551.583 : 551.577.3 (540.13)

SPATIAL AND TEMPORAL DISTRIBUTION AND TRENDS IN SEASONAL RAINFALL AND RAINY DAYS ACROSS DIFFERENT STATIONS OF HIMACHAL PRADESH DURING THE PERIOD 1971-2014

1. Spatial and temporal distribution of rainfall is a key factor which affects the availability of water for human use including agriculture and ultimately crop productivity. Climate change is likely to have adverse effects on crop production due to abiotic stresses in which water is an important variable. Intergovernmental Panel on Climate Change (IPCC, 2007) has projected that future climate change especially in temperature and rainfall are likely to affect agriculture, increasing the risk of hunger, water scarcity and rapid melting of glaciers. The freshwater availability in river basins is also likely to decrease due to the changing climate (Gosain *et al*., 2006). Several recent studies have observed the decreasing rainfall trends in Asia (Min *et al*., 2003; Goswami *et al*., 2006; Dash *et al*., 2007). But in India studies showed that there is no trend of increase or decrease in average rainfall over the country (Lal, 2001; Sinha Ray and De, 2003; Kumar and Jain, 2010). However, significant changes in long-term rainfall on regional scale have been identified (Singh and Sen Roy, 2002; Kumar *et al*., 2005; Guhathakurta and Rajeevan, 2007; Dash *et al*., 2007; Kumar *et al*., 2010). An increasing trend was observed in annual rainfall in nine river basins of northwest and central India (Singh *et al*., 2008). An increasing trend was also reported in most of the south India, except Kerala whereas decreasing trend in central India and northern Indian plain (Kumar *et al.*, 2010). On an annual scale and for the entire country, most of studies have come up with more or less similar results indicating no change over the country but when it comes to the seasons and regional level, the changes are certain. About 80% of the rainfall in India occurs during the monsoon months (June-September) with large spatial and temporal variations over the country. But at the same time other seasons with lower concentration of rainfall results in scarcity of water in many parts of the country. Significant spatial, temporal and inter-seasonal variations in the trends and variability of rainfall have been noticed in India (Ghosh *et al.*, 2009).

Rainfall over India based on 100 years observations suggested that the mean monsoon rainfall has not been significantly changed, however several locations across the country showed a decreasing trend in monsoon and an increasing trend in the pre-monsoon and post-monsoon rainfall during 1871-2002 (Sinha Ray and Srivastava, 2000; Dash *et al*., 2007). Decreasing trend in summer monsoon rainfall in northern India and increasing trend in south India has also been observed by Naidu *et al.* (2009). According to Sinha, Ray and Srivastava (1999), the frequency of heavy rainfall events during the southwest monsoon has shown an increasing trend over certain parts of the country, whereas a decreasing trend has been observed during winter, pre-monsoon and post-monsoon seasons. Since, the cropping patterns and productivity are influenced by spatial and temporal distribution of rainfall affecting the runoff, soil moisture and groundwater reserves; there is an urgent need of systematic documentation of characteristics and alterations in rainfall at regional/local level for developing prediction models and appropriate water management in near future. The state of Himachal Pradesh is the biggest montane ecosystem in India situated in northern part of the country. It is seventeenth largest state in area and twentieth in population of which 65 per cent people are dependent on agriculture and 60 per cent of GDP comes from agriculture sector. Increasing temperature and reducing rainfall affecting the crop growth and crop production is a major issue everywhere in the world nowadays and this state has also not remained untouched by these prime issues of climate change. For sustainable development of agriculture in state, there is a need to identify and quantify climatic change where agriculture has a significant influence on both the economy and livelihood. Hence in the present study, we have analyzed the characteristics of rainfall and long-term (1971-2014) trends in rainfall amount and number of rainy days over 40 stations in Himachal Pradesh for different seasons.

2. The state of Himachal Pradesh encompasses a geographical area of 55.7 lakh ha. Situated between 31°22′40″ and 33°12′40″ N latitude and 75°45′55″ and 77°10′20″ E longitude, the state is bordered by Jammu and Kashmir on the north, Punjab on the west and Haryana on the south-west. About 12 per cent of the state area is under agriculture which is mostly rain is fed (80 per cent). Wheat, maize, rice and barley are the principal crops in State. In state, there are 12 districts, *viz*., Bilaspur, Chamba, Hamirpur, Kangra, Kinnaur, Kullu, Lahaul & Spiti, Mandi, Shimla, Solan, Sirmaur and Una. About 20 per cent of the area is under forest cover. It is rich in biodiversity of flora and fauna. Nearly 27 per cent of the area of the state is covered under permanent pastures. The state is endowed with a wide range of physiography/ landform, climate, vegetation and geology which have influence on genesis of soils. The soils are mostly shallow, medium deep to deep, well/excessively drained, sandy, sandy-skeletal, loamy-skeletal, coarse-loamy and fine-loamy, calcareous as well as non-calcareous with low available water capacity. The observed daily rainfall data of 40 stations in the state has been used to calculate mean, standard deviation and coefficient of variation of rainfall. The time period for which data of various stations is used

