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Hydro-climatic characteristics of hill stations of India

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सार – इस शोध पत्र में देश के सभी क्षेत्रों से चयन किए गए 18 पर्वतीय स्थानों की जलीय जलवायविक विशेषताओं का विवेचन किया गया है। चुनिंदा सभी 18 स्थानों में वर्ष 1961-2010 तक की अवधि के जलवायु स्थायित्व, जल बजट तत्वों के नार्मल और चरम मानों को आर्द्रता, शुष्कता एवं नमी घातांकों के अन्तर वार्षिक विभिन्नता के अध्ययन से प्राप्त किया गया है। नमी घातांक पर ऐन्सो और ला-नीना की परिघटनाओं का तथा स्टेशन विशेष पर जल बजट तत्वों के चरम मानों का प्रभाव इस शोध के अध्ययन का एक दूसरा पहलू है। इसके लिए यह उचित है कि आर्द्र (बाढ़) और सूखा की परिघटनाओं के होने तथा उसकी तीव्रता की बारंबारता का अध्ययन वार्षिक आधार के बजाय दक्षिण-पश्चिमी मॉनसून ऋतु के दौरान किया जाए, क्योंकि वार्षिक वर्षा की 75 प्रतिशत वर्षा दक्षिण-पश्चिमी मॉनसून ऋतु के दौरान ही होती है। कई शोध पत्रों में भी इस निष्कर्ष पर पहुँचा गया है कि दक्षिण-पश्चिमी मॉनसून की सक्रियता का सीधा संबंध एन्सो (ENSO) और ला-नीना की घटनाओं से होता है। आर्द्र (बाढ़) और सूखे की परिघटनाओं के होने और उसकी तीव्रता की बारंबारता को दक्षिण-पश्चिमी मॉनसून ऋतु के दौरान आर्द्रता एवं शुष्कता घातांकों को ऋतुनिष्ठ परस्पर भिन्नताओं के अध्ययन के द्वारा प्राप्त किया गया है। आर्द्रता और शुष्कता घातांकों पर ऋतुनिष्ठ आर्द्रता सूचकांक और एन्सो (ENSO) एवं ला-नीना परिघटनाओं के प्रभाव की प्रवृति को भी इस शोध पत्र में प्रस्तुत किया गया है। बाढ़/सूखा पड़ने की परिघटनाओं की बारंबारता को क्षेत्रवार और दशकवार प्रस्तुत किया गया है। नम जलवायु वाले कुल 17 पर्वतीय स्थानों की बाढ़ वाली कुल परिघटनाओं के प्रतिशत को आपस में मिलाकर श्रेणीवार उनकी प्रवृति को दर्शाया गया है। वाष्पोत्सर्जन एवं वर्षा की मात्रा की माहवार गणना की गई है जिससे कि मौलिक जलीय बजट तत्वों एवं इनसे संबंधित अन्य प्राचलों को प्राप्त करने के लिए संशोधित थ्रोन्थवेट एवं मैदर जल संतुलन मॉडल को सुदृढ़ किया जा सके।

ABSTRACT. Hydro climatic characteristics of 18 hill stations selected from all regions of the country is taken up in the present investigation. Climatic shifts and stability, normal as well as extremities of water budget elements at all the 18 selected stations for the 1961-2010 period are obtained through study of inter annual variation of humidity, aridity and moisture indices. Decadal frequency of climatic shifts, influence of ENSO and La Nina events on moisture index and extremities of water budget elements at individual stations is another aspect that is studied. It is appropriate that frequency of occurrence and intensities of humid (Flood) and drought events are studied during southwest monsoon season rather on annual basis, as 75% of annual rainfall occur during southwest monsoon season. Also several studies concluded that performance of southwest monsoon has teleconnection to the ENSO and La Nina phenomena. Frequency of occurrence and intensities of humid (Flood) and drought events have been obtained through study of inter seasonal variation of humidity and aridity indices during southwest monsoon season. Trend in seasonal humidity index and the influence of ENSO and La Nina events, in the study period, on the humidity and aridity indices is also presented. Region-wise and decadal frequency of occurrence of humid / drought events is brought out. Percentage occurrence of total humid events over all 17 moist climate hill stations put together, category wise as well as total, along with their trend is also brought out. Potential evapotranspiration and precipitation are computed on a monthly basis to force the revised Thronthwaite and Mather water balance model to derive the basic water budget elements and thereby other parameters.

Key words – Annual humidity index I_h, Annual aridity index I_a, Annual moisture index I_m, Seasonal humidity index I_{sh}, Seasonal aridity index I_{sa}, Seasonal moisture index I_{sm}, ENSO – El Nino Southern Oscillation, La Nina, Potential evapotranspiration P. E., Precipitation P, Water deficit W. D., Water surplus W. S.

