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Spatiotemporal distribution of Weekly Hydroclimatic Potentialities of India – Monsoon period

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ABSTRACT
Hydroclimatic potentialities such as precipitation, potential evapotranspiration, actual evapotranspiration, water surplus, water deficit, soil moisture storage along with the indices such as humidity, aridity and moisture, soil wetness and soil moisture adequacy over India for the monsoon period on a weekly basis are reported by following the revised water balance model. The paper address the occurrence of varied degrees of drought and humid events for the selected stations drawn from the climate spectrum along with All India during the monsoon period and are of vital importance for crop scheduling especially in the context of increased climate variability.

INTRODUCTION

India being an agrarian country, its agricultural operations starting from the soil bed preparation to the harvesting are dependent on the hydroclimatic potentialities such as precipitation, potential evapotranspiration, actual evapotranspiration, water surplus, water deficit along with the effectivity of humidity and aridity, soil wetness and moisture adequacy. Rainfall plays the primary role in modulating the climate stress .The quantum of annual rainfall over India is quantified as 4000 cubic km and out of which 3000 cubic km is derived from southwest monsoon period that prevails for a period of 18 weeks over India.

The varied physiography of India in association with the monsoon systems impart the climate spectrum over it that consists of perhumid to arid through humid, subhumid, semi arid. The causal factors for the existence of low rainfall over Deccan plateau and northwestern part of India are briefly summarized here. The wind reversal due to the temperature gradient from land to Indian Ocean is the causal factor for the prevalence of southwest monsoon. The existence of the vast Asiatic continent in the northern hemisphere and the Indian Ocean in the south with contrasting geographical features along with its proximity to the equator are also the causal factors for the performance of southwest or summer monsoon over India and its adjoins. The low rainfall over Deccan plateau is on account of the rain-shadow effect of the Western Ghats.

The hydroclimatic regime of India and its' adjoint regions are governed by the southwest and northeast monsoon systems .The highly uneven distribution of rainfall along with the physiography are responsible for the evolution of varied climate types that constitute the spectrum of the moisture regime over India and as a consequence India is endowed with monsoonal, tropical , subtropical, temperate, cold and hot desert climate types .

The interference between the massive overriding of hot dry continental air that subsides after its long passage over the hot dry plateaus of Persia and Baluchistan with the moist monsoon current from Arabian sea is not conducive for weather development and there -by results in dryness of the north western part of India. The continental air is projected into and above the oceanic monsoon current and thereby preventing the ascent of moist air and thus inhibiting the evolution of rainfall except for occasional downpour when conditions of instability temporarily dominate. The inclined plane of the Inter Tropical Convergence Zone (ITCZ) reaches the land surface south of Karachi and all oceanic air mass is excluded in reaching the region under consideration but farther east, the amount of rainfall is roughly proportional to the height of the ITCZ above the ground since the higher the plane of discontinuity, the higher the air can ascend and the greater is the possibility for rainfall. The highly irregular and scanty rainfall is the result in the arid conditions of Western Rajasthan and Sindh.

Sikka (1999, 2000) reported that apart from the occurrence of droughts on local scale due to the chaotic nature of monsoon rainfall and floods from heavy monsoon rains on different spatiotemporal

scales over India, the large scale atmospheric features coupled with ocean and atmospheric factors are also involved in the performance of southwest monsoon over India and its adjoins. The coupled ocean – atmosphere interaction is in terms of warming-up or cooling of equatorial Pacific Ocean sea surface temperatures (SSTs) along with the see-saw pressure oscillations south of the equator known as Southern Oscillation (SO) modulates the global rain bearing weather systems with regional implications (Rasmusson & Wallace1983; Ropelewski & Halpert (1987) and Webster et al.,1998) .In this context Sarma et al., (2005a) and Sarma & Srinivas (2005b) made an exercise in unfolding the impacts of El Nino – Southern Oscillation (ENSO) and La Nina-Southern-Oscillation (LNSO) on surface hydrologic fluxes derived from the southwest monsoon system not only for All India but also for Krishna river flows at Vijawada point through water balance model. Further to understand the changes in the magnitude of hydrologic fluxes from the water balance model during the monsoon period on a weekly basis which is of utmost importance in scheduling the crops. Sivaram &Sarma (2008) and Sarma & Sivaram (2010) dealt the implications of ENSO and LNSO on hydroclimatic regime of not only for All India and for selected stations in different epochs but also for the extended and compressed duration of the length of the growing period in moist and dry climates respectively. Adopting the limiting values proposed by Mather (1966) for the moisture index the annual climate spectrum of India is reported by Subrahmanyam and Sarma (1981) which unfolded the existence of perhumid to arid climate types.

The spatial distribution of hydroclimatic parameters on a monthly and seasonal basis are dealt by Sarma and Ravindranadh (1984, 1986). Kambete (1992) and Bhalme & Mooley (1980, 1981) have reported the occurrence and frequency aspects of droughts and floods over India, while the variability in floods during the summer monsoon was dealt by Chowdhury & Mhasawade (1991) . It is very important to note that the study of the agrohydroclimatic aspects over India on a weekly basis is much needed aspect in crop and irrigation scheduling. The present investigation address some of the aspects of hydroclimatic aspects over India for the monsoon period based on weekly temperature and rainfall data through the revised water balance model of Thornthwaite & Mather (1955) based on the works reported by Sarma (1987, 2006), and Sarma, Srinivas & Karthikeya (2005a). The occurrence, frequency and intensity of flood and drought events during the monsoon period are obtained through the humidity and aridity index respectively that serve as a measure of weekly effectivity of moisture.

MATERIALS AND METHODOLOGY

The revised water balance concept of Thornthwaite & Mather (1955) is followed in computing the weekly basic water budget elements for the 90- stations that are drawn from the varied geographical settings of India based on the Normals of Agroclimatic Observatories of India Meteorological Department (IMD) on a weekly basis for the standard monsoon period (22nd week to 39th week) (Gore & Thapliyar 1999). The weekly agrohydroclimatic indices such as humidity, aridity, moisture, soil wetness and soil moisture adequacy are derived from the basic water budget elements. Weekly humidity and aridity indices of All India as well as for selected stations serve in tracing the weekly effectivity of moisture for the occurrence of humid and drought events in moist and dry climates respectively. To determine the severity of humid and drought events in moist and dry climates, percentage departures from the mean are obtained and are normalized with mean of the respective stations. To obtain the varied categories of humid and drought events, standard deviation (ó) is used and the scheme of Sarma, Padma Kumari & Srinivas (1999) is modified to suit to the weekly hydroclimate analysis and the schema is as given Table 1.

Table 1. Classification of climate stress in moist and dry climates.

