 cubic km. The long term mean annual rainfall of 33 Meteorological Subdivisions is 1389.54mm. The annual natural flow available in India is about 1880 cubic km only, but the availability of water is curtailed to 1100 cubic km (this includes a quantum of 420 cubic km from ground water) due to varied topography and hydrologic constraints (Anonymous 1988). This quantum of basin wise annual utilizable water resources (Table 1) is subjected to primarily interannual and intra seasonal variations with respect to the performance of the monsoon circulation patterns over India that are modulated under intensified Global hydrologic cycle through LNSO (LaNina – Southern Oscillation) and ENSO (ElNino – Southern Oscillation) signals that originate from

Table 1. Basin wise annual utilizable water resources (Unit: cubic Km)
(Source: Water resources of India, CWC, 1988, New Delhi)

Sl. No.	Basin	Estimated utilizable flow excluding ground water	Utilizable ground water	Total utilizable flow
1.	Indus (up to Border)	46.000	17.810	63.810
2.	a) Ganga	250.000	172.010	422.010
	b) Brahmaputra (at Jogigupa)	24.000	20.820	46.150
	c) Barak	-	1.330	-
3.	Godavari	76.300	44.980	121.280
4.	Krishna	58.000	24.620	82.620
5.	Cauvery	19.000	10.420	29.420
6.	Pennar	6.858	5.350	12.208
7.	East flowing rivers between Mahanadi and pennar	13.110	11.690	24.800
8.	East flowing rivers between pennar and Kanyakumari	16.732	21.080	37.812
9.	Mahanadi	49.990	18.200	68.190
10.	Brahmani & Baitarni	18.297	7.890	26.187
11.	Suvernarekha	6.813	2.850	9.663
12.	Sabarmati	1.925	4.380	6.305
13.	Mahi	3.095	4.440	7.535
14.	West flowing rivers of Kutch, Saurashtra including Luni	14.980	12.610	27.590
15.	Narmada	34.500	13.000	47.500
16.	Tapati	14.500	6.730	21.230
17.	West flowing rivers from Tapi to Tadri	11.936	8.890	20.916
18.	West flowing rivers from Tadri to Kanyakumari	24.273	7.740	32.013
19.	Area of Inland drainage in Rajasthan desert	-	1.330	1.330
20.	Minor river basins drainage to Bangladesh and Burma	-	0.280	0.280
	Total	**690.309** **say 690.000**	**418.540**	**1108.849** **say 1110.000**

southern tropical Pacific ocean. It is pertinent to note in this context that the normal total utilizable flow of 82.62 km^3 (Table.1) from the Krishna river system might have decreased as a consequence of failure of s-w monsoon consecutively for the years 2002 and 2003. The aim of the present investigation is to study the spatiotemporal variation of humid and drought events not only for selected stations from the climate spectrum of India but also for All India using year climate concept in the context of intensified hydrologic cycle.

Sikka (1999) and Sikka (2000) investigations have pointed out that in case of incidence of droughts on local scale the chaotic nature of monsoon rainfall, and for floods the occurrence of heavy to very heavy monsoon rains on different spatiotemporal scales over India are likely to be higher, in addition to large scale atmospheric and coupled ocean-atmosphere factors that are involved in the performance of s-w monsoon rains over India.

Normal climatic patterns of moisture and thermal regimes are presented in Fig.1. The monsoon systems in relation to the physiography of India imparting the complete climate spectrum consisting of perhumid to arid through humid, subhumid and semiarid for both the north and south India. The spatiotemporal

