Hydro-climatic characteristics of hill stations of India

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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 Thornthwaite 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_s, 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.

\[ \text{Storage} = \text{Field capacity} \times \exp \left( \sum \frac{(P - P_E)}{\text{Field capacity}} \right) \]

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 evapotranspiration are computed and used in study of droughts and humid events. At each station annual aridity
(I_a) and humidity (I_h) indices have been worked out as shown under.

\[ I_a = \frac{(100 \times WD)}{PE} \]

\[ I_h = \frac{(100 \times WS)}{PE} \]

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) (I_m 0 - 20%), Dry subhumid (C) (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

\[ I_{sa} = \frac{(100 \times SWD)}{SPE} \]

\[ I_{sh} = \frac{(100 \times SWS)}{SPE} \]

where, SPE, SWS and SWD are the potential evapotranspiration and seasonal water surplus and water deficiency for southwest monsoon season respectively. To make an intercomparison 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 (\(\sigma\)) 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 1\(\sigma\), 1 to 2\(\sigma\) and greater than 2\(\sigma\) 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 0.5\(\sigma\), 0.5 to 1\(\sigma\), 1 to 2\(\sigma\) and greater than 2\(\sigma\) 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

| Station     | No. of years | Climatic $I_a$ | Standard deviation of $I_a$ | ENSO & La Nina years with significant change in $I_a$ | No. of humid events % in brackets | Trend       |
|-------------|--------------|----------------|-----------------------------|---------------------------------------------|---------------------------------|------------|
| 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 |
| Mussoorie   | 27           | 326            | 131                         | Lowest 1987 & third lowest 1965            | 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 |
| Dharamasala | 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, Lowest 1987, 2nd lowest 1982 | 00 (00) 00 (00) 04 (12) 04 (12) | Insignificant |
| Medikeri    | 50           | 439            | 235                         |                                             | 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

| Region            | 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)   |

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 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
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. Interseasonal 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.
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 subhumid on 12 and dry subhumid in 3 years (Table 4). Improvement in climatic type on 13 occasions (perhumid on 4, fourth humid on 3 and third humid during 6 years) and deterioration on 12 years (first humid in 7, moist subhumid in 4 and dry subhumid in 1 occasions 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

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**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 (%) | E - Arid, D - Semi arid, C1 - Dry subhumid, C2 - Moist subhumid, B1 - B4 Fourth - First humid, A - perhumid |
|------------------|--------------|----------------|------------------------------------------|--------------------------------------------------------------------------|-----------------------|---------------------------------------------------------------------------------------------------------------------------------|
| Dalhousie        | 28           | A              | 13 (B6-3,B5-2, B4-2, B2-1, B1-2)         | 1982, 87, 1973, 88                                                       | 0.54                  | 0.056                                                                                                                            |
| Simla            | 33           | B3             | 21 (A4-2, B5-3)                           | 1982, 87, 1973, 88, 1991                                                  | 0.036                 | 0.056                                                                                                                            |
| Mussoorie        | 27           | A              | 12 (B6-3, B5-3, B4-2)                     | 1982, 87, 1973, 88, 1991                                                  | 0.036                 | 0.056                                                                                                                            |
| Mukteswar        | 50           | B2             | 41 (A4-2, B5-4, B4-2, B3-3)              | 1982, 87, 1973, 88, 1991                                                  | 0.036                 | 0.056                                                                                                                            |
| Naintal          | 19           | A              | 02 (B1-2, B1-1)                           | 1982, 87, 1973, 88, 1991                                                  | 0.087                 | 0.018                                                                                                                            |
| Joshimat         | 28           | B3             | 16 (B5-3, B4-2)                           | 1982, 87, 1973, 88, 1991                                                  | 0.036                 | 0.056                                                                                                                            |
| Dharmasala       | 47           | A              | 07 (B5-3, B4-3, B3-1)                     | 1982, 87, 1973, 88, 1991                                                  | 0.077                 | 0.185                                                                                                                            |
| Mount Abu        | 50           | C2             | 39 (B6-3, B5-3, B4-2, B3-1, B2-1)         | 1982, 87, 1973, 88, 1991                                                  | 0.087                 | 0.082                                                                                                                            |
| Darjeeling       | 48           | A              | 06 (B1-2, B1-1)                           | 1982, 87, 1973, 88, 1991                                                  | 0.036                 | 0.077                                                                                                                            |
| Kalipong         | 48           | A              | 11 (B1-2, B1-2, B1-1)                     | 1982, 87, 1973, 88, 1991                                                  | 0.087                 | 0.082                                                                                                                            |
| Kohima           | 28           | B4             | 18 (A-11)                                 | 1982, 87, 1973, 88, 1991                                                  | 0.036                 | 0.082                                                                                                                            |
| Shillong         | 47           | A              | 20 (B5-3, B5-3)                           | 1982, 87, 1973, 88, 1991                                                  | 0.036                 | 0.082                                                                                                                            |
| Chirapunji       | 45           | A              | 08 (B5-3, B5-3)                           | 1982, 87, 1973, 88, 1991                                                  | 0.036                 | 0.082                                                                                                                            |
| Pachmarhi        | 31           | B3             | 25 (B6-3, B5-3, B4-2, A4)                | 1982, 87, 1973, 88, 1991                                                  | 0.036                 | 0.082                                                                                                                            |
| Mahabaleswar     | 48           | A              | 00 (Conserved)                            | 1982, 87, 1973, 88, 1991                                                  | 0.036                 | 0.100                                                                                                                            |
| Udagamandalam    | 45           | C1             | 20 (C5-13, B1-5)                          | 1982, 87, 1973, 88, 1991                                                  | 0.036                 | 0.100                                                                                                                            |
| Medikeri         | 50           | A              | 20 (B5-3, B5-3, B4-2, A4)                | 1982, 87, 1973, 88, 1991                                                  | 0.036                 | 0.100                                                                                                                            |
| Coonoor          | 33           | B3             | 22 (B6-3, B5-3, B4-2, A4)                | 1982, 87, 1973, 88, 1991                                                  | 0.036                 | 0.100                                                                                                                            |