Moist Climates		Dry Climates		Climate shifts	
Limit	**Category**	**Limit**	**Category**	**Limit**	**Category**
$0 < \sigma$	Moderate humid week	$0 < \sigma$	Moderate drought week	$0 < \sigma$	Moderate climate shift
σ - 2 σ	Very humid week	σ - 2 σ	Severe drought week	σ - 2 σ	Large climate shift
$> 2\ \sigma$	High humid week	$> 2\ \sigma$	Very severe drought week	$> 2\ \sigma$	High climate shift

SOIL WETNESS AND SOIL MOISTURE ADEQUACY

Soil wetness plays an important role in crop performance, which is defined as the percentage ratio of water storage to field capacity (St*100/Fc) of the station. The crops sustain as long as the wetness is above the threshold value and starts wilting when it drops below the threshold. Moreover the rainfall alone cannot give neither the availability of soil moisture nor the extent of it in meeting the waterneed of the station and on which the crop performance depends. The soil moisture adequacy parameter takes into consideration both the actual evapotranspiration and potential evapotranspiration and a ratio of actual evapotranspiration to potential evapotranspiration expressed in percentage is known as soil moisture adequacy and is used in scheduling and understanding the performance of cropping pattern over the given landscape(Subrahmanyam, Subba Rao & Subramaniam1963 and Sarma 1983).

RESULTS AND DISCUSSION

a) Mean weekly precipitation pattern:

The mean weekly precipitation during the monsoon period ranges from 8 mm to 185 mm over India (Fig.1). The lowest is recorded at Kovilpatti (KVP) from southeastern region, while the highest was at Karjat (KJT) from southwest coastal region. Along the southwest coast of India the rainfall is more than 100 mm per week, except at Kayamkullam (KKM) and Vellayani (VLY) that registered 84 mm and 63 mm respectively. The rainfall is decreased from the west coast to east coast in south India and as a consequence the regions that received the rainfall between 75-100 mm and 50-75mm are spread along the west coast while the extreme southeastern region that comprise interior Karnataka and Tamilnadu have received less than 25 mm rainfall even during the monsoon period. The two isolated stations of Padegoan (PDG) and Shakkarnagar (SKN) have recorded less than 25 mm and more than 50 mm respectively from the regions that receive a rainfall of 25 and 50 mm in south India. In north India, the regions bounded by Chatra (CHT) and Silicorie (SLC) have registered more than 100 mm rainfall. The rainfall is decreased from east to west and as a result the regions from the north of Gurudaspur (GDP) to the west of Viramgam (VRM) have witnessed less than 25 mm weekly rainfall during the monsoon period. Patna (PTN) is an isolated station with less than 50 mm rainfall from a region that receives a rainfall of over 50 to75 mm.

b) Mean weekly Potential evapotranspiration pattern:

It is a known fact that the potential evapotranspiration speaks about the total amount of the water need of the location and its spatial variation over India is varied from 14 mm to 44 mm (Fig.2). It is clear that the south-west coastal region, interior Karnataka and parts of Tamilnadu have recorded less than 30 mm potential evapotranspiration with an isolated hill station of Ooty (OTY) that recorded only 14 mm, which is the least compared to any other station in India. The southeast coastal region bordered by Kovilpatti (KVP) and Rajahmundry (RJY) and the northwestern region bounded by Gurudaspur (GDP) in north, Jobner (JBR) in south, Bikaner (BKR) and Viramgam (VRM) in east and west respectively have registered more than 40 mm . The maximum potential evapotranspiration of 44 mm was observed at Hanumangarh (HMG) from the north-western region, while the rest of India has recorded 30 - 40 mm but the stations Mashobra (MSB), Chaubatia (CHB) and Nagrifarm (NGR) from the same region did register less than 30 mm of potential evapotranspiration per week.

c) Mean weekly actual evapotranspiration pattern:

The weekly actual evapotranspiration ranges from 6 mm to 42 mm over India (Fig.3). The lowest was recorded at Udaipur (UDP) and the highest was at Hanumangarh (HMG) from the northwestern region. It is clear that the regions from north of Surat (SRT) to south of Karjat(KJT) and north of Kayamkullam (KKM) to south of Vellayani (VLY) on the west coast have recorded more than 30 mm of actual evapotranspiration. The extreme southeast coastal region bounded by Mandya (MDY) in north, Hansu (HNS) in the west, Kovilpatti (KVP) in the south and parts of Karnataka has registered less than 20 mm of actual evapotranspiration. The central India and northeastern regions have experienced 30 mm to 40 mm of actual evapotranspiration, while the north western regions are at less than 20 mm. Mashobra (MSB), Chaubatia (CHB) and Nagrifarm (NGF) are isolated stations from the region that could record more than 30 mm of actual evapotranspiration. Udaipur (UDP) and Padegoan (PDG) are the two isolated stations that have recorded less than 20 mm of actual evapotranpiration.

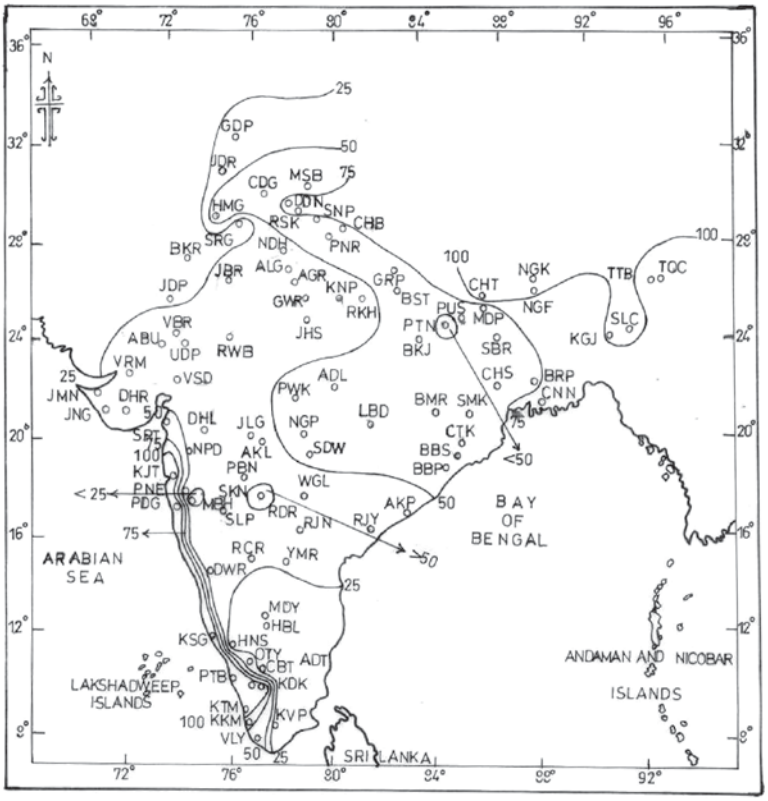

Figure 1. Mean weekly precipitation (mm) over India – Monsoon period.