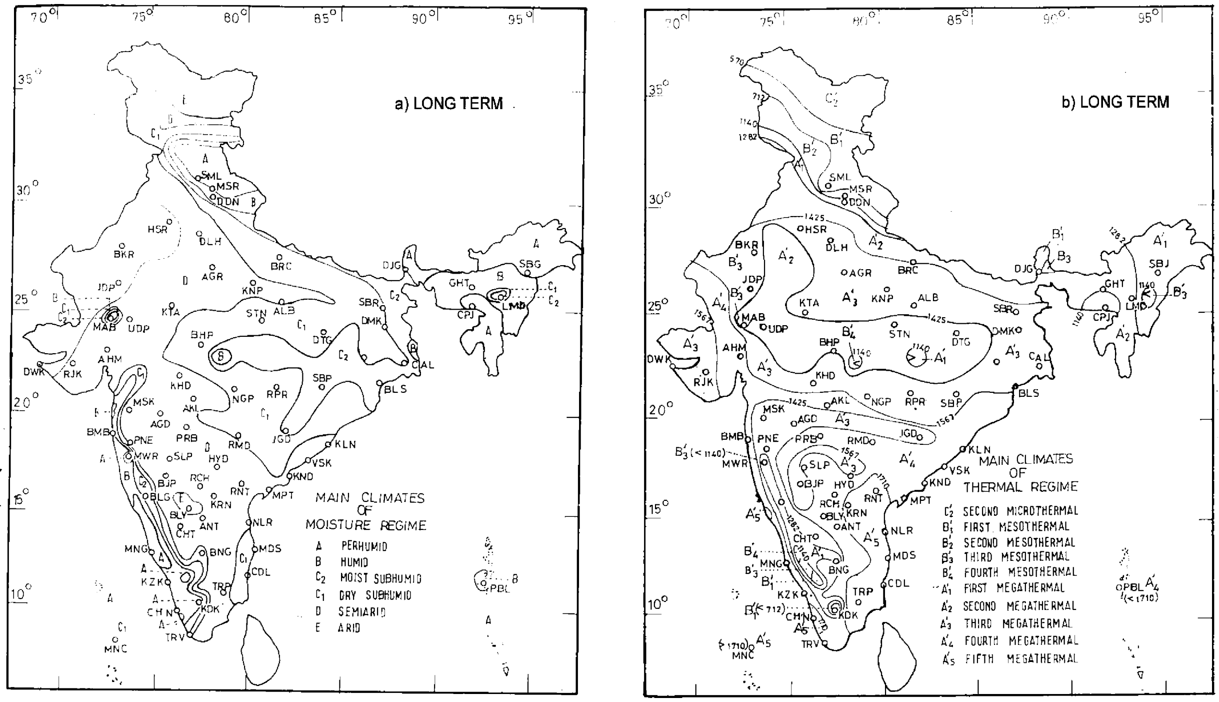

Figure 1. Moisture and thermal regimes - India.

seasonal cycles of the basic water budget elements over India determine its hydrologic regime (Fig.1a). More than three fourths of the Indian landscape is influenced by varied degrees of megathermal regime that supports luxuriant vegetal cover provided enough moisture is available and is the limiting factor due to not only aberrations in spatiotemporal variations of monsoonish weather over India (Fig.1b) but also due to the physiography of the region.

MATERIALS AND METHODS

The revised water balance concept of Thornthwaite & Mather (1955) is followed in computing the basic water budget elements for the selected stations that are drawn from the varied geographical settings of India for a period of 90 years starting from 1901. Yearly climatic indices such as aridity, humidity and moisture for the selected 12 stations are derived from the basic water budget elements. Humidity and aridity indices that reflect seasonal effectivity of moisture are chosen for the study of the prevalence of humid and drought events in the moist and dry climates respectively. To obtain the severity of humid or drought events in moist and dry climates, percentage departures from the median are obtained and are normalized with median of the respective stations. To delineate the varied categories of humid and drought events, standard deviation is used and the following scheme is adopted as suggested by Sarma, Padma Kumari & Srinivas (1999a) and Sarma, Srinivas & Sastry (1999b) in identifying the humid and drought events for the selected stations under study.

Moist Climates		**Dry Climates**	
Limit	Category	Limit	Category
0< s	Moderate humid year (MH)	0 to 1/2s	Slight drought year (SL)
s>2s	Very humid year (VH)	1/2s to s	Moderate drought year (MO)
>2s	High humid year (HH)	s to 2s	Severe drought year (SE)
		> 2s	Very severe drought year (VS)

The revised expression of Carter & Mather (1966) is made use of in determining the moisture status of the selected stations. A station is considered as stable if it maintains the same moisture grade equal to or greater than 70% of its study period by following the year climate concept of Sarma & Sainath (1990/91). The 5th order polynomial fit is adopted for the thirty year normalized moving average values of All India moisture index, equatorial sea surface temperature (SST) of SON (Sept, Oct, Nov) of NINO3 region and the southern oscillation (SO) index in an attempt to understand the trends during the study period.