TABLE 1

Rainfall data catalogue

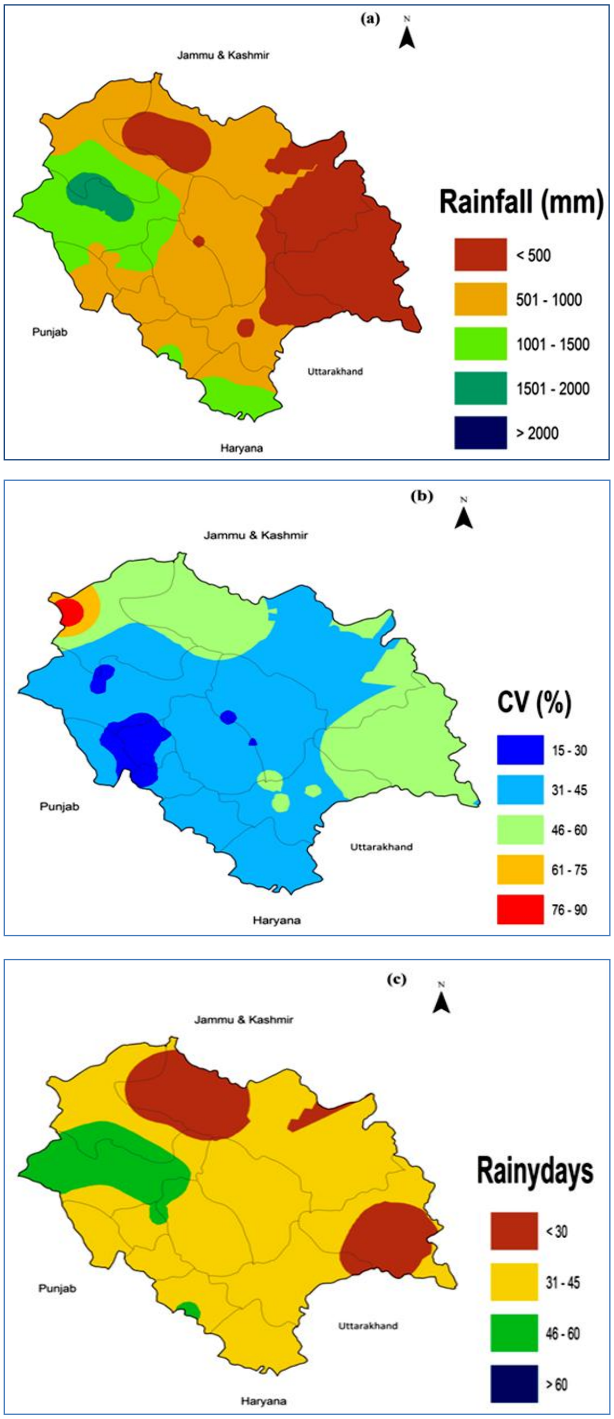
District	Station	Data period	Latitude (°N)	Longitude (°E)	Elevation M (amsl)
Bilaspur	Ghumarwin	1982-2013	31.43 N	76.71 E	829
	Berthin	2004-2014	31.41 N	76.62 E	661
Chamba	Salooni	1991-2014	32.72 N	76.04 E	1766
Hamirpur	Bhoranj	2000-2014	31.68 N	76.52 E	933
	Hamirpur	1971-2014	31.70 N	76.50 E	782
	Nadaun	1991-2014	31.78 N	76.35 E	491
Kangra	Dehra	1973-2013	31.87 N	76.32 E	767
	Dharmashala	1972-2013	32.22 N	76.31 E	1246
	Nurpur	1974-2013	32.18 N	75.53 E	584
	Kangra	2003-2014	32.10 N	76.27 E	787
	Malan	2000-2014	32.11 N	76.41 E	1109
	Palampur	1974-2014	32.10 N	76.54 E	1253
Kinnaur	Nichar	1974-2010	31.55 N	77.96 E	2004
	Sangla	1970-2014	31.42 N	78.26 E	2649
Kullu	Banjar	1988-2014	31.63 N	77.34 E	1419
	Bajaura	1986-2014	31.84 N	77.16 E	1074
Lahaul & Spiti	Keylong	1972-2014	32.57 N	77.03 E	3098
	Udaipur	2001-2014	32.70N	76.70 E	2617
Mandi	Chachiot	2001-2014	31.39 N	77.20 E	1055
	Jogindernagar	2001-2014	31.99 N	76.79 E	1207
	Karsog	1974-2014	31.38 N	77.20 E	1465
	Mandi	1970-2014	31.70 N	76.93 E	771
	Sarkaghat	1974-2014	31.70 N	76.74 E	1031
	Sundarnagar	1974-2014	31.53 N	76.90 E	849
Shimla	Shimla	1985-2014	31.09 N	77.17 E	2208
	Jubbal	1974-2014	31.10 N	77.70 E	1927
	Kothkhai	1974-2014	31.11 N	77.53 E	1640
	Kumarsain	1971-2014	31.31 N	77.44 E	1693
	Mashobra	1981-2014	31.13 N	77.22 E	2107
	Rohru	1972-2014	31.20 N	77.75 E	1553
	Theog	1974-2014	31.12 N	77.33 E	2033
Sirmaur	Dhaulakuan	1987-2014	30.56 N	77.30 E	411
	Nahan	1973-2014	30.55 N	77.28 E	677
	Pachhad	1972-2014	30.56 N	77.30 E	1567
	Paonta	1988-2014	30.44 N	77.60 E	388
Solan	Arki	1973-2014	31.15 N	76.97 E	1090
	Kandaghat	1972-2014	30.97 N	77.10 E	1484
	Kasauli	1975-2014	30.90 N	76.96 E	1783
Una	Akrot	1999-2014	31.37 N	76.10 E	430
	Una	1974-2014	31.48 N	76.28 E	389