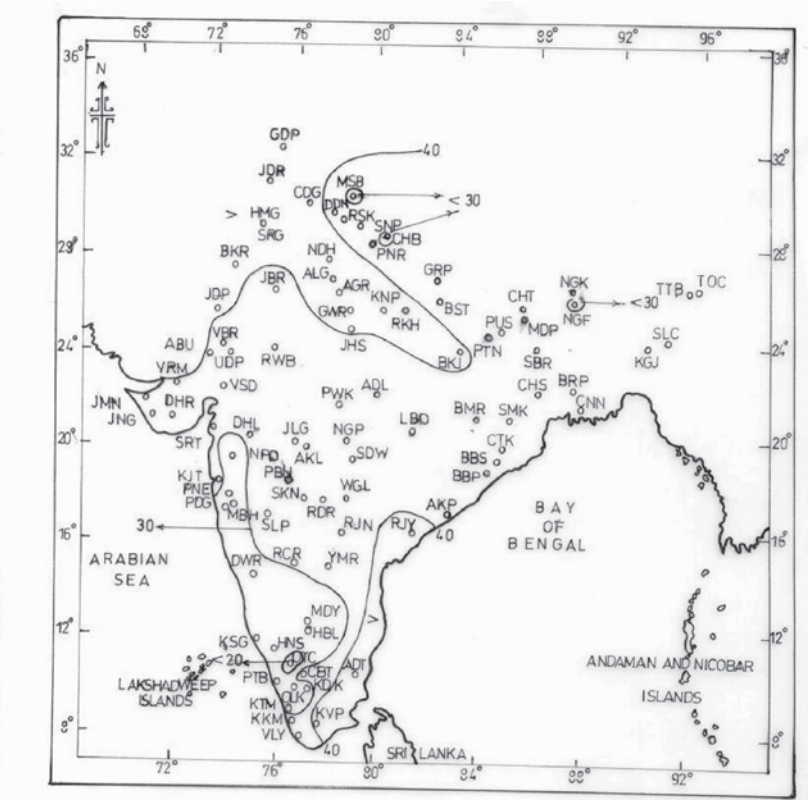

Figure 2. Mean weekly potential evapotranspiration (mm) over India – Monsoon period.

d) Mean weekly water surplus pattern:

Fig.4 depicts the distribution of water surplus over India during the monsoon period. The water surplus varied over India from zero to 146 mm. The regions along the west coast and northeast have registered a water surplus of higher than 100 mm. The water surplus falls to zero mm in the interior of south India and extreme northwestern regions bounded by Rajahmundry (RJY) Niphad (NPD). Dharwar (DWR) and Kovlopatti (KVP) in south and Gurudaspur (GDP), Sriganganagar (SRG) and Jamnagar (JMN) in north India. The extreme higher and lower values of water surplus are due to the large spatial variability in the monsoonish circulation pattern over India. The region that covers Adhartal (ADL), Labhandi (LBD), Bamra (BMR) and Samakunta (SMK) has recorded more than 25 mm of water surplus while that of covering Agra (AGR) and Kanpur (KNP) could register from zero to 25 mm.

e) Mean weekly water deficit pattern:

The spatial distribution of water deficit over India during the monsoon period is varied from zero to 35 mm (Fig.5).The maximum values of greater than 20 mm are observed ,west of 20 mm isoline from northwestern part of India commencing from west of Gurudaspur (GDP) down to Jodhpur (JDP) and in the south the southeastern part of Tamilnadu bounded by Aduthurai (ADT), Coimbatore (CBT) and Kovilpatti (KVP) while the rest of India has recorded a moderate water deficit of 10 mm per week.

f) Mean weekly humidity index pattern:

The distribution of humidity index over India is presented in the Fig.6. The humidity index values range from zero to 421% during the monsoon period. The highest was observed at Nagarkatta (NGK) from northeastern region of India. The stations along the west coast have recorded more than 33% and the index dropped towards the east coast and as a result except the west coastal regions and its adjoins the entire south India is subjected to less than 16% indicating there by the possibility of little or no water surplus but Shakkarnagar (SKN) solitarily registered greater than 30% as its humidity index from this region. In north India, areas with the higher humidity index (>33%) are extended from north of Mashobra (MSB) to south of Bhubaneswar (BBS) and on east the entire north eastern portion, while the lower humidity index

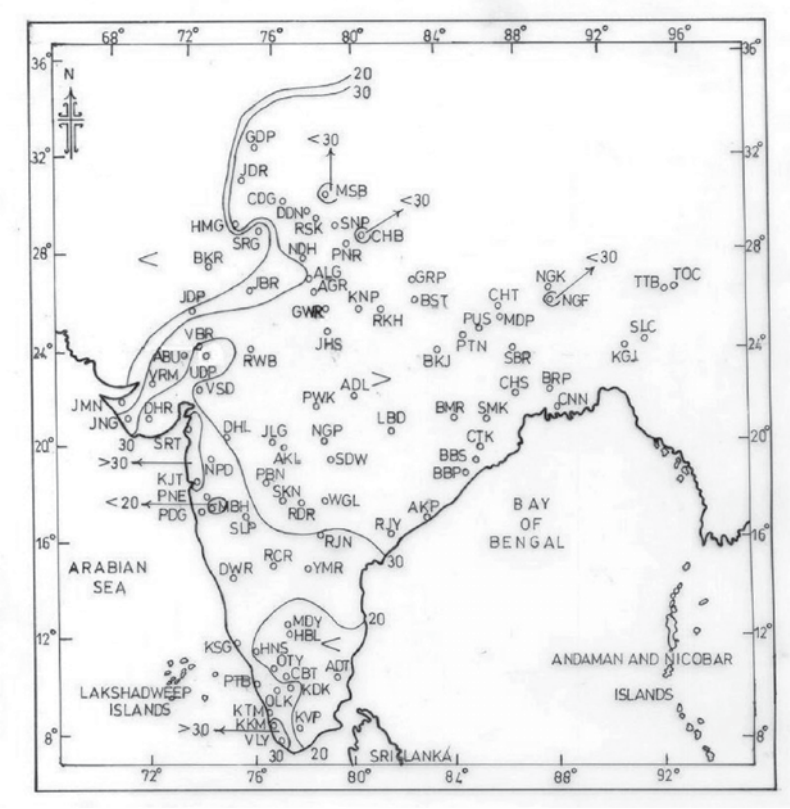

Figure 3. Mean weekly actual evapotranspiration (mm) over India – Monsoon period.

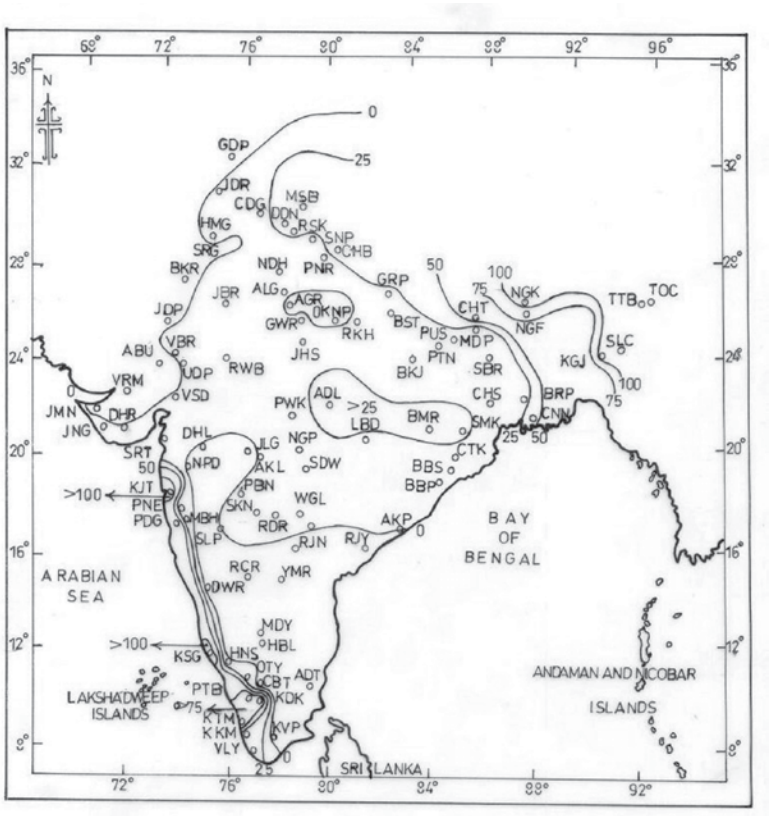

Figure 4. Mean weekly water surplus (mm) over India – Monsoon period.