Table 2. Occurrence of humid (*) and drought events – Distinct epochs

Station	Climate Type	Median Ih(*)/Ia	SD (s)	Total number of humid (*)/drought events				
				1901-'30	1931-'60	1961-'90	1901-'70	1971-'90
Cherrapunji	A	1193.7*	26.1*	12*	18*	10*	32*	8*
Mahabaleswar	A	545.8*	25.5*	-	20*	8*	24*	4*
Guwahati	B	36.3*	157.2*	12*	15*	16*	35*	8*
Kozhikode	B	110.7*	30.3*	13*	21*	13*	39*	8*
Sambalpur	C_2	40.6*	51.2*	16*	16*	9*	36*	5*
Belgaun	C_2	43.9*	69.5*	12*	19*	10*	37*	4*
Daltonganj	C_1	34.1	23.5	16	11	17	32	12
Bangalore	C_1	36.9	20.3	19	11	15	33	12
Allahabad	D	43.6	19.8	16	10	15	32	9
Chitradurg	D	57.2	15.8	14	10	20	30	14
Bikaner	E	82.7	10.7	15	17	12	37	7
Bellary	E	69.4	12.2	19	12	12	34	9

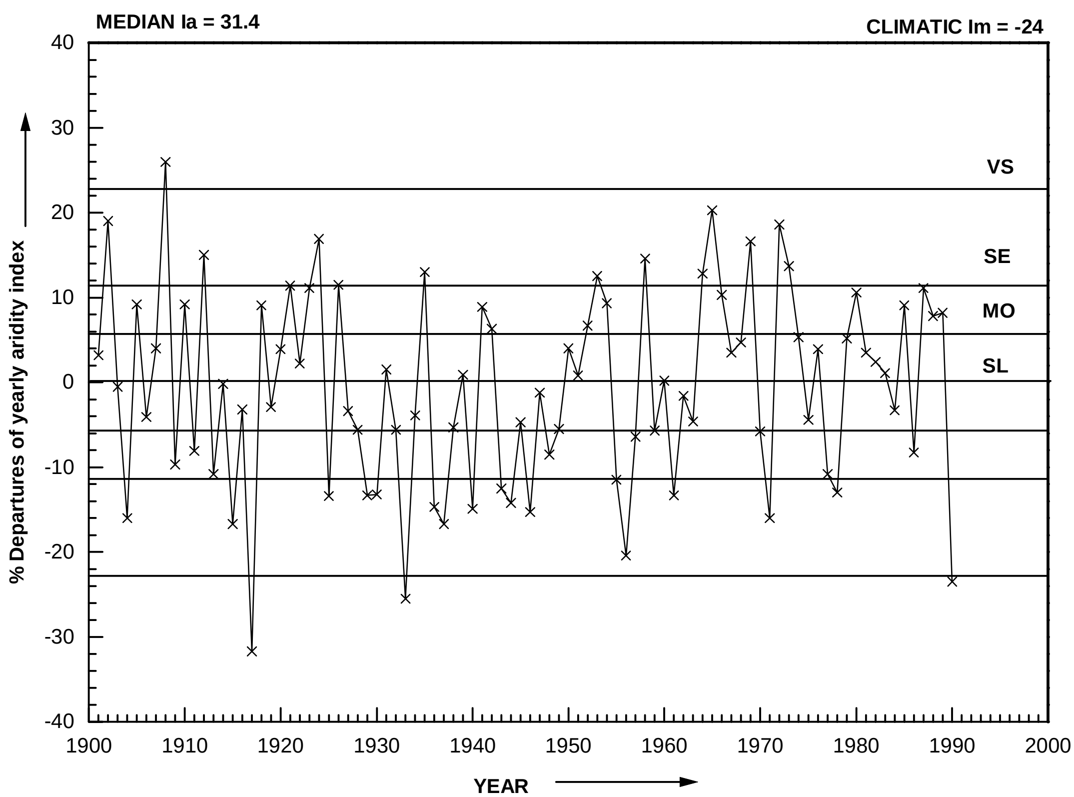

Figure 2. March of All India yearly aridity index.

RESULTS AND DISCUSSION

PREVALENCE OF HUMID AND DROUGHT EVENTS

Cherrapunji from the perhumid zone experienced higher variability in humidness during 1971 to 1992 compared to Mahabaleswar. The perhumid zone is characterized by higher median humidity index with a low standard deviation (Table 2). Guwahati from the humid zone recorded the maximum standard deviation. The standard deviation of either humidity or aridity indices is constantly decreasing from the moist subhumid to arid zone through dry subhumid and semiarid and is least in arid zone. The yearly fluctuations of humidity and aridity indices are marked for all the selected stations except Bikaner. It is important to note here that the yearly fluctuations during the second half of the 20th century is marked compared to the first half.