for present investigation is given in Table 1. The data period vary from 11 to 40 years. The stations with long period and short period data have been combined as in the upper half of the state the rain gauge station network is very sparse (only 7 per cent stations). Station level daily (rainfall recorded in 24 hour period) rainfall data was segregated in to four seasons, *viz.*, southwest monsoon, post monsoon, winter and summer season. The historical data was subjected to data quality check through Weathercock 15 (Rao *et al*., 2015) before undertaking analysis. The RClimDex, a program script written in R language developed at the Meteorological Service of Canada was used for working out the indices and their trends (Venables and Smith, 2012). Rainfall data of all the seasons for all the stations was also analyzed to assess the changes in heavy rainfall events under two categories *viz*., 75-100 mm and more than 100 mm. The significance of the trends was tested by trend/change detection software (Chiew and Siriwardena, 2005). The rainfall data was plotted using inverse distance weighted interpolation technique in geographic information system.

3. Rainfall during SWM was highest in the state which accounted for 69 per cent of the total annual rainfall followed by summer season (13 per cent) and winter season rains (11 per cent). The rainfall during post monsoon season was, however, considerably small (7 per cent).

4. As a first approximation, the temporal distribution of rainfall can be understood from the number of rainy days. A rainy day is defined as a day when cumulative rainfall received in a period of 24 hours is ≥2.5 mm. The mean annual rainfall of 1267 mm is received over 66 rainy days with a variability of 21 per cent in the state. The rainy days closely followed the total rain received during south west monsoon (SWM) and summer season. During post monsoon season, however lesser rainy days were observed with higher rainfall hence higher variability in the season. The annual variability in rainy days is low but amongst seasons, it is highest (72 per cent) during post monsoon season. This high variability reflects the frequency of intermittent dry spells during continuous wet spells. The highest (59 per cent) of total annual rainy days is received during the SWM season in the state. Percentage of rainy days is 19 for summer, 13 for winter and 9 for post monsoon season.

5. *Features of SWM rainfall*: The state receives 872 ± 305 mm rain during SWM season which contributes 62 per cent to total annual rainfall in the state. During recent years (2006 to 2014), the wettest SWM season occurred in 2010 (888.5 mm which was 15 per cent above normal) and year 2014 was the driest (521.6 mm which was 38 per cent below normal). Dharamshala station



Figs. 1 (a-c). (a) Rainfall, (b) Variability and (c) Number of rainy days during southwest monsoon over Himachal Pradesh

received highest rainfall (2121 mm) during SWM period. Lowest rainfall was noticed at Udaipur (150 mm) followed by Keylong (176 mm). The spatial distribution of rain, its variability and rainy days during SWM are presented in Figs. 1(a-c).

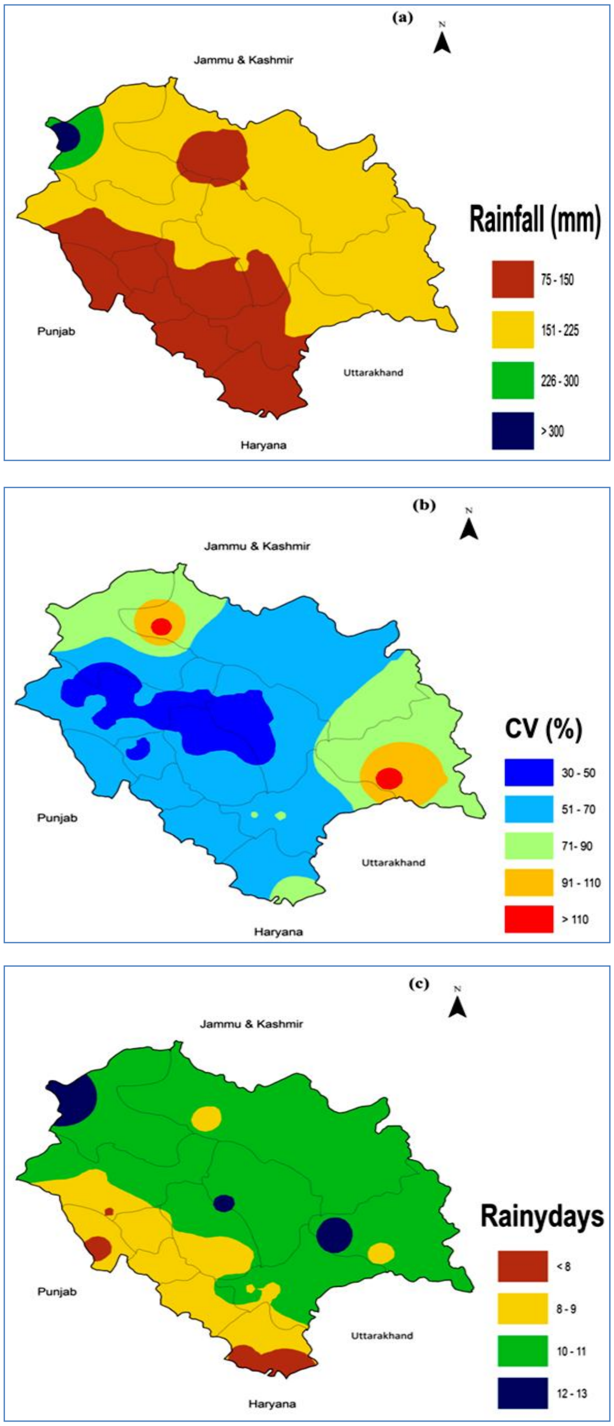
State as a whole is subjected to 38 per cent variable monsoon rainfall. It is considerably high compared to All India monsoon rainfall variability (11 per cent). The variability in the rainfall during SWM, was found to be highest at Salooni (83 per cent) followed by Keylong (61 per cent) and the least at Bhoranj station (18 per cent).