values (<16%) are observed in the regions bounded by Gurudaspur (GDP) in north and Patna (PTN) in the east, Jhansi (JHS) in the south and Jodhpur (JDP) in the west. Humidity index is decreased from west to east and east to west in south and north India respectively. The extremities in the weekly effectivity moisture (humidity index and aridity index in the dry and moist climates respectively) over India might be due to the spatial variation in the strength and depth of the monsoonish weather along with the associated circulation pattern.

g) Mean weekly aridity pattern:

Fig.7 shows the distribution of mean weekly aridity index over India. The mean weekly aridity index for the monsoon period ranges from zero to 79%. The highest aridity index of 79% was recorded at Sriganganagar (SRG) from the northwestern region. The regions of less than 10% of aridity index are found along the west coast from north of Surat to south of Vellayani (VLY) in south India and from north of Jallander (JDR) to northeastern states and south of Sakkarnagar_SKN) and Rajahmundry (RJY). Higher aridity index of more than 20% prevailed at and around Solapur (SLP), Yammiganur (YMR). Mandya(MDY) and Kovilpatti(KVP) in south and Gurudaspur(GDP), New Delhi(NDH), Kanpur(KNP) and Dhari(DHR) from north while the rest of India subjected to an aridity index of 10-20% with an exception to Junagarh ((JNG) from coastal Gujarat that recorded less than 20% aridity index.

h) Mean weekly moisture index pattern:

The moisture index plays an important role in delineating the climate zonation over any given landscape. The moisture index is varied from minus 79% to 421 % over India (Fig.8). The lowest moisture index was recorded at Vedasandore (VSD) from south India while the highest was experienced by Nagarkatta (NGK) from northeastern region of India. It is of interest to observe that all along the west coast that commences from north of Karjat (KJT) down to south of Vellayani (VLY) supporting a moisture index of greater than 100% that imparts the perhumid climate (A) status to it. The humid (B) and moist subhumid (C_2) climates are running parallel to the perhumid zone as long narrow belts from north to south. The south eastern region of Tamilnadu indicated a moisture status of less than –33.3% that keeps it at semiarid (D) type with isolated stations of Coimbattore and

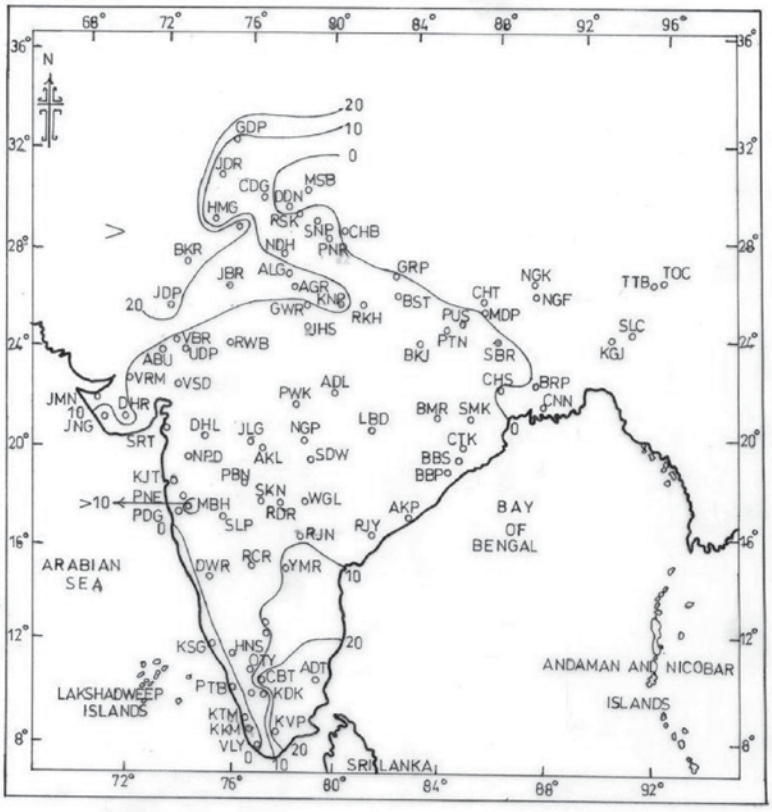

Figure 5. Mean weekly water deficit (mm) over India – Monsoon period.

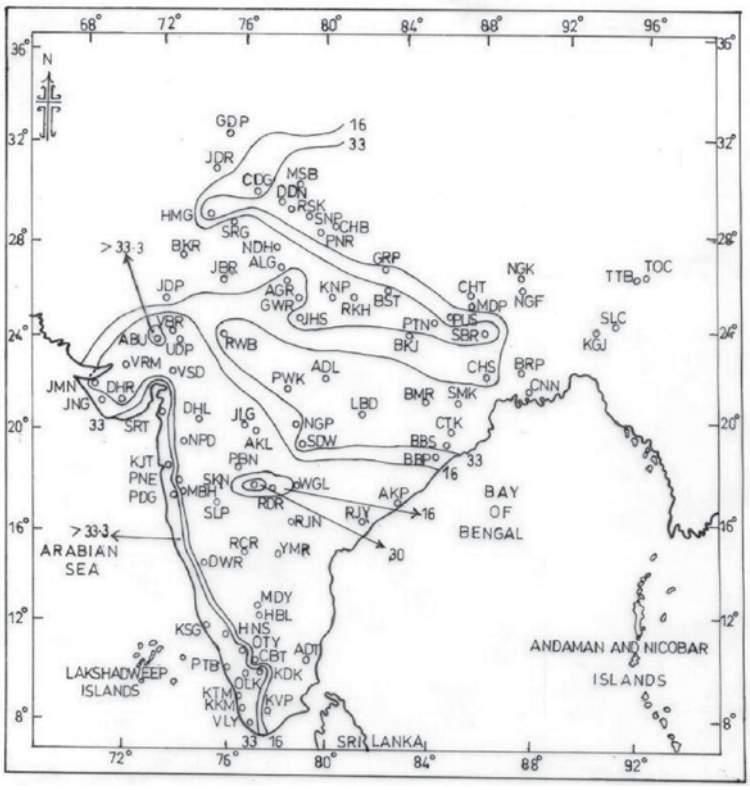

Figure 6. Mean weekly humidity index (%) over India – Monsoon period.