The total number of humid (moderate humid, very humid and high humid) and drought (slight, moderate, severe and very severe) events of moist (perhumid, humid and moist subhumid) and dry (dry subhumid, semiarid and arid) climates are high during 1931-1960 and 1961-1990 periods compared to 1961-1990 and 1931-1960 respectively. In general the total number of humid and drought events are on decrease in moist and increase in dry climates respectively during 1971-1990 compared to 1901-1970 period (Table 2).

The yearly fluctuations in All India aridity is marked and has a bearing on the strength of the respective monsoon systems circulation patterns in space and time over India. The maximum and minimum departures of All India aridity are recorded in the first two decades of the 20th century and the variability in these two is maximum compared to any other decade (Fig. 2).

On All India basis the region experienced a total of 45 drought years during the study period of 1901 to 1990 with 17- Slight, 16-Moderate and 12-Severe category types (Fig.2). On an average All India per decade recorded a total of 4.5 drought years for the period 1901 to 1970 while the period 1971-1990 had 6.5 per decade and this clearly indicates that the increased frequency of droughts might be due to changes in regional circulation pattern which in turn are teleconnected to the increased frequency of warm phase of ENSO phenomenon (Fig.3). The water balance model has well captured the frequency of humid and drought events in moist and dry climates respectively. It is very important to note that in the opinion of Kabat et al (2000) that the past and current anthropogenic land use changes have paved the way

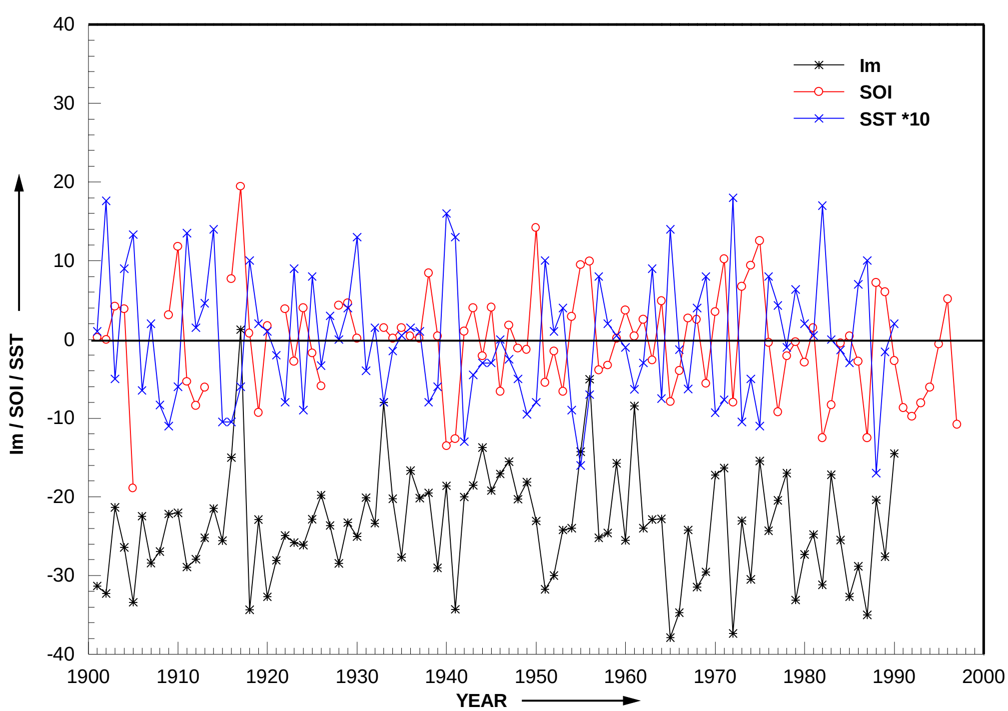

Figure 3. Yearly march of SOI, SST (NINO3) of September, October, November and All India moisture index.