1. Introduction

Hill stations are fragile to weather as they are subjected to different weather processes compared to counterpart plain stations, therefore experience varied climates at once. Hill stations play an important role in atmospheric circulation, biodiversity, rainfed and irrigated agriculture, hydropower and tourism. Himalayas often referred as 'Roof of the World' contains the most extensive and rugged hill stations of Earth. Its water resources drain through ten of the largest rivers in Asia and basins of these rivers are inhabited by about 1.3 billion people. Cherrapunji in eastern Himalayas is the world's second highest rainfall point with annual, monsoon season and 24 hour highest rainfall values of 1126, 841 and 98 cm respectively and world's highest 48 hour rainfall of 2493 mm. Mahabaleswar, known as queen of hills in the western ghats region, with monsoon season rainfall of 536 cm, has water resources that drain through five rivers including mainstream Krishna. Mount Abu with famous name "Queen of Oasis" and Pachmarhi in Aravalli region are the important sources of fresh water. It is reported that water resources of hilly regions are currently facing threats due to climate change which has serious implications for downstream water and livelihood of people. Forecasts of climate change offer possible impacts on water resources and predicted impacts vary by region, but include increased temperature, evaporation rates and shift in the proportionate form of rain which ultimately cause summer droughts (Adams and Peck, 2008). The reported global average warming in only 0.74 °C over the last 100 years while it is 0.6 °C per decade in Nepal in greater Himalayas. Changes in precipitation are ambiguous with both increasing and decreasing trends in different parts of the region. The most serious changes are probably related to the frequency and magnitude of occurrence of two extremes of hydrological cycle, *i.e.,* droughts and floods. Mall *et al.* (2006) have reported that climate change can influence the soil moisture and thereby the frequency of floods. Mooley, *et al.* (1984) have predicted no trend in monsoon rainfall and mainly random in nature over long period. There is gap in the climatological studies over the hill stations of India due to complex and extreme topography and inadequacy of observational network. Even though floods and droughts are the two sides of hydrological cycle, numerous studies has piled up on the incidence of droughts over different parts of India (Sinha Ray & Shewale, 2001; Sarma & Ravindranath, 1983; Sarma & Vizaya Bhaskar, 2003; Sarma & Srinivas, 2005) but very meagre research has been done in understanding the nature, magnitude and frequency of occurrence of floods/ humid events (Sarma & Sanyasi Rao, 1981). Incidence of floods/humid events even though cause dislocation in day-to-day life through inundation of agricultural fields, public roads and residential colonies are beneficial also, as it fortifies the water resources in the region of their occurrence. In the present investigation, some of the aspects of frequency of extreme climate variability, which as a consequence of global warming, is reported through water balance model with reference to selected hill stations of India, in terms of humidness, droughts, climate shifts and stability and water budget elements. Trend of humidity index and frequency of humid events in the study period is also presented. Modulation of annual basic water budget elements compared to normal and in the context of ENSO and La Nina events is another aspect studied. Climatic shifts and stability at a station is significant in the assessment of climatological potentiality for development and this is addressed in the present study.

2. Data and methodology

Potential evapotranspiration is obtained from the modified equation of Penman (1948) as employed by (Rao *et al*., 1971; Abbi *et al*., 1976) and is one of the inputs along with the rainfall in forcing the revised water balance model of Thornthwaite and Mather (1955) that provides a quantitative assessment of water deficiency and water surplus. Precipitation is compared with potential evapotranspiration on a monthly basis and positive difference between precipitation and potential evapotranspiration indicates excess of water which is available during certain period in the year for soil moisture recharge upto its water holding capacity and any excess precipitation is treated as water surplus resulting in surface run-off. On the other hand, negative difference between precipitation & potential evapotranspiration shows the amount by which the precipitation falls short of the potential water need of vegetation covered area and water is drawn from the soil moisture storage. Accumulated values of difference between precipitation and potential evapotranspiration in such case give an estimation of the moisture stored in the soil at the end of the period of negative difference between precipitation and potential evapotranspiration as per following equation.

$$\text{Storage} = \text{Field capacity} * \text{Exp}\ (\Sigma\ (P - P_E)/\text{Field capacity})$$

The amount by which the potential and the actual evapotranspiration differ in any month is the moisture deficit for that month. In determining the water holding capacity of the soils, the structure and texture of the soil and the type of vegetation or crop that is grown are considered as suggested by Thornthwaite and Mather (1955) and for the 18 stations in the present study, it was 150 and 200 mm. Water balances for 18 hill stations of India for the time period of 1961 to 2010 are evaluated following the procedure of Thornthwaite and Mather (1955). Since water deficiency and water surplus obtained from the model are absolute quantities, these are compared with the water need and annual aridity and humidity indices defined as the ratio of annual water deficiency or surplus to the annual potential evapotraspiration are computed and used in study of droughts and humid events. At each station annual aridity