Kovilpatti recording less than – 66.6% as their moisture index are under arid (E) type of climate. The north- eastern region has recorded more than 100% of moisture index and is under perhumid climate status. The moisture index is decreasing towards the northwestern part of India from east and accordingly the march of zonation is perhumid, humid, moist subhumid, dry subhumid and semiarid types. Sriganganagar from arid zone has recorded a moisture index of less than – 66.6%.

i) Mean weekly soil moisture adequacy pattern:

The soil moisture adequacy over India ranges from 19% to 100% (Fig.9).The areas with a moisture adequacy of 100% are in northeast and southwest coast of India that indicates the moisture of these regions have strong bearing on prevalence of the strength and depth of southwest monsoon circulation .The index falls to less than 25% near the northwestern regions and southeastern regions of peninsular India. A major part of India displayed an adequacy of 75% to 100%.Higher values of adequacy are due to the availability of soil moisture after meeting the water need of the places that might be responsible in supporting apart from crops the forest vegetation also. The intensive and sustained agricultural practices over any landscape need the prevalence of higher moisture adequacy values.

j) Mean weekly soil wetness pattern:

The mean weekly soil wetness over India for the monsoon period is depicted in Fig.10. The wetness is varied from zero to 100%. The saturated soils (100% wetness) are found at Kasargod (KSG), north of Kottayam (KTM) and south of Kayamkullam (KKM) in south India and in the northeastern states of India. The steep gradients in soil wetness both meridionally and zonally are observed over India and as a consequence areas with less than 25% soil wetness are found in between the region bounded by Dhule (DHL), Rajendranagar (RJN), Dharwar (DWR) and Kovilpatti (KVP) in south and from north of Gurudaspur (GDP) to south of Jodhpur (JDP) in north -western India. The regions at and around Sindewahi (SDW) and Labhandi(LBD) and Canning(CNN), Barrackpore (BRP) and Samakunta(SMK) have recorded more than 75% of soil wetness from regions whose soil wetness is varied from 50 to 75% while the rest of the regions have recorded a soil wetness that fluctuated from 50 to 75%.

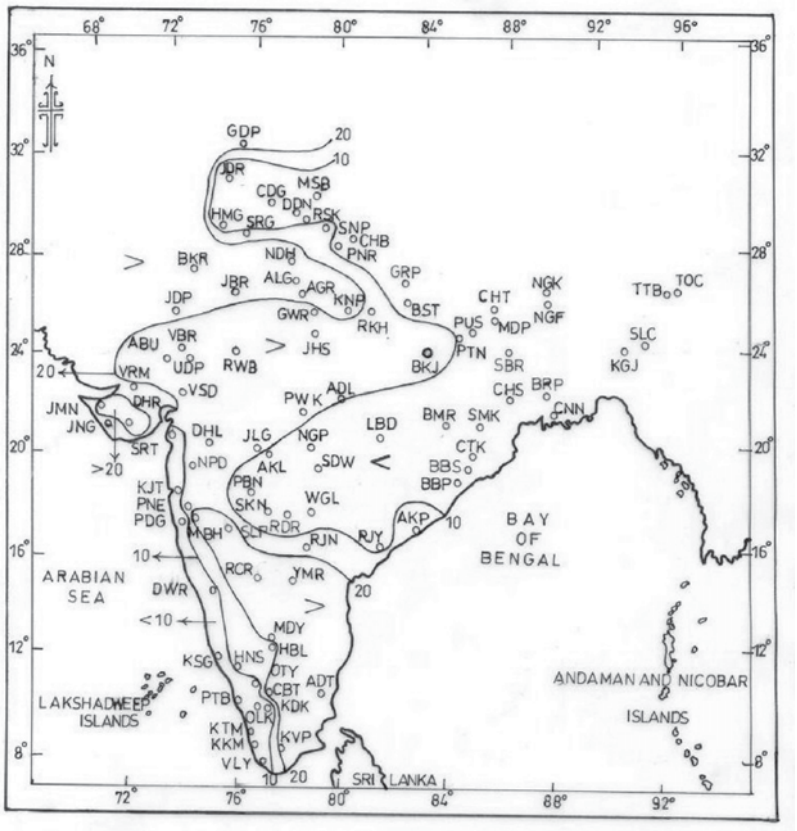

Figure 7. Mean weekly aridity index (%) over India – Monsoon period.

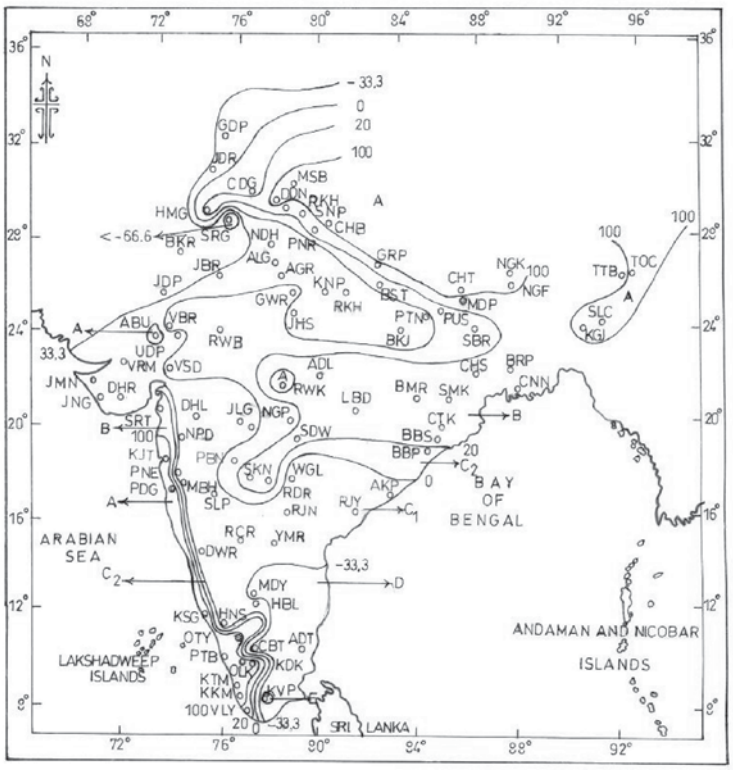

Figure 8. Mean weekly moisture index (%) over India – Monsoon period.