On an average, SWM rainfall was spread over 39 days with variability of 25 per cent. Dharamshala station recoded maximum number (66) of rainy days followed by Palampur (63), Jogindernagar (56) and Malan (53). These were observed to be the least at two stations, *viz*., Keylong (14) and Udaipur (15 days) situated in rain shadow area. Keylong registered highest variability in the number of rainy days (44 per cent) followed by Kotkhai (37 per cent) whereas Akrot (14 per cent) registered least variability followed by Berthin, Kangra, Mashobra and Palampur 15 per cent each.

6. *Features of Post monsoon rainfall*: The contribution of rainfall during post monsoon season was least with on an average the state received 82 ± 73 mm with a variability of 92 per cent, which is more than double the variability of SWM monsoon. Thus amongst seasons, this season can be regarded as the driest with highly variable rainfall. The season also coincides with the sowing of the *rabi* crops in the state. During recent years, the highest rainfall was observed in 2014 (98.5 mm, 4 per cent below normal) and lowest in 2011 (17.8 mm, 84 per cent below normal). Salooni station receives significant amount of rainfall (395 mm) mainly in the form of snow. Nurpur station receives a fairly good (214 mm, variability 41 per cent) amount of rainfall followed by Mandi (199 mm, variability 175 per cent), Sundernagar (111 mm, variability 69 per cent) and Dharamshala (109 mm, variability 71 per cent). The lowest rainfall was noticed at Chachiot (31 mm, variability 138 per cent) and Poanta (49 mm, variability 139 per cent) and a relatively higher consistency was observed in Nurpur followed by Sangla station (119 mm, variability 52 per cent).

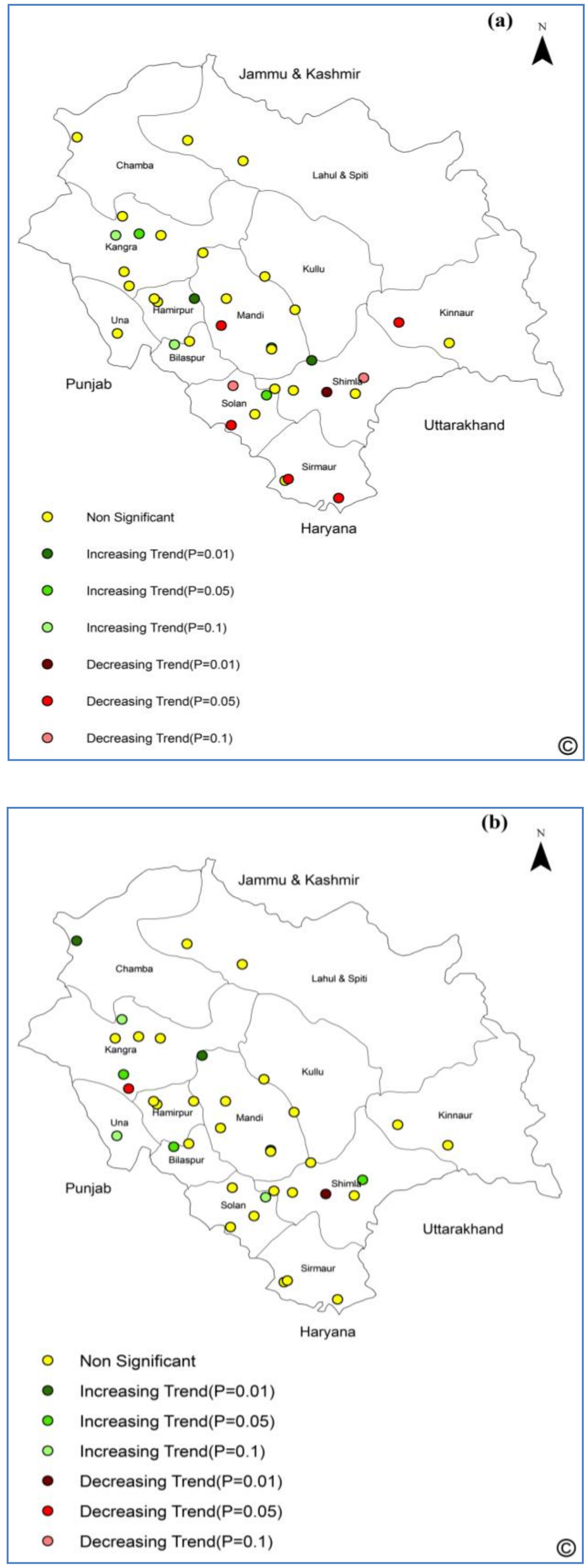
The rainy days varied from 2 days each at Bhoranj and Chachiot to 15 days at Salooni. Average number of rainy days during the season were 6 with higher variability 72 per cent.

7. *Features of winter rainfall*: Rainfall during winter season was 143 ± 88 mm with variability 61 per cent which is the third wet season. In recent years, the winter of 2013 was the wettest (249.8 mm, above normal by 35 per cent) and 2009 being the driest with 97.3 mm rainfall, which was below normal by 39 per cent. Highest rainfall is received at Salooni (333 mm) and Nichar (222 mm) whereas Poanta (80 mm) and Chachiot (81 mm) received lowest rainfall. Winter rain is highly variable



Figs. 2 (a-c). (a) Rainfall, (b) Variability and (c) Number of rainy days during winter season over Himachal Pradesh

both at Sangla and Udaipur (117 per cent) stations followed by Chachiot (106 per cent) whereas least variable at Dharamshala (31 per cent) and Bajaura (34 per cent). Winter rainfall was spread over 9 days only with 44 per cent variability [Figs. 2 (a-c)].