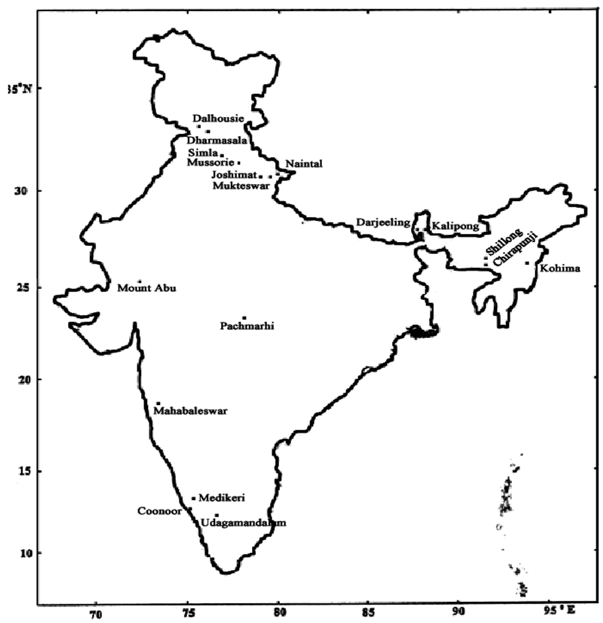


Fig. 1. Spatial location of selected stations

(I_a) and humidity (I_h) indices have been worked out as shown under.

$$I_a = (100 * WD) / PE$$

$$I_h = (100 * WS) / PE$$

where, PE is the annual potential evapotranspiration and WS and WD are the annual water surplus and water deficiency respectively.

The revised expression for moisture index (I_m) and its limits for classification of main climate types as suggested by Carter and Mather (1966) is followed and is obtained on yearly climate concept for determining the main climate type of selected stations.

$$I_m = I_h - I_a$$

Perhumid (A) ($I_m > 100\%$), Humid (B) (I_m 20-100%), Moist subhumid (C_2) (I_m 0 - 20%, Dry subhumid (C_1) (I_m 0- -33.3%), Semi-arid (D) (I_m -33.3 - -66.7%) and Arid (E) ($I_m < -66.7\%$). Out of 18 stations, 17 are moist climates and lone station is dry climate. Climate types of stations are considered stable, if it experiences the given climate type, more than 70% time of total observations as suggested by Yoshino and Urishibara (1981) and Sarma and Ravindranath (1983) and yearly concept is adopted. Water budget elements during extreme wet and dry spells are obtained through the maximum and minimum values of annual moisture index respectively in the study period at each of 18 stations.

It is well known that more than 75% of annual rainfall of India occurs during southwest monsoon season and most of the agricultural production takes place during the season. India meteorological Department (IMD) monitor the floods and droughts during monsoon seasons only and teleconnection to the ENSO and La Nina events exists only to the southwest monsoon season rainfall. Hence, it is meaningful to study incidence and intensity of humid and drought events during southwest monsoon season rather on annual basis. In view of the above seasonal concept is employed for determining the water surplus, water deficiency, water need and aridity and humidity indices similar to annual notion as explained above to study frequency and intensity of humid and drought events. Also, it is appropriate to study humid events (Floods) over moist climate stations and droughts for dry climate stations. Seasonal aridity (I_{sa}) and humidity (I_{sh}) indices have been obtained as below

$$I_{sa} = (100 * SWD) / SPE$$

$$I_{sh} = (100 * SWS) / SPE$$

where, SPE, SWS and SWD are the potential evapotranspiration, water surplus and water deficiency for southwest monsoon season respectively. To make an inter comparison of humidity and aridity indices among the selected stations, the departures of seasonal humidity and aridity indices from the median are normalized by expressing the departures as percentage of the respective median values. To classify the humid and drought events severity wise, standard deviation (σ) is used. Humid events are classified as moderate humid (MH), very humid (VH) and high humid (HH) according as the percentage departure of humidity index from the median is 0 to 1σ , 1 to 2σ and greater than 2σ as suggested by Sarma and Sanyasi Rao (1981) and Sarma *et al*. (1999). Similarly droughts are classified as slight (SLT), moderate (MDT), severe (SEV) and very severe (VSEV) according as the percentage departure of aridity index from the median is 0 to 0.5σ, 0.5 to 1σ, 1 to 2σ and greater than 2σ as suggested by Sarma & Ravindranadh (1986) and Sarma and Bhaskar (2003). Humid events are studied for moist climate stations and droughts for lone dry climate station. Using the number of years of study, percentage occurrence of humid and drought events is worked out category wise as well as for all categories. Trend in seasonal humidity and aridity indices has been studied using linear trend analysis and statistical significance test has been carried out on results for more than 95% level. All category and each category frequency of humid events over four broad regions of India (North, Northeast, West and Peninsular) is worked out using the humid events data at the individual stations in the respective regions. Decadal results in terms of occurrence of humid events and

TABLE 1

Statistic of humidity index of selected hill stations of India - humid events - SW monsoon season - moist climates