Total 705 299 93 206
### 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 $I_a$ |
|---------------|-----------|------|---------|--------|---------|---------|-----------------------|--------------------------------------|-----------------------------|
| Dalhousie     | Normal    | 1961 | 984     | 2134   | 1217    | 068     | 116                   | Very Humid                          | 0.108                       |
|               | Wet       | 1961 | 1074    | 3907   | 2805    | 022     | 259                   |                                      |                             |
|               | Dry       | 1970 | 1032    | 1343   | 512     | 201     | 030                   |                                      |                             |
| Simla         | Normal    | 1962 | 877     | 1516   | 734     | 096     | 073                   | Very Humid                          | 0.148                       |
|               | Wet       | 1962 | 857     | 3701   | 3010    | 092     | 340                   |                                      |                             |
|               | Dry       | 1987 | 955     | 958    | 104     | 058     | 005                   |                                      |                             |
| Mussorie      | Normal    | 1971 | 940     | 2899   | 1991    | 087     | 203                   | Moderate Humid                      | 0.313                       |
|               | Wet       | 1971 | 940     | 2899   | 1991    | 087     | 203                   |                                      |                             |
|               | Dry       | 1979 | 960     | 1490   | 683     | 158     | 055                   |                                      |                             |
| Mukteswar     | Normal    | 1979 | 960     | 1490   | 683     | 158     | 055                   |                                      |                             |
|               | Wet       | 1980 | 834     | 2870   | 2108    | 139     | 236                   | High Humid                          | 0.081                       |
|               | Dry       | 1965 | 1204    | 881    | 136     | 454     | -026                  |                                      |                             |
| Naintal       | Normal    | 1971 | 836     | 2950   | 2077    | 012     | 247                   | Moderate Humid                      | 0.196                       |
|               | Wet       | 1971 | 836     | 2950   | 2077    | 012     | 247                   |                                      |                             |
|               | Dry       | 1965 | 1063    | 1856   | 884     | 097     | 074                   |                                      |                             |
| Dharmasala    | Normal    | 1964 | 1131    | 2928   | 1899    | 103     | 159                   | Moderate Humid                      | 0.102                       |
|               | Wet       | 1964 | 1131    | 2928   | 1899    | 103     | 159                   |                                      |                             |
|               | Dry       | 1965 | 1173    | 1608   | 584     | 108     | 041                   |                                      |                             |
| Darjeeling    | Normal    | 1993 | 1017    | 21079  | 20017   | 002     | 968                   | Very Humid                          | 0.435                       |
|               | Wet       | 1993 | 1017    | 21079  | 20017   | 002     | 968                   |                                      |                             |
|               | Dry       | 2002 | 952     | 1440   | 599     | 075     | 055                   |                                      |                             |
| Kalipong      | Normal    | 1999 | 675     | 3208   | 2513    | 012     | 371                   | Moderate Humid                      | 0.158                       |
|               | Wet       | 1999 | 675     | 3208   | 2513    | 012     | 371                   |                                      |                             |
|               | Dry       | 1980 | 1102    | 0938   | 328     | 0391    | -006                  |                                      |                             |
| Mount Abu     | Normal    | 1994 | 999     | 2990   | 2435    | 455     | 198                   | High Humid                          | 0.157                       |