Figs. 3 (a&b). (a) Stations in Himachal Pradesh showing a change in southwest monsoon rainfall pattern and (b) rainy days

8. *Features of summer rainfall*: The mean summer rainfall for the state is 170 ± 98 mm with variability 60 per cent which is second most wet season. In recent years, the wettest summer is 2014 (244.6 mm, above normal by 9 per cent) and driest in 2008 (100.9 mm, below normal by 59 per cent). At the station level, Salooni gets more rainfall (294 mm) than Nichar (275 mm) and Bajaura (257 mm). The lowest rainfall is received at Poanta (67 mm) and Nadaun (86 mm). Due to occasional development of convective clouds, pre-monsoon showers are received during later part of the season and giving copious rains at least in six districts, *viz*., Hamirpur, Kangra, Kullu, Mandi, Shimla and Una. Farmers take benefit of these rains for preparation of land and sowing of maize and direct seeded rice. The summer season rainfall over the state is spread over 13 rainy days with 45 per cent variability.

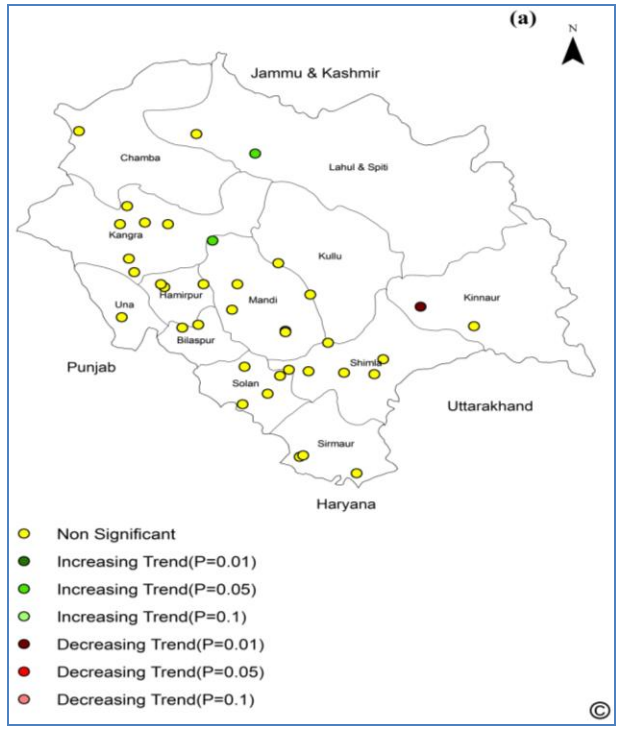
9. *Trends in seasonal rainfall and rainy days*: During SWM rainy season, 15 out of 40 stations showed a significant trend. At eight (20 per cent) stations spread over in Mandi, Sirmaur, Solan and Shimla districts it was decreasing. The rest of the stations in Bilaspur, Mandi, Kangra and Shimla districts had increasing trend.

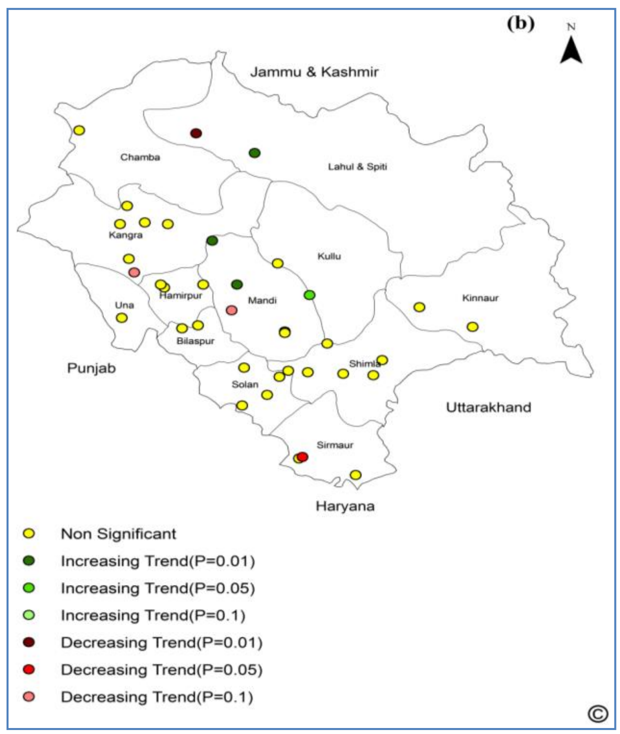
In case of rainy days, trends were significant at 12 stations. Twenty five per cent (10 out of 40) stations spread over in Una, Chamba, Bilaspur, Mandi, Shimla and Kangra district showed increasing trend. Among these, three stations, Berthin (Bilaspur), Chachiot (Mandi) and Shimla (Shimla) followed the increasing rainfall trend. Remaining two stations situated in Shimla and Hamirpur districts showed decreasing trend [Figs. 3 (a&b)].

During post monsoon season, trends were significant at 28 per cent of the stations (11 out of 40). Six (15 per cent) stations showed increasing trends in three stations in Mandi and one each in Kangra, Bilaspur and Una districts. The decreasing trends are observed at remaining five stations spread over in Shimla district and Chamba and Sirmaur districts.