Table 3. Basic water budget elements at selected stations – Extreme climate shifts (Units: mm)

Station/Climate Type	Category of the year	Rainfall	Water Need	Water Deficit	Water Surplus	Main Climate	Climate Regime
Cherrapunji (A)	Normal	10,847	816	2	10,033	A (1229.5)	Stable(100%)
	Wet (1988)	17,946	828	1	17,118	A (2067.0)	
	Dry (1964)	5,248	851	29	4,445	A (518.0)	
Mahabaleswar (A)	Normal	5,777	941	313	5,149	A (513.9)	Stable(100%)
	Wet (1961)	8,407	918	341	7,822	A (814.0)	
	Dry (1935)	2,388	945	262	1,677	A (149.0)	
Guwahati (B)	Normal	1926	1362	59	623	B2 (41.4)	Unstable
	Wet (1965)	4702	1265	32	3461	A (271.0)	
	Dry (1935)	885	1406	437	0	C1 (-31.0)	
Kozhikode (B)	Normal	3172	1705	416	1883	B4(86.1)	Unstable
	Wet (1968)	4334	1692	391	3055	A (157.0)	
	Dry (1976)	2160	1708	509	965	B1 (26.0)	
Sambalpur (C2)	Normal	1581	1547	503	537	C2(2.4)	Unstable
	Wet (1961)	2713	1503	386	1521	B3(75.0)	
	Dry (1979)	642	1561	982	262	D (-46.0)	
Belgaum (C2)	Normal	1371	1244	411	538	C2 (10.2)	Unstable
	Wet (1957)	2847	1269	348	1915	A (23.0)	
	Dry (1973)	681	1367	859	204	D (-47.0)	
Daltonganj (C1)	Normal	1193	1432	422	183	C1(-16.7)	Unstable
	Wet (1971)	1843	1350	343	845	B1(37.0)	
	Dry (1966)	536	1520	924	0	D(-60.0)	
Bangalore (C1)	Normal	910	1235	361	36	C1 (-26.3)	Unstable
	Wet (1916)	1349	1205	386	524	C2(11.0)	
	Dry (1927)	592	1290	707	21	D (-53.0)	
Allahabad (D)	Normal	974	1486	557	45	D (-34.4)	Unstable
	Wet (1953)	1676	1517	620	757	C2 (9.0)	
	Dry (1973)	336	1491	1087	0	D(-72.0)	
Chitradurg (D)	Normal	703	1685	982	0	D (-58.2)	Stable(84.6%)
	Wet (1962)	1895	1367	667	1123	B1 (33.0)	
	Dry (1945)	303	1400	1087	0	E (-77.0)	
Bikaner (E)	Normal	291	1509	1218	0	E(-80.7)	Stable(92%)
	Wet (1974)	868	1508	896	257	D (-42.0)	
	Dry (1939)	69	1461	1392	0	E (-95.0)	
Bellary (E)	Normal	527	1670	1143	0	E (-68.4)	Unstable
	Wet (1956)	1030	1561	688	90	D (-38.0)	
	Dry (1985)	189	1602	1413	0	E (-88.0)	

for significant variations of land surface dynamic parameters such as surface albedo, surface resistance, vegetation index and vegetational fractional coverage and inturn resulted in large changes in surface energy and water balance, which in turn modulate atmospheric circulation over the region (Asia).

SURFACE HYDROLOGIC FLUXES – EXTREME CLIMATE SHIFTS

Table 3 presents the magnitudes of basic hydrologic elements of the selected stations in the climate spectrum of India for the normal as well as for the extreme climate shifts of wetness and dryness. Even though stations selected from perhumid zone maintained the same hydrologic status during the extreme shift on to dry side, the water surplus of Cherrapunji and Mahabaleswar are reduced by 2.3 and 3.1 times of the respective climatics but are elevated during extreme wet shifts by 1.7 and 1.5 times of the climatics (Table 3).

During extreme dry year the hydrologic regimes of Guwahati and Kozhikode from the humid zone of India are diminished by three grades compared to the normals with a simultaneous increase of water deficit by 7.4 and 1.2 times respectively from their normals (Table 3). Sambalpur and Belgaum from moist subhumid zone witnessed a reduction in water surplus during extreme dry years by 2.1 and 2.5 times of their respective climatics and the subnormal activity of the monsoon systems might be responsible for their semiarid status. During the extreme wet years the dry climates experienced improvement in their hydrologic regimes by one to three grades compared to respective normals due to frequent and intense rain bearing systems and infact the water surplus on such occasions rose to several times from zero levels. It is also evidenced from this type of study that at best the arid zone during extreme wet year records an improvement from normal hydrologic regime by one grade and that too to semiarid from arid. During extreme dry years the zones of semiarid and arid harbour hyper aridity coupled with seasonal failure of normal rainfalls together with a simultaneous increase of water need and water deficit.