Station	No. of years	Climatic I_{sh}	Standard deviation of I_{sh}	ENSO & La Nina years with significant change in I_{sh}	No. of humid events % in brackets				Trend
					Moderate	Very	High	Total	
Dalhousie	28	198	108	Second lowest 1987 & third lowest 1982	12 (43)	02 (07)	00 (00)	14 (50)	Decreasing
Simla	33	195	148	Lowest 1987 & second lowest 1965	15 (45)	01 (03)	01 (03)	17 (52)	Insignificant
Mussorie	27	326	131		14 (52)	00 (00)	00 (00)	14 (52)	Decreasing
Mukteswar	50	135	081	Lowest 1987 & third lowest 1965	19 (38)	03 (06)	03 (06)	25 (50)	Insignificant
Naintal	19	395	096	Lowest 1965	10 (53)	00 (00)	00 (00)	10 (53)	Insignificant
Joshimat	28	062	047	Lowest 1965	02 (07)	02 (07)	10 (36)	14 (50)	Decreasing
Dharmasala	47	311	102	Lowest 1965 second lowest 1987& third lowest 1982	24 (51)	00 (00)	00 (00)	24 (51)	Insignificant
Mount Abu	50	191	157	Lowest 1987, 2002	21 (42)	03 (06)	01 (02)	25 (50)	Insignificant
Darjeeling	48	534	435	Lowest 2002 Second highest 1998	25 (52)	01 (02)	00 (00)	26 (54)	Decreasing
Kalipong	48	348	158	second lowest 1965 & third lowest 1997	24 (50)	00 (00)	00 (00)	24 (50)	Insignificant
Kohima	28	266	080	Lowest 1982	15 (54)	01 (04)	00 (00)	16 (57)	Insignificant
Shillong	47	309	107		24 (51)	00 (00)	00 (00)	24 (51)	Insignificant
Chirapunji	45	2344	875	Second highest 1988	23 (51)	00 (00)	00 (00)	23 (53)	Insignificant
Pachmarhi	31	313	141		16 (52)	00 (06)	00 (00)	16 (52)	Insignificant
Mahabaleswar	48	1555	474		24 (50)	00 (00)	00 (00)	24 (50)	Decreasing
Coonoor	33	022	011	Lowest 1972, 1982, 87, 2009	00 (00)	00 (00)	04 (12)	04 (12)	Insignificant
Medikeri	50	439	235	Lowest 1987 Second lowest 1982	24 (48)	01 (02)	00 (00)	25 (50)	Insignificant
Total	660				292 (44)	14 (02)	19 (03)	325 (49)	

climatic shifts is computed and separated for 1971-1990 period with a view to verify report of PAGES News (1997). Spatial location of the stations is shown in Fig. 1.

3. Results and discussion

3.1. *Inter seasonal variation of humidity index– moist climates – humid events*

Out of 18 stations selected, 17 stations are harbouring moist climates on annual basis. More than 75% of annual rainfall realize during southwest monsoon season. IMD monitors the floods and droughts through its flood forecasting offices and drought monitoring unit during monsoon seasons only. Therefore an attempt is made to study humid events during the southwest monsoon season following the seasonal concept rather annual basis at these moist climate stations. Percentage departure of monsoon season humidity indices from the study period median are worked out and compared with standard deviation at each station. Occurrence of seasonal humid events intensity wise as moderate, very and high humid are arrived according as, percentage departure of seasonal humidity index is 0 to 1, 1 to 2 and more than 2 times of the standard deviation respectively and shown in Table 1 along with some statistical details. It is revealed from Table 1, that there is incidence of 325 humid events of all categories at 17 stations put together in 660 seasons studied, *i.e.,* there is 49% susceptibility to humid events. Among the individual stations, the liability to total humid events varied from 12 to 57%. Kohima from northeast India recorded the highest frequency of 16 (57%) total humid events and category wise these are 15 (54%) moderate and 01 (04%) very humid events. Darjeeling again from northeast India has registered the second highest frequency of 26 (54%) total humid events and category wise these are 25(52%) moderate and 01(2%) very humid (Table 1). Many stations have subjected to 50% frequency of total humid events. Analysis of category wise susceptibility to humid events at individual

TABLE 2

Region wise frequency of humid events over selected hill stations - SW monsoon season- moist climates

	No. of years	No. of humid events. Events per season in bracket			
		moderate	very	high	All category
North India	232	096 (41)	08 (03)	14 (06)	118 (51)
North east India	216	111 (51)	02 (01)	00 (00)	113 (50)
Peninsular India	162	064 (40)	01 (01)	04 (02)	069 (40)
Western India	050	021 (42)	03 (06)	01 (02)	025 (50)

hill stations (Table 1) shows that Kohima and Nainital had highest frequencies of 54 and 53% respectively to moderate humid. In respect of very humid category Dalhousie and Joshimat both from western Himalaya region have recorded the maximum frequency of 7% humid events. Similarly Joshimat and Coonoor from western Himalaya and Peninsular India regions had first and second highest frequency of 36 and 12% respectively to high humid category (Table 1). Seasonal humidity indices are tested for statistical significance (Significant ≥ 95% level) and shown in Table 1. Among 17 stations, significant decreasing trend observed at five stations and at the remaining stations the trend is insignificant. In the study period 1965, 1972, 1982, 1987, 1991, 1997, 2002 and 2009 years ENSO events and 1973, 1975, 1988, 1998 and 2010 years La Nina events are considered to know their influence on the seasonal humidity index. Shimla, Mukteswar and Medikeri stations have recorded the study period lowest departure of seasonal humidity index during ENSO year of 1987 and Nainital, Dharamsala and Joshimat stations have registered the same during 1965 ENSO year. Mount Abu had registered lowest departures of humidity index during 1987 and 2002. Coonoor from south Peninsular India had lowest departure of seasonal humidity index during 1972, 1982, 1987 and 2009 ENSO years. Dalhousie had study period second and third lowest departure of seasonal humidity index during ENSO 1987 and 1982 respectively. It is pertinent to note that influence of ENSO/La Nina is not marked over northeast hill stations. It is also evident from the Table 1 that effect of ENSO event is more prominent than La Nina events on the seasonal humidity index as many stations have recorded significantly lower values of humidity index during ENSO events while few stations registered higher values of seasonal humidity index during La Nina events. Percentage frequency of total humid events over all 17 hill stations together, is plotted, for each category and total Figs. 3 (a-d). La Nina year 2010 has recorded the highest frequency (100%) to moderate as well as all total humid events and ENSO year 1982 has recorded the second