|               | Wet       | 1994 | 999     | 2990   | 2435    | 455     | 198                   |                                      |                             |
|               | Dry       | 2001 | 1087    | 031    | 000     | 1043    | -096                  |                                      |                             |
| Pachmarhi     | Normal    | 1961 | 1231    | 3394   | 2669    | 0516    | 175                   | Moderate Humid                      | 0.141                       |
|               | Wet       | 1961 | 1231    | 3394   | 2669    | 0516    | 175                   |                                      |                             |
|               | Dry       | 1979 | 1294    | 1209   | 417     | 0491    | -006                  |                                      |                             |
| Mahabaleswar  | Normal    | 1961 | 1313    | 8407   | 7732    | 0624    | 541                   | Moderate Humid                      | 0.474                       |
|               | Wet       | 1961 | 1313    | 8407   | 7732    | 0624    | 541                   |                                      |                             |
|               | Dry       | 1995 | 1608    | 4066   | 3094    | 0660    | 151                   |                                      |                             |
| Coonoor       | Normal    | 1979 | 1262    | 2974   | 1830    | 0117    | 136                   |                                       | 0.011                      |
|               | Wet       | 1979 | 1262    | 2974   | 1830    | 0117    | 136                   |                                       |                             |
|               | Dry       | 1974 | 1257    | 0917   | 12      | 295     | -023                  |                                       |                             |
| Kohima        | Normal    | 1971 | 776     | 2243   | 1510    | 060     | 557                   | Very Humid                          | 0.080                       |
|               | Wet       | 1971 | 776     | 2243   | 1510    | 060     | 557                   |                                      |                             |
|               | Dry       | 1982 | 1210    | 1633   | 610     | 0218    | 129                   |                                      |                             |
| Chirrupunji   | Normal    | 1968 | 995     | 10623  | 9722    | 081     | 969                   | Moderate Humid                      | 0.875                       |
|               | Wet       | 1968 | 995     | 10623  | 9722    | 081     | 969                   |                                      |                             |
|               | Dry       | 1982 | 947     | 10542  | 9719    | 075     | 018                   |                                      |                             |
| Shillong      | Normal    | 1988 | 980     | 3492   | 2535    | 050     | 254                   | Moderate Humid                      | 0.107                       |
|               | Wet       | 1994 | 985     | 1598   | 667     | 074     | 060                   |                                      |                             |
|               | Dry       | 1980 | 670     | 542    | 000     | 228     | -034                  |                                      |                             |
| Joshimat      | Normal    | 1977 | 878     | 1509   | 703     | 076     | 071                   | High Humid                          | 0.047                       |
|               | Wet       | 1977 | 878     | 1509   | 703     | 076     | 071                   |                                      |                             |
|               | Dry       | 1980 | 670     | 542    | 000     | 228     | -034                  |                                      |                             |
| Medikeri      | Normal    | 1961 | 1222    | 5831   | 4928    | 309     | 378                   | Very Humid                          | 0.235                       |
|               | Wet       | 1961 | 1222    | 5831   | 4928    | 309     | 378                   |                                      |                             |
|               | Dry       | 1987 | 1638    | 1889   | 682     | 452     | 014                   |                                      |                             |
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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