The number of rainy days during post monsoon season showed increasing trend at 9 stations (out of 40) of which majority of the stations (5) followed the rainfall pattern which was increasing. Whereas decreasing trend was observed at two stations, each in Chamba and Lahaul & Spiti districts of which Salooni station (Chamba) follow the rainfall pattern.

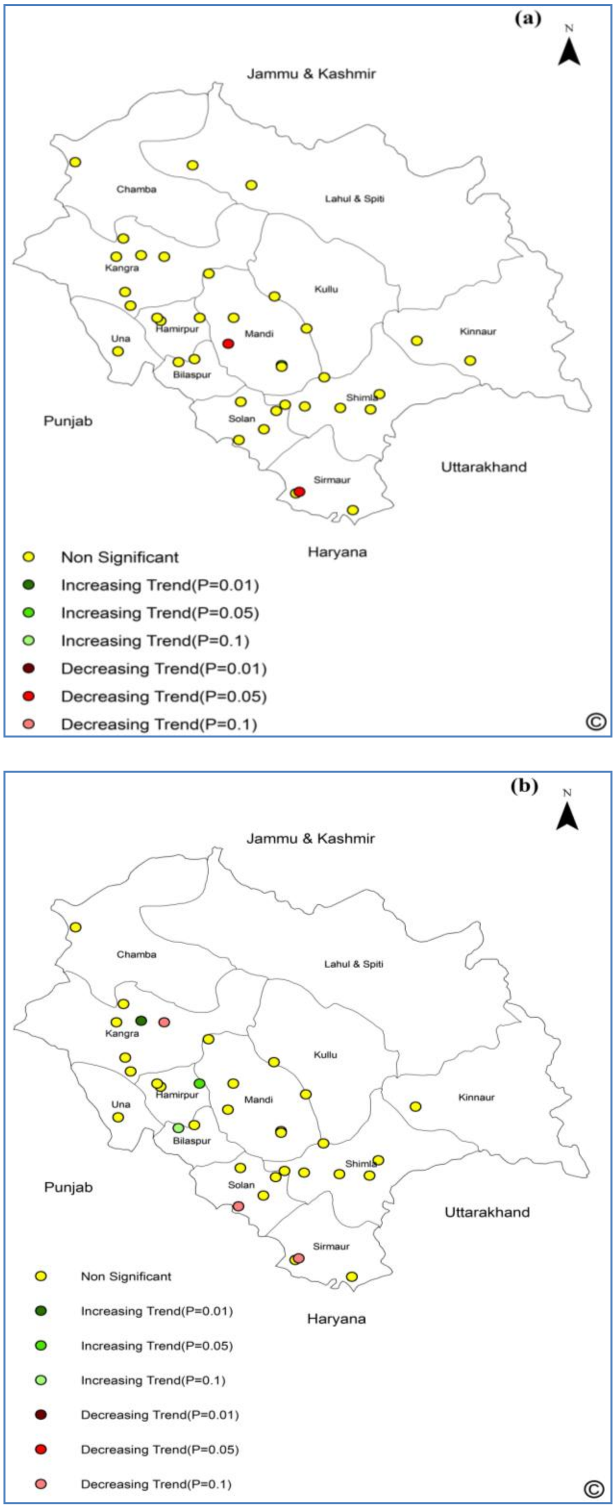
During winter season at 13 per cent (5 out of 40) of the stations, trends in rainfall were significant. An increasing trend was observed at 3 stations, spread over in Mandi, Lahaul and Spiti districts [Figs. 4 (a&b)]. Two stations in Kinnaur & Kangra districts showed deceasing trend.





Figs. 4 (a&b). (a) Stations in Himachal Pradesh showing a change in winter season rainfall pattern and (b) rainy days

The number of rainy days during winter season showed increasing trend at 5 out of 9 stations out of which 3 stations, Chachiot, Jogindernagar and Keylong followed



Figs. 5 (a&b). (a) Stations showing a change in SWM rainfall events in 75-100 mm and (b) 100 mm category

the rainfall pattern which was increasing. Whereas decreasing trend was observed at remaining four stations, spread over in Hamirpur, Sirmaur, Mandi and Lahaul & Spiti districts.

During summer season, trends in rainfall were significant at 25 per cent (10 out of 40) stations out of which 9 stations showed decreasing trend in Una, Kullu, Bilaspur, Kinnaur, Solan and Shimla districts. Increasing trend was observed only at one station, Chachiot in Mandi district which also followed the increasing rainfall pattern.

Trend for the number of rainy days was significant at 40 per cent (16 out of 40) of the stations out of which 9 stations showed decreasing trend of which four stations followed the rainfall pattern. Increasing trend was observed at rest of the 7 stations of which Chachiot station followed the rainfall pattern which was increasing.

The mountainous and hilly environments are more vulnerable for the expected changes in climate in near future, (IPCC, 2001) due to their physiographic characteristics. The state of Himachal Pradesh being mountainous and hilly is therefore expected certainly to face these changes. This analysis indicates significant decreasing trend in about half a dozen stations with equal number of stations showing increasing trend in annual rainfall. The similar pattern was also observed in the south west monsoon. There are no trends (change) in ≥62 per cent stations for rainfall and ≥60 per cent stations for rainy days during different seasons. Indicating a mixed picture with regional increasing or decreasing trends.