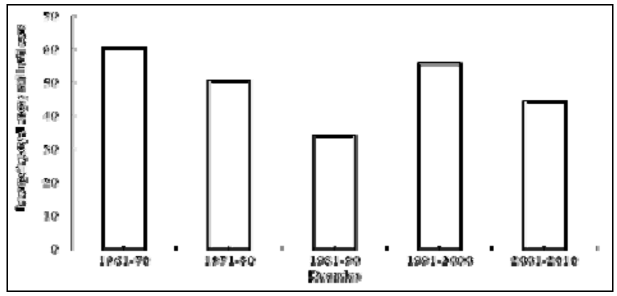


Fig. 2(a). Decadal frequency of total humid events over 17 hill stations

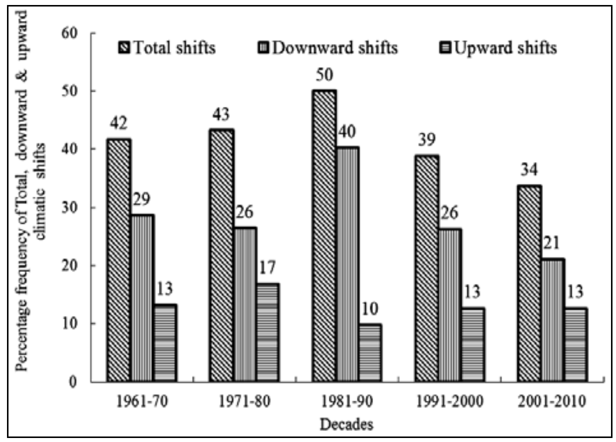
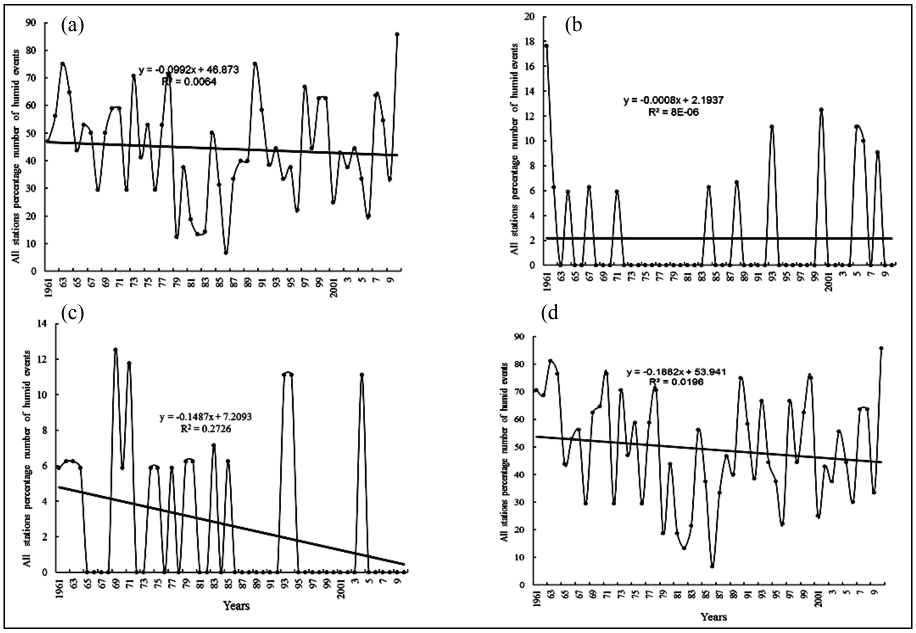


Fig. 2(b). Decadal frequency of total, downward and upward climatic shifts over 18 hill stations

lowest frequency to moderate as well as total humid events. It is also observed that total frequency of very humid and high humid category events, over all 17 hill stations together is nil, in the ENSO years in the study period. Apart from trend of seasonal humidity index at individual stations, trend in the percentage frequency of total humid events over all 17 stations is also studied for each category and total. Each and total humid categories have exhibited the decreasing trend. However, the trend of none of the categories is significant Figs. 3(a-d). Comparison of occurrence of humid events over hill stations in four broad regions of India (Table 2) indicated that liability to total humid events is low over Peninsular India mainly because of low incidence over Coonoor. In the remaining three regions it is same and is 0.5 humid event per season, *i.e.,* on an average there would be one humid event in every alternate southwest monsoon seasons. Examination of category wise frequency of humid events over the four regions revealed that hill stations of northeast India have experienced highest frequency to moderate category among the four regions and the frequency is almost same in the other regions. This may be due to the fact that southwest monsoon current sway over northeast region for longer time of more