ALL INDIA'S WATER BUDGET – LNSO AND ENSO SIGNALS

All India basic water budget elements during LaNina and ENSO years along with the normal are presented in Table 4. All India has an over all improvement in its hydrologic regime during LaNina years. The year 1917 was an extreme wet and was in coincidence with the LaNina phenomena where in the water surplus is elevated to roughly 3.5 times the normal (Table 4), which in turn elevated its moisture status from C1 to C2. ElNino years of 1972 and 1987 imparted impoverished hydrologic regime to India by depleting it from C1 to D compared to the ElNino years of 1905 and 1982. The adverse affects of the years 1972 and 1987 due to failure of seasonal rains might have reflected on the river flows of Indian river systems as All India recorded zero water surplus from a normal of 86mm.

Table 4. All India basic water budget elements – LaNina and ElNino years (Units: mm)

Category of the Year	Annual Rainfall	Annual PE	Annual WD	Annual WS	Climate Type
Normal	1088	1432	430	86	-24 (C_1)
Extreme Wet (1917)	1349	1346	289	306	1 (C_2)
Good Monsoon (1975)	1201	1400	421	205	-15 (C_1)
LaNina (1988)	1160	1467	498	199	-20 (C_1)
Extreme Dry (1905)	923	1393	479	14	-33 (C_1)
ElNino (1972)	850	1435	536	0	-37 (D)
ElNino (1982)	980	1439	464	15	-31 (C_1)
ElNino (1987)	967	1475	516	0	-34 (D)