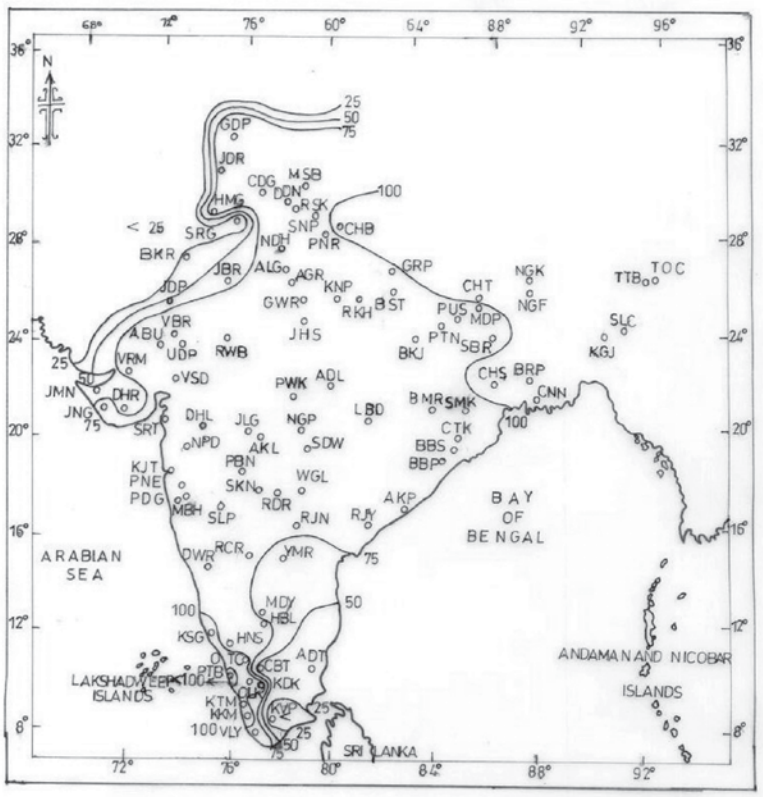

Figure 9. Mean weekly soil moisture adequacy (%) over India – Monsoon period.

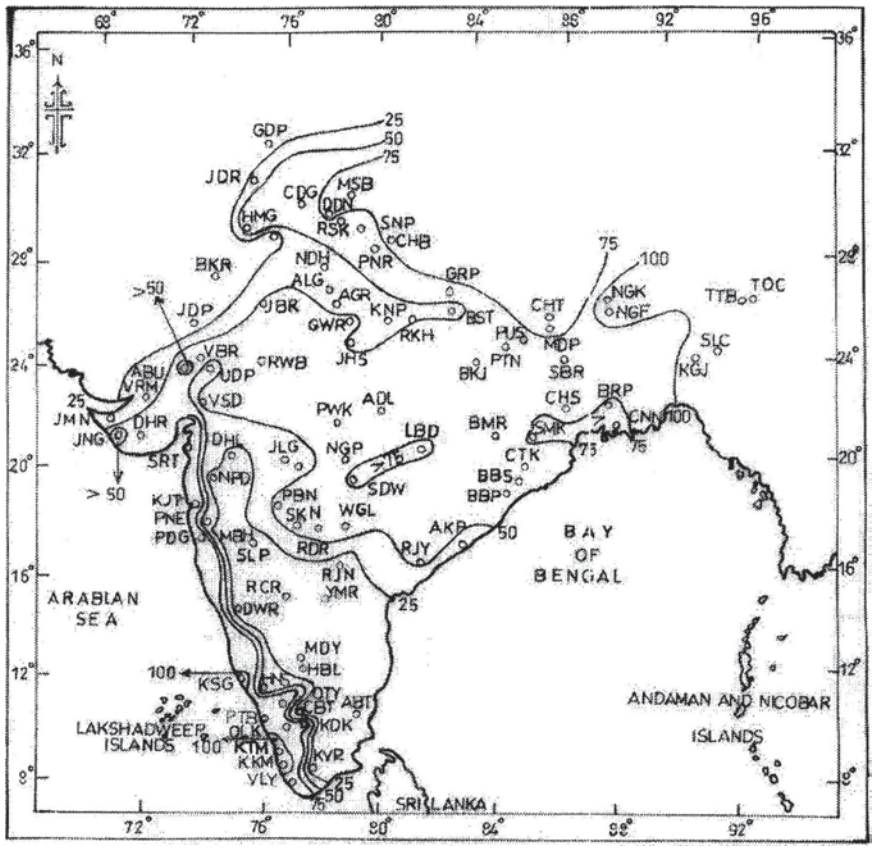

Figure 10. Mean weekly soil wetness (%) over India – Monsoon period.

WEEKLY WATER BALANCE – INDIA

Comparing the water supply from rainfall with the expenditure by way of potential evapotranspiration, one can account the way how the rainfall is accounted through land surface processes for the given point. In this context it is very important to give the due weightage to the soil since the soil plays the role of a capacitor capable of storing infiltrated soil water during the periods of excessive rainfall and releasing the stored soil water to meet the water need during deficit timings.

It is evident from the present investigation that the hydrologic regime of All India during the monsoon period is first humid climate (B_1), with a mean weekly precipitation of 57 mm and a potential evapotranspiration of 36 mm that could result in a moderate water surplus of 14 mm and a water deficit of 1 mm. The soils are at 98% of moisture adequacy with a 74% of wetness in general (Table 2.).

The water budget elements of the selected stations that represent the varied climates of India are presented in Table 2. The analysis of water budget elements for a station gives information regarding the quantity, duration and prevalence of the water surplus along with water deficit and can be used to plan not only for the optimum utilization of available water resources but also for a better management during extreme climate shifts.

In perhumid zone (A), the water balances of Karjat (KJT) and Tocklai (TOK) from north and south India respectively displayed a rainfall distribution that produced huge amounts of water surplus during the monsoon period with no water deficit. The high quantum of rainfall maintains the soils of these regions at 87% and 79% of soil wetness with a soil moisture adequacy of 97% and 100% respectively (Table 2.).

In the humid climates (B), there was an increase in the water deficit, associated with a diminished water surplus compared to the perhumid climates and is evident from the water balances of Adhartal (ADL), and Rudrur (RDR) that represent the humid climates of north and south India respectively (Table 2). The moist subhumid climate zone (C_2), exhibits a further reduction in the water surplus combined with an increase in water deficiency and is evidenced from the water balances of Sabour (SBR) and Junagarh (JNG) that are drawn from north and south India respectively (Table 2.) and the consequence of increased water deficit reflected in the natural vegetation of this zone namely open jungle type interspersed with shrubs and tall grasses.

The climate feature of dry subhumid zone (C_1) is perceptible for Solapur(SLP) and Rajendranagar (RJN) that are from north and south India respectively and that the water surplus is absolutely absent with an increase in the water deficit due to the fall in the rainfall by 50% from its counterparts of moist ones (Table 2.). The water surplus in this boarder zone is not uncommon but occurs in small amounts depending upon the strength of the sw monsoon circulation pattern. The soil wetness in this zone is less than 20% and as a result, the drought resistant vegetation can sustain successfully here.

Table 2. Mean weekly water budget elements and climate indices - Monsoon period.