Figs. 3(a-d). Seasonal march of percentage of total humid events over 17 selected hill stations – SW monsoon season (a) moderate humid (b) very humid (c) high humid and (d) all category

TABLE 3

Statistic of aridity index of selected hill stations of India-droughts-SW monsoon season-dry climates

Station	No. of years	Climatic I_{sa}	Standard deviation of I_{sa}	ENSO & La Nina years with significant change in I_{sa}	No. of drought events % in brackets					Trend
					Slight	Moderate	Severe	Very severe	Total	
Udagamandlam	45	-004	09	Third highest 2002	03 (7)	00 (0)	00 (0)	21 (47)	24 (53)	Insignificant

than six months compared to other parts of India. But frequency to higher order humid events (very and high category) is more over North India and Joshimat and Mukteswar stations chiefly contributed for this which together had 13 high humid events out of total 19 high humid events recorded over all 17 stations together in the study period (Table 1). In other wards humidity index triggered by southwest monsoon current has characteristic of large variations over hill stations of western Himalayas while it is comparatively steady and more frequent over eastern region.

3.2. Inter *seasonal variation of aridity index – Dry climates – Droughts*

Percentage departure of monsoon season aridity index from the study period median is worked out and compared with standard deviation at lone dry climate station, Udagamandlam. Occurrence of seasonal droughts intensity wise as slight, moderate, severe and very severe is arrived according as, percentage departure of seasonal aridity index is 0 to 0.5, 0.5 to 1, 1 to 2 and more than 2 times of the standard deviation and shown in Table 3 along with other details. It is revealed from Table 3, that there is incidence of 24 droughts of all categories at Udagamandlam in 45 monsoon seasons studied. In other wards, there is 53% susceptibility to droughts. Category wise these are 3 (7%) slight, 0 (0%) moderate and severe, 21 (47%) very severe droughts respectively. As in the case of humid events, influence of ENSO and La Nina phenomena on the aridity index in the study period revealed that during ENSO 2002, the aridity index pushed up to study period third highest value. Trend of aridity index found to be insignificant.

3.3. *Climatic shifts and stability*

Conditions responsible for humidness and aridity variations naturally produce pronounced variations in the moisture regime of the climate too. Shifting of very climatic type of the station by one to two steps toward wetter or drier direction, though temporary is significant

TABLE 4

Climatic shifts and stability of selected hill stations of India

Station	No. of years	Normal climate	No. of climatic shifts, type with symbol			ENSO & La Nina years associated with shift in previous year climatic status		Climate Stability (%) occurrence
			Total	Upward	Downward	ENSO	La Nina	
Dalhousie	28	A	13	-	13(B_4-6,B_3-4, B_2-1, B_1-2)	1982, 87	-	054
Simla	33	B_3	21	06(A-4, B_4-2)	15(B_2-6,B_1-6,C_2-3)	1965, 72, 87, 91	1973, 88	036
Mussorie	27	A	12	00	12(B_4-6, B_3-3, B_2-3)	1965, 72	-	056
Mukteswar	50	B_2	41	11(A-4, B_4-4, B_3-3)	30(B_1-15, C_2-12, C_1-3)	1965, 72, 82, 87, 91, 2009	1975, 88 98, 2010	018
Naintal	19	A	02	00	02(B_4-1, B_3-1)	1965	-	**089**
Joshimat	28	B_1	16	07(B_3-3, B_2-4)	09(C_2-4,C_1-4,D-1)	1965, 72, 87	1973	043
Dharmasala	47	A	07	00	07(B_4-3, B_3-3, B_2-1)	1965, 72, 82, 87, 1991, 2009	-	**085**
Mount Abu	50	C_2	39	17(B_1-4, B_2-5, B_3-2, B_4-2, A-4)	22(C_1-16, D-3, E-3)	1982, 87, 2002	1973, 75, 88 2010	022
Darjeeling	48	A	06	00	06(B_4-2,B_3-3, B_2-1)	-	-	**087**
Kalipong	48	A	11	00	11(B_4 -5, B_3-2, B_2-1, B_1 -1 C_2-1, D-1)	1965, 72, 97	-	**077**
Kohima	28	B_4	18	11(A-11)	07(B_3 -5, B_2-1, B_1-1)	1972, 82	1973	036
Shillong	47	A	18	00	18(B_4 -10, B_3-8)	1972	1973	062
Chirapunji	45	A	08	00	08(B_4 -2, B_3-4, B_2-1, C_2-1)	1965, 82	-	**082**
Pachmarhi	31	B_2	25	13(B_3 -6, B_4-3, A-4)	12(B_1-7, C_2-4, C_1-1)	1965, 72, 91	1973, 75	019
Mahabaleswar	48	A	00	Conserved	Conserved	-	-	**100**
Udagamandalam	45	C_1	20	18(C_2-13, B_1-5)	02(D-2)	1982	1988	056
Medikeri	50	A	20	00	20(B_4 -10, B_3-5, B_2-4, C_2-1)	-	-	060
Coonoor	33	B_1	22	10(B_2 -5 B_3-3, A-2)	12(C_2-3, C_1-9)	1987		033
Total	**705**		**299**	**93**	**206**			