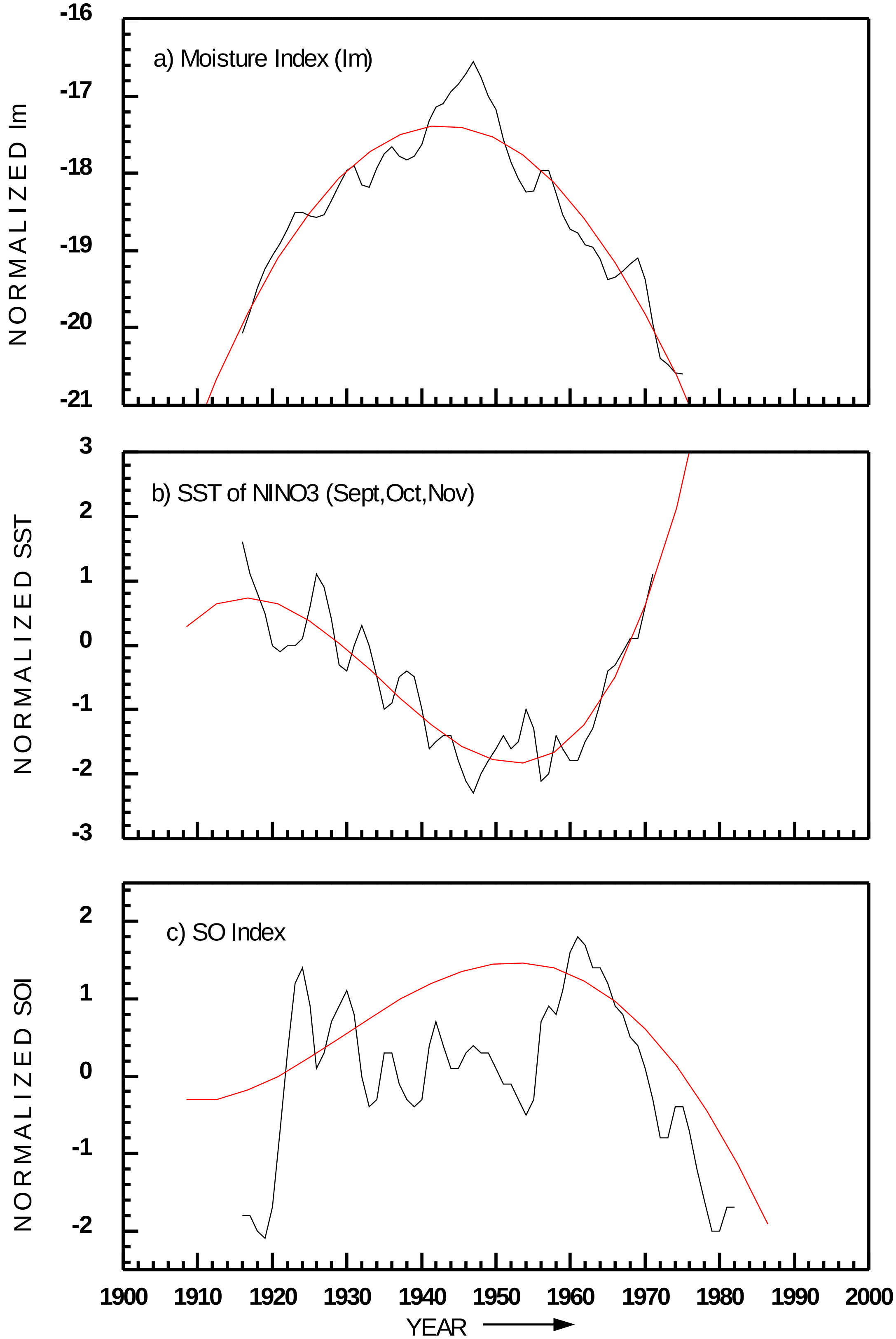

Figure 4. Polynomial fit for normalized 30-year running averages of moisture index, SST of NINO3 and SO index.

STABILITY OF MOISTURE REGIME

Among the twelve stations that are selected from each of its climate zones of India only the perhumid zone and Chitradurg and Bikaner from semiarid and arid zones (Table 3) are indicated stable hydrologic regimes while the rest are unstable.

The water balance analysis of All India indicated its hydrologic regime is stable in dry subhumid climate type (C1) with a frequency of 92.2% through the year climate model.

ALL INDIA'S HYDROLOGIC REGIME – LNSO AND ENSO SIGNALS

Good monsoon patterns due to the prevalence of well developed quasi permanent weather systems in and around India augurs a well balanced hydrologic regime to All India but when the same systems are modulated by either LaNina or ElNino, the hydrologic regime over India perturbs resulting in an improvement or deterioration in its moisture status considerably from the normal. In the present investigation an attempt is made to study the variability in hydrologic regime of India making use of All India's moisture index in relation to LaNina and ENSO signals.

Fig.3 presents the march of All India moisture index (Im), SST (Sea Surface Temperatures of Sept, Oct and Nov) of NINO3 region (5°N-5°S, 150°-90°W) and the Southern Oscillation Index (Sea Level Pressure difference between Tahiti and Darwin) from 1901 to 1990. The yearly fluctuations in SSTs are pronounced compared to All India's Im and SOI and the second half of the 20th century displayed marked yearly variations in the three indices.

Fig.4 depicts the 5th order Polynomial fit for the normalized 30 year running averages of All India Im from water balance model, SST of NINO3 region and SO index. An interesting feature of Fig.4 is that there is a general enrichment (1916-1948) and impoverishment (1949-1975) of the hydrologic status (Fig.4a) of All India are associated with a simultaneous decrease (1916-1956) and increase (1957-1971) of SSTs of NINO-3 together with an increase of (1916-1961) and decrease of (1962-1982) of SO index respectively. A comparative study of this feature with the results of Sikka (1999) and Sikka (2000) from All India summer monsoon rainfall (ISMR) indicated the similarity of a wetter epoch between 1920-1960 and dry epoch of 1961-1990 with slight differences in duration.

CONCLUSIONS

We may draw the following conclusions for the study: In general it is observed, there is a reduction and increase of total humid and drought events during the period 1971-1990 compared to 1901-1970 in the moist and dry climates respectively. The hydrologic regime of All India is stable in dry subhumid climate. Even the perhumid zone is not spared from a reduction in its hydrologic status during its shift on to dry side compared to long-term status. It is clear from the present study that the hydrologic regime of India is improving in accordance with LNSO that is abnormals and subnormals of SOI and equatorial SSTs of NINO3 region respectively and deteriorating (diminishing) with ENSO that is subnormals of SOI and abnormals of equatorial SSTs of NINO3 region. The analysis of droughts and humid years on All India scale from the water balance model and that of from the All India Summer Monsoon Rainfall Index (ISMRI) indicates that while on most occasions the major hydrological and meteorological droughts overlap but on less severe/mild categories, there are intensity variations in these two approaches.

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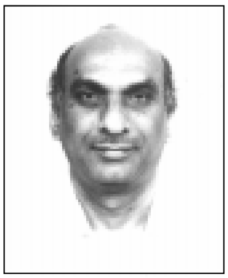

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