Kumar *et al*. (2005) had also found an increasing trend in rainfall at some stations and a decreasing at other stations in Himachal Pradesh. On the contrary, Jaswal *et al*. (2015) observed significantly decreasing trend in monsoon (-3.71 mm/year) at Shimla. Trend detection of rainfall for the period 1901-1984 at 11 stations in Himachal Pradesh indicated a decreasing trend in monsoon rainfall at 95% confidence level (Kumar *et al*., 2005). Decrease in monsoon season rainfall by 61 mm during last 100 years has also been reported in the state (Guhathakurta and Rajeevan, 2006). A slight downward trend in monsoon rainfall has been observed for the river Beas catchment by Singh and Sen Roy (2002). The decreasing trend of -2.85 mm/yr for the state has been observed by Himachal Pradesh Knowledge Cell on Climate Change (HPKC CC, 2015).

Trends in post monsoon season rainfall were observed to be increasing at more number of stations and most of them are located in Mandi district and the decreasing trends mainly in Shimla district. Dash *et al*. (2007) have also found decreasing trend in monsoon and an increasing trend in the pre- monsoon and post-monsoon rainfall for the period 1871-2002. Decrease in monsoon rainfall and increase in pre-monsoon, post-monsoon and winter rainfall at the national scale has also been observed by Kumar *et al.* (2010). Non-significant trends at 36 stations out of 37 for winter season were also observed by Jaswal *et al*. (2015). Although increasing significant trend is observed only at few stations in present study but similar slightly upward trend has also been observed for the river Beas catchment in the state by Singh and Sen Roy (2002). Bhan and Singh (2011) have reported decreasing trends in snowfall in winter months at Shimla during 1992-2011 however trends were non significant for Shimla in the present study. A deceasing trend (-0.18 mm/yr) for winter season in the entire state has already been reported (HPKCCC, 2015).

During summer season, decreasing trends was observed at most of the stations; majority of them were located in Solan and Shimla districts. On the contrary, increasing trend for summer rainfall (0.31 mm/yr) for the period 1951-2010 for the state and for Shimla, (+1.77 mm/year) has been reported by HPKCCC (2015) and Jaswal *et al*. (2015). Though again the data periods and number of stations are different in these studies.

10. *Trends in receipt of heavy rainfall events*: Trends in the heavy rainfall (75-100 mm) events were significant only at 3 out of 40 (8 per cent) stations during SWM season. Out of these 2 stations, each in Sirmaur and Mandi districts showed significant declining trend and one station, in Mandi district showed increasing trend under 75-100 mm events [Figs. 5 (a&b)]. In case of above 100 mm category, 7 stations were found to be significant out of which 4 (10 per cent) stations in Solan, Sirmaur and Kangra districts showed significant decreasing trend. On the other hand, increasing tendency was observed at remaining stations in Bilaspur, Kangra and Mandi districts. The number of rainy days with the heavy rainfall events are also observed to be decreasing at the six stations mentioned above in both the categories, *viz*., 75-100 mm and >100 mm. The results are somewhat similar to Jaswal *et al*. (2015) who have observed significantly decreasing trends for daily heaviest rainfall in at Hamirpur, Kotkhai, Nahan, Nurpur, Renuka and Pachhad and increasing trends in annual daily heaviest rainfall at Kalpa and Palampur stations.

During post monsoon and summer season, the heavy rainfall trends were non-significant at all the stations for both the categories. In winter season, decreasing trend in 75-100 mm category was observed at only one station, Nurpur in Kangra district whereas it was non-significant at all the stations for above 100 mm category. Decrease in some of the extreme rainfall indices during monsoon for Shimla has been observed by Joshi and Rajeevan (2006). Trends for Shimla were however observed to be non significant in the present study. Though, significant trends could be observed at only few stations and that also were decreasing. Some researchers however have observed significant increasing trends in the frequency and intensity of extreme monsoon rain events in spite of considerable year to year variability over the past 50 years in central India (Goswami *et al.*, 2006) and during summer over northwest India (Mall *et al*., 2006). Krishnamurthy *et al.* (2009) and Ghosh *et al.* (2009) however depicted significantly increasing and decreasing trends in extremes of rainfall over many parts of India. Rajeevan *et al*. (2008) have concluded that the frequency of extreme rainfall events shows significant inter-annual and inter-decadal variations.

In present study it was clearly found that for heavy rainfall events of 75-100 mm and $\geq$100 mm category no trend was observed in the state during different seasons at most ($\geq$92 per cent and $\geq$82 per cent) of the stations, respectively. Significant increase/decrease in extreme rainfall events (75-100 mm and $\geq$100 mm) were observed only at few stations during SW Monsoon with more stations showing decrease in rainfall then the stations showing increase in rainfall.

11. Commencement of growing season, length of growing season, choice of cropping systems, allocation of resources and inputs depend significantly on the weekly distribution of rain. Distribution of rain on a weekly basis for the state and for the individual stations along with their statistics indicates that the considerable ($\geq$ 20 mm / week) rain was received over the state during the period from 23rd Standard Meteorological Week (SMW) (4-10 June) to 38 SMW (17- 23 September). This indicates a total growing period of 16 weeks (around 112 days). Only four weeks out of this growing period exhibit less than 50 per cent variability and in remaining weeks it was more than 50 per cent even reaching to 60 per cent up to 39 SMW.