E - Arid, D - Semi arid, C_1 - Dry subhumid, C_2 -Moist subhumid, B_4 - B_1 Fourth - First humid, A - perhumid

for planning the development of the region. Details such as normal climatic type, shifts during the study period, climate stability and influence of ENSO and La Nina phenomena at 18 selected hill stations are shown in Table 4. There are 299 shifts (206 downward and 93 upward) in total over 18 stations in the study period, in other words the selected stations are subjected to 42% frequency of climatic shifts. Analysis of climatic shifts at individual stations indicates that, the frequency varied from 0 to 82%. (Table 4). Mukteswar had the highest frequency of 41 (82%) total shifts followed by Pachmarhi with 19 (81%). Normal climate of Mukteswar is improved on 4 occasions each to perhumid and fourth humid and on 3 occasions to third humid. Its climate is impoverished on 30 years in the study period, to first humid on 15, moist sub humid on 12 and dry subhumid in 3 years (Table 4). Improvement in climatic type on 13 occassions (perhumid on 4, fourth humid on 3 and third humid during 6 years) and deterioration on 12 years (first humid in 7, moist sub-humid in 4 and dry subhumid in 1 occasssions respectively) is witnessed at Pachmarhi, a station from central India region. Mahabaleswar from peninsular India had conserved its normal climate type in the study period (Table 4). Naintal, Dharmasala, Darjeeling, Kalipong, Chirapunji and Mahabaleswar are stable to their normal climate as these stations are experiencing the same more than 70% time of observations. Deterioration and improvement in climate status in association with ENSO and La Nina events is witnessed at many station (Table 4).

3.4. *Decadal frequency of humid events and climatic*

Percentage frequency of all category humid events, over 17 stations together and percentage frequency of

TABLE 5

Annual water budget elements – Moist climates

Station	Extremity	Year	PE (mm)	P (mm)	WS (mm)	WD (mm)	Annual Moisture index	Monsoon season Humid/Drought intensity	Standard deviation of I_{sh}
Dalhousie	Normal	-	984	2134	1217	068	116		
	Wet	1961	1074	3907	2805	022	259	Very Humid	108
	Dry	1970	1032	1343	512	201	030		
Simla	Normal	-	877	1516	734	096	073		
	Wet	1962	857	3701	3010	092	340	Very Humid	148
	Dry	1987	955	958	104	058	005	-	
Mussorie	Normal	-	956	2054	1249	150	116		
	Wet	1971	940	2899	1991	087	203	Moderate Humid	131
	Dry	1979	960	1490	683	158	055		
Mukteswar	Normal	-	897	1263	511	145	043		
	Wet	1980	834	2870	2108	139	236	High Humid	081
	Dry	1965	1204	881	136	454	-026		
Naintal	Normal	-	965	2401	1562	129	150		
	Wet	1971	836	2950	2077	012	247	Moderate Humid	096
	Dry	1965	1063	1856	884	097	074		
Dharmasala	Normal	-	1131	2928	1899	103	159		
	Wet	1964	1155	9057	7998	053	688	Moderate Humid	102
	Dry	1965	1173	1608	584	108	041		
Darjeeling	Normal	-	866	2932	2136	070	221		
	Wet	1993	1017	21079	20017	002	968	Very Humid	435
	Dry	2002	952	1440	599	075	055		
Kalipong	Normal	-	979	2258	1422	142	138		
	Wet	1999	675	3208	2513	012	371	Moderate Humid	158
	Dry	1980	1102	0938	328	0391	-006		
Mount Abu	Normal	-	1203	1364	831	0671	014		
	Wet	1994	999	2990	2435	455	198	High Humid	157
	Dry	2001	1087	031	000	1043	-096		
Pachmarhi	Normal	-	1243	1949	1269	0561	058		
	Wet	1961	1231	3394	2669	0516	175	Moderate Humid	141
	Dry	1979	1294	1209	417	0491	-006		
Mahabaleswar	Normal	-	1390	5693	5005	0702	314		
	Wet	1961	1313	8407	7732	0624	541	Moderate Humid	474
	Dry	1995	1608	4066	3094	0660	151		
Coonoor	Normal	-	1249	1605	551	0195	029		
	Wet	1979	1262	2974	1830	0117	136	-	011
	Dry	1974	1257	0917	12	295	-023		
Kohima	Normal	-	926	1818	975	086	098		
	Wet	1971	776	2243	1510	060	557	Very Humid	080
	Dry	1982	1210	1633	610	0218	129		
Chirapunji	Normal	-	961	11273	10363	051	471		
	Wet	1968	995	10623	9722	081	969	Moderate Humid	875
	Dry	1982	947	10542	9719	075	018		
Shillong	Normal	-	944	2126	1273	090	126		
	Wet	1988	980	3492	2535	050	254	Moderate Humid	107
	Dry	1994	985	1598	667	074	060		
Joshimat	Normal	-	959	1172	348	134	023		
	Wet	1977	878	1509	703	076	071	High Humid	047
	Dry	1980	670	542	000	228	-034		
Medikeri	Normal	-	1517	3220	2142	440	115		
	Wet	1961	1222	5831	4928	309	378	Very Humid	235
	Dry	1987	1638	1889	682	452	014		