Station	*P (mm)*	*PE (mm)*	*AE (mm)*	*S (mm)*	*D (mm)*	*I wh (%)*	*I wa (%)*	*Iwm (%)*	*Soil wetness (%)*	*Soil moisture adequacy (%)*
All India	**57**	**36**	**35**	**14**	**1**	**40**	**1**	**39**	**74**	**97**
					Perhumid zone (A)					
Tocklai	**75**	**37**	**37**	**38**	**0**	**107**	**0**	**107**	**79**	**100**
Karzat	**185**	**34**	**33**	**144**	**1**	**439**	**2**	**437**	**87**	**97**
					Humid zone (B)					
Adhartal	**67**	**37**	**33**	**29**	**4**	**91**	**10**	**81**	**70**	**89**
Rudrur	**48**	**34**	**31**	**9**	**3**	**31**	**8**	**23**	**63**	**91**
					Moist subhumid zone (C_2)					
Junagarh	**45**	**37**	**31**	**8**	**6**	**22**	**15**	**7**	**67**	**84**
Sabour	**50**	**39**	**37**	**3**	**2**	**7**	**5**	**2**	**50**	**94**
					Dry subhumid zone (C_1)					
Solapur	**31**	**34**	**27**	**0**	**7**	**0**	**21**	**-21**	**9**	**78**
Rajendra Nagar	**21**	**38**	**30**	**0**	**8**	**0**	**20**	**-20**	**16**	**79**
					Semiarid zone (D)					
Jodhpur	**20**	**41**	**20**	**0**	**21**	**0**	**50**	**-50**	**3**	**50**
Aduthurai	**18**	**38**	**18**	**0**	**20**	**0**	**51**	**-51**	**0**	**48**

Jodhpur (JDP) and Aduthurai (ADT) from the semiarid climate of north and south India clearly displayed a sharp rise in water deficit and water need for a drastic fall in rainfall and as a consequence the soils are dry with a steep fall in the soil moisture adequacy. The prolonged duration of dryness resulting in higher quantum of water deficit that could support only the deciduous or dormancy in vegetation with tiny and thick leaves of hardy trees and scrubby type of low vegetation.

OCCURRENCE OF HUMID AND DROUGHT EVENTS

a) All India: The hydrological regime of All India during the monsoon period is studied through the humidity, aridity and moisture indices (Table 3). Among three indices, the moisture index has registered high standard deviation followed by humidity and aridity (Table.3). The percentage departures of humidity and moisture indices of All India during the monsoon period have crossed the two sigma limit , six times from the 29th week to 34th week in recording 6 high humid and 6 high climate shifts respectively with only one severe drought event (Fig.11).

b) Moist Climates: Among the six stations from moist climate zones Karjat (KJT) experienced a total of 9 moderate humid events and higher variability in humidness with a high mean of 437% and a standard deviation of 311% of humidity index on a weekly basis during the monsoon period (Table 4.). On the other hand Sabour (SBR) from moist subhumid zone with its lowest mean (7%) and standard deviation (16%) has registered only 3-high humid events during the monsoon period.

c) Dry Climates: **In the dry climates (dry subhumid and semiarid), Aduthurai(ADT) witnessed a maximum total of 9 drought events of which eight were severe and** one was very **severe drought category with a mean of 51% and standard deviation of 26% in aridity index respectively (Table 5.). The frequency of very severe droughts is greatest (7) at Solapur (SLP) followed by Jodhpur (JDP) and Rajendranagar (RJN) from semi arid and dry subhumid zones respectively.**

The total number of humid events is decreasing from perhumid to moist subhumid climates while the total number of drought events is almost constant (9) in dry climates (Tables. 4&5). A characteristic feature of perhumid climate is that the magnitude of the mean humidity index is very high (> 100 to 400) compared to humid and moist subhumid zones and this might be attributed to the prevailing weather systems associated with the southwest monsoon system. Apart from other factors the fluctuations in the varied categories of humid and drought events in humid and dry climates has a strong bearing on the waxing and waning monsoon circulation pattern in time and space over India.

Table 3. Climate stress statistic of All India– Monsoon period.

Mean humidity index (%)	Standard Deviation (%)	**Humid Events**			Total
		High	Very	Moderate	
40	**46**	**6**	**0**	**0**	**6**
Mean aridity index (%)	Standard Deviation (%)	**Drought Events**			Total
		Very Severe	Severe	Moderate	
2	6	1	0	0	1
Mean moisture index (%)	Standard Deviation (%)	**Climate Shifts (%)**			Total
		High	Large	Moderate	
38	48	6	0	0	6

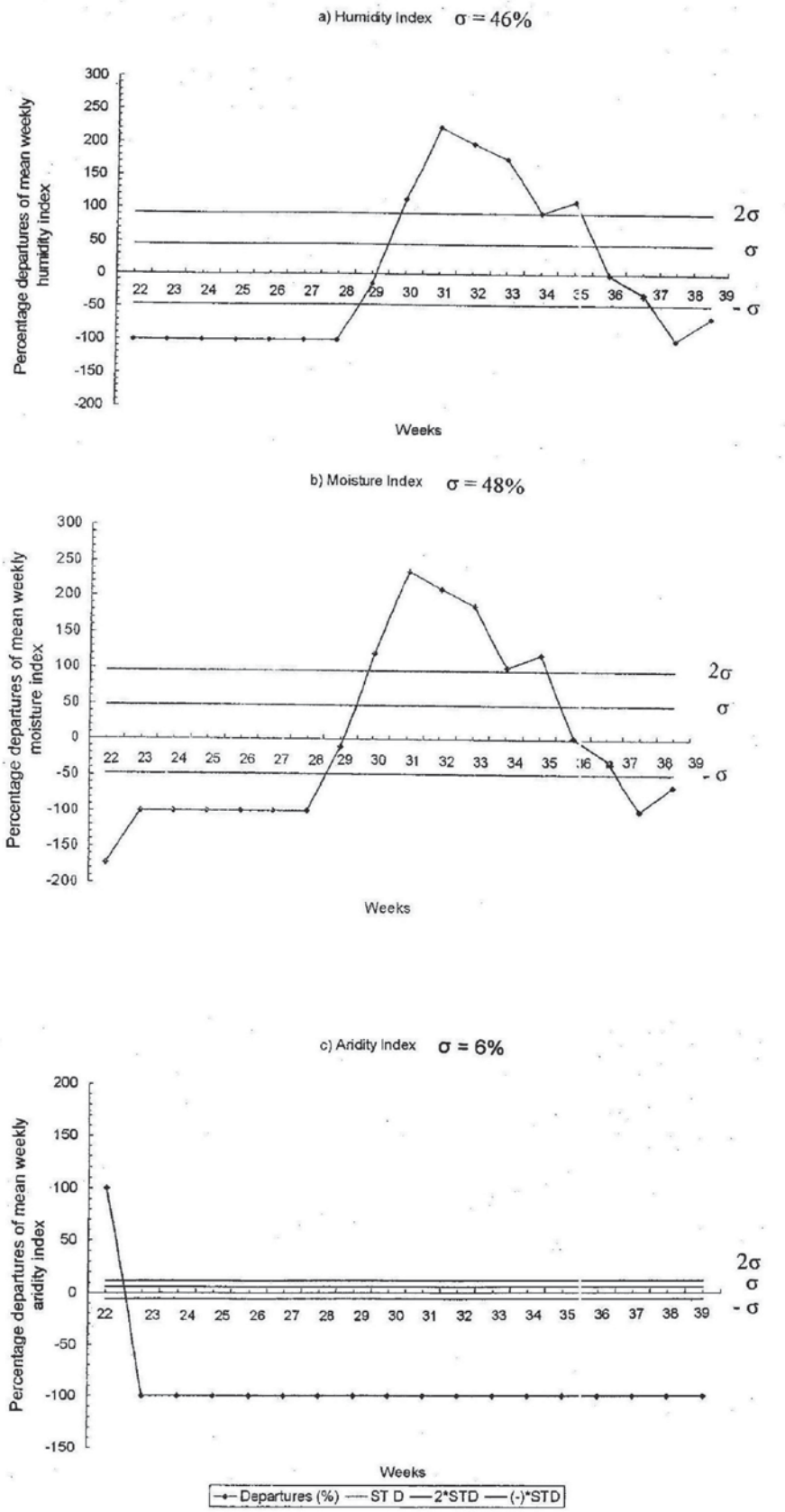

Figure11. March of All India mean weekly humidity, moisture and aridity indices – Monsoon period.

Table 4. Proneness to humid events – Moist climates.

Station	Mean aridity index (%)	Standard Deviation (%)	Drought Events			Total
			Very Severe	Severe	Moderate	
Dry subhumid Zone (C_1)						
Solapur	21	22	7	1	0	8
Rajendranagar	20	21	5	2	1	8
Semi arid Zone (D)						
Jodhpur	50	33	6	2	0	8
Aduthurai	51	26	1	8	0	9

Table 5. Proneness to drought events- Dry climates.

Station	Mean humidity index (%)	Standard Deviation (%)	Humid Events			Total
			High	Very	Moderate	
Perhumid Zone (A)						
Tocklai	107	44	0	4	7	11
Karjat	439	311	0	0	9	9
Humid Zond (B)						
Adhartal	91	116	1	3	1	5
Rudrur	31	48	4	2	0	6
Moist subhumid Zone (C_2)						
Sabour	7	16	3	0	0	7
Junagarh	22	42	4	0	0	4

SUMMARY AND CONCLUSIONS

The meridional and zonal gradients in rainfall, actual evapotranspiration, water surplus, soil wetness, soil moisture adequacy, humidity and moisture indices are from west coast to southeast coastal region in south and are from east to west in north India with an exception to potential evapotranspiration. The increase in aridity is west to east in south and is east to west in north. The hydrological regime of All India has witnessed 6 high humid events that forced it to experience 6 high climate shifts. The mean and standard deviation values of humid index are decreasing from perhumid to moist subhumid climates. It is interesting to note that the total number of climate stress events are high in dry climates compared to humid and moist subhumid types.

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REFERENCES

Bhalme, H.N. & Mooley, D.A., 1980. Large scale droughts, floods and monsoon circulation, Mon. Weather Rev., (USA), 108, 1197.

Bhalme, H.N. & Mooley, D.A., 1981. Cyclic fluctuations in the flood/drought area and relationship with the double (Italy) sunspot cycle. J. Appl.Meteorology, 29, 1041.

Chowdhury, A & Mhasawade, S.V., 1991. Variations in

meteorological floods during summer monsoon over India, Mausam, 42, 157-170.

Gore, P.G., & Thapliyar, V., 1999. Occurrence of Dry and Wet weeks over Maharashtra, Mausam, 51 (1).

Kambete, N.N., 1992. Agroclimatic Classification for assessment of the Crop potential of Karnataka, Mausam, 43 (1), 91-98.

Mather, J.R., 1966: Elements of the classification. Climatic Classification for Environmental Biology.Publ.in clim. 19 (4), 341-352.

Sarma, A.A.L.N., 1983. Moisture adequacy in relation to forestry and agriculture land use in Mahanadi river basin. IAHS Publ.no.140, U.K, 259-264.

Rasmusson, E.M. & Wallace, J.M., 1983. Meteorological aspects of El Nino/Southern Oscillation.Science, 222, 1195-1202.

Ropelewski, C.J. & Halpert & M.S., 1987: Global and regional scale precipitation associated with ENSO.Mon.Wea.Rev, 115, 1606- 1626.

Sarma, A.A.L.N. & Ravindranath, M., 1984. A study of aridity and droughts in the climatic spectrum of south Indian region, Mausam, 35 (3), 287-290.

Sarma, A.A.L.N. & Ravindranath, M., 1986: Studies on the incidence of droughts through seasonal aridity index, Mausam, 37 (2), 207-210.

Sarma, A.A.L.N., Padma Kumari, B. & Srinivas, S., 1999. Studies on Hydrological Extremes – ENSO Signal. IAHS Publication No.255, U.K., 73-80.

Sarma, A.A.L.N., Srinivas, S. & Karthikeya, A., 2005 a. Studies on aberrations in climate impacts – Water balance model, J.Indian Geophysics Union, 9 (3) 209-218.

Sarma, A.A.L.N. & Srinivas, S., 2005b: Studies on the intensification of the hydrologic cycle over India. J.Ind.Geophys.Union., 9 (4), 299-313.

Sarma, A.A.L.N., 1987. Occurrence of aridity an droughts – SW monsoon, IAHS, W-7 Hydrological sciences in developing countries, XIX IVGG Assembly, Vancouver (Canada).

Sarma, A.A.L.N., 2006. Modeling of water budget elements – Extreme events, Indian J. Radio & Space Physics, 35, 26-34.

Sarma.A.A.L.N. & Sivaram, B., 2010. Weekly growing periods in extremities over India-Monsoon period, J. Ind.Geophys. Union, 14 (1), 57-66.

Sikka, D.R., 1999. Monsoon droughts in India. Joint COLA/CARE Tech.Report.No.2, COLA/IGES Calverton, Md, U.S.A., pp.270.

Sikka, D.R., 2000.. Monsoon Floods in India. Joint COLA/CARE Tech.Report.No.4, COLA/IGES Calverton, Md, U.S.A.

Sivaram, B., & Sarma, A.A.L.N.:2008: Studies on hydrologic extremities over India-Monsoon period. J.Ind. Geophys.Union, 12(2), 79-88.

Subrahmanyam, V.P., Subba Rao, B. & Subramaniam, A.R.,1963. Moisture adequacy in relation to the distribution of some crops in India.IAHS Publ.no.62, U.K.

Subrahmanyam, V.P. & Sarma, A.A.L.N., 1981. Evolution of the Indian climates and water use planning, Trans. Inst. Indian Geographers, 3 (2) 103-114.

Thornthwaite, C.W. & Mather, J.R., 1955. The Water Balance, Publ.in Clim. Drexel Instt.Tech, 8 (1), U.S.A.

Webster,P.J., Palmer,T.N., Manga,V.O., Shukla,J., Thomas,R.A.,Yani,T.M. &Yasunari, A., 1998.Monsoon: Processes, Predictability and the Prospects for Prediction, J. Geophys.Res, 103, C7.14451-14510.

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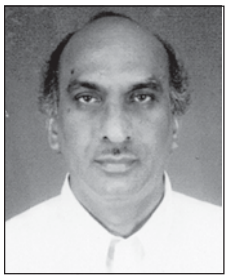

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