TABLE 6

Annual water budget elements – Dry climates

Station	Extremity	Year	PE (mm)	P (mm)	WD (mm)	WS (mm)	Annual Moisture index	Monsoon season Humid/ Drought intensity	Standard deviation of I_{sa}
Udagmandalam	Normal	-	1139	1080	197	256	-004		
	Wet	1961	1000	1378	500	131	037		
	Dry	2003	1328	892	000	466	-035	Very severe	09

climatic shifts over 18 stations together (total, upward and downward shifts), both decade wise, for the study period is shown in Figs. 2 (a&b), Decrease in frequency of humid events during 1971-1990 and sharp fall in the frequency during 1981-90 decade from previous and raise in subsequent decade is observed. Similarly increase in frequency of total as well as downward shifts and slight decrease in upward climatic shifts during 1971-1990 is observed. Rise / fall of total and downward / upward shifts during 1981-90 decade from previous and vice versa in the subsequent decade is observed. (Sarma and Srinivas, 2005 have reported decrease in humid events and increase in climate shifts over India during 1971-1990 compared to 1901-1970 and attributed this to the seasonal performance of southwest monsoon in response to ENSO signal).

3.5. *Water budget elements*

Basic annual water budget elements such as P.E., P, W.D., W.S. and Im during the normal and extreme wet and dry spells in the study period at all the 17 moist climate stations is shown in Table 5. It is observed from the Table 5, that extreme wet year at a station is also either a high humid / very humid / moderate humid season except at Coonoor. The general feature that observed is decrease in water deficit with an increase in water surplus during the wettest season and *vice versa* in the driest season. In 15 out of 17 moist climate stations, there is no cessation of water surplus even in a driest season but it appears with a reduced magnitude along with a rise in water deficit account. In eight moist climate stations, extreme dry year has occurred in association with ENSO year.

Basic water budget elements during the normal and extreme wet and dry spells for the study period at lone dry climate station Udagamandlam is shown in Table 6. It is evident from the Table 6, that extreme dry year triggered a very severe drought.

Aforesaid discussions through 3.1 to 3.5, indicates that southwest monsoonish weather highly varies in space and time over India and has a bearing on the structure and intensity of El Nino and La Nina events over Nino - 3 region together with the Southern Oscillation index in such a way, that a particular event bring changes in the weather systems that normally prevail which might perturb the seasonal effectivity of moisture through waxing and waning circulation pattern and departures in water balances of high magnitude through triggering humid and drought events in the climate spectrum of India accompanied by climate shifts in one region and elsewhere free from this kind of stress.

4. Conclusions

There is 49% susceptibility to incidence of humid events over selected moist climate stations and 53% to droughts at lone dry climate station.

Trend of humidity index found to be decreasing at 5 stations and insignificant at remaining 12 stations.

Influence of ENSO / La Nina events on seasonal humidity as well as moisture indices is found to be insignificant over selected northeast hill stations relative to other region hill stations.

Liability to total humid events is found to be low over Peninsular India and in the remaining three regions it is same. Hill stations of northeast India are subjected to highest frequency to moderate category while north India stations witnessed highest frequency to higher order humid events. It suggests that humidity index triggered by southwest monsoon current has characteristic of large variations over hill stations of western Himalayas while it is comparatively steady and more frequent over eastern region.

La Nina year 2010 has recorded the highest frequency to moderate as well as all total humid events and ENSO year 1982 has recorded the second lowest frequency to moderate as well as total humid events. None of the 17 stations recorded very humid and high humid category event, in the ENSO years of study period.

Frequency of climatic shifts found to be 42%. Mukteswar and Pachmarhi stations had first and second highest frequency of shifts (82 & 81%) respectively. Only one out of 18 stations has conserved its climate in the study period.

Six out of eighteen stations are stable for their normal climate.

Decadal frequency to humid events revealed that decrease in humid events during 1971-1990 and sharp fall in the frequency during 1981-90 decade from previous and raise in subsequent decade is observed. Similarly increase in frequency of total as well as downward climatic shifts and slight decrease in upward climatic shifts during 1971-1990 is observed. Rise / fall of total and downward / upward shifts during 1981-90 decade from previous and vice versa in the subsequent decade is observed. The results are in conformity with earlier studies.

ENSO phenomena induced driest spell at eight moist climate stations. Extreme wet spell generated a humid event at all but one station and extreme dry spell triggered a very severe drought over lone dry climate station. At many of the moist climate stations there is no cessation of water surplus even during dry spell. In general decrease in water deficit and increase in water surplus during wet and vice versa during dry spell are observed.

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