Only isolated rainfall events are noticed over the entire state during 40 to 20 SMW and the rains get momentum with the onset of pre-monsoon showers from 21 SMW (21 -27 May) onwards and later with the onset of monsoon from 26 SMW (25 June-01 July). Only 7.5 per cent stations (3) received $\geq$20 mm / week rainfall by SMW 22, 52.5 per cent stations (21) by SMW 23 and 83 per cent stations (33) by SMW 24 and 93 per cent stations (37) by SMW 28. Out of these 37 stations, no station received on an average less than 20 mm per week rainfall with coefficient of variation 50-60 per cent in which the mean weekly rainfall varied between 68-83 mm up till SMW 33. At Keylong, Sangla & Udaipur stations, the wettest period with more than 20 mm precipitation was however limited for couple of weeks during winter. The period of 6 weeks (SMW 28 to 33) with rainfall >20 mm per week with coefficient of variation of 50-60 per cent for all the 40 stations in which the mean weekly rainfall varied between 68 to 83 mm was found to be highly risk free and the safest period for successful transplanting and establishment of varied kind of saplings under rain fed conditions in the state. Increasing rainfall *vis-a-vis* rain days were observed during post monsoon and winter season at Chachiot and Jogindernagar in Mandi district. During post monsoon season stations with similar behavior were Akrot, Chachiot, Jogindernagar, Malan and Sundernagar and during winter Chachiot, Jogindernagar and Keylong. Decreasing trend in rainfall *vis-a-vis* rainy days was also observed at Bajaura, Ghumarwin, Jubbal and Mashobra during summer. It is amply clear that majority of the stations in the state do not indicate any significant increasing or decreasing trend in heavy rainfall events except at very few stations in Mandi, Bilaspur, Solan, Sirmaur and Kangra districts. This type of information would give insights to the policy makers and farmers for focused attention towards soil and soil moisture conservation measures, as heavy rainfall events could trigger landslides, aggravate soil erosion and extensive crop damage in these five districts.

The authors wish to thank ICAR providing the financial support and CSKHPKV, Palampur for providing the necessary facilities. Analysis work done by Mr. Ajay Kumar is duly acknowledged.

The contents and views expressed in this letter are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

References

Bhan, S. C. and Singh, M., 2011, "Analysis of total precipitation and snowfall pattern over Shimla", *J. Agromet*., **13**, 2, 141-144.

Chiew, F. and Siriwardena, L., 2005, "Trend/change detection software", Scientific development, Code development by Arene S and Rahman J. CRC for catchment hydrology Australia.

Dash, S. K., Jenamani, R. K., Kalsi, S. R. and Panda, S. K., 2007, "Some evidence of climate change in twentieth-century India", *Clim. Change*, **85**, 299-321.

Ghosh, S., Luniya, V. and Gupta, A., 2009, "Trend analysis of Indian summer monsoon rainfall at different spatial scales", *Atmos. Sci. Lett.*, **10**, 285-290.

Gosain, A. K., Rao, S. and Basuray, D., 2006, "Climate change impact assessment on hydrology of Indian river basins", *Current Science*, **90**, 346-353.

Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanam, M. S. and Xavier, P. K., 2006, "Increasing trends of extreme rain events over India in a warming environment", *Science*, **314**, 1442-1445.

Guhathakurta, P. and Rajeevan, M., 2006, "Trends in the rainfall pattern over India", India Meteorological Department Research Report No.2/2006, p23.

Guhathakurta, P. and Rajeevan, M., 2007, "Trends in the rainfall pattern over India", *Int. J. Climatol.*, **28**, 1453-1469.

HPKCCC (Himachal Pradesh Knowledge Cell on Climate Change), 2015, "Climate Modelling for Himachal Pradesh", Department of Environment, Science & Technology, Government of Himachal Pradesh, Paryavaran Bhawan, Shimla.

IPCC, 2001, "Climate Change 2001: Imapcts, Adaptation and Vulnerability", Cambridge University Press, Cambridge, U.K.

IPCC, 2007, "Summary for policymakers", In: Climate Change 2007: The Physical Science Basis, (ed. by S. Solomon, D. Qin, M. manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller), Cambridge University Press, Cambridge, U.K.

Jaswal, A. K., Bhan, S. C., Karandikar, A. S. and Gujar, M. K., 2015, "Seasonal and annual rainfall trends in Himachal Pradesh during 1951-2005", *MAUSAM*, **66**, 2, 247-264.

Joshi, U. R. and Rajeevan, M., 2006, "Trends in precipitation extremes over India", Research Report No: 3/2006, National Climate Centre, India Meteorological Department, Pune.

Krishnamurthy, C. K. B., Lall, U. and Kwon, H. H., 2009, "Changing frequency and intensity of rainfall extremes over India from 1951 to 2003", *J. Climate*, **22**, 4737-4746.

Kumar, V. and Jain, S. K., 2010, "Trends in seasonal and annual rainfall and rainy days in Kashmir valley in the last century", *Quaty. Intl.*, **212**, 64-69.

Kumar, V., Jain, S. K. and Singh, Y., 2010, "Analysis of long-term rainfall trends in India", *Hydrol. Sci. J.*, **55**, 484-496.

Kumar, V., Singh, P. and Jain, S. K., 2005, "Rainfall trends over Himachal Pradesh, Western Himalaya, India", Proceedings of Conference on Development of Hydro Power Projects – A Prospective Challenge, Shimla, 20-22 April, 2005 Central Board of Irrigation and Power, New Delhi, India.

Lal, M., 2001, "Climatic change – implications for India's water resources", *J. Indian Water Resour. Soc.*, **21**, 101-119.

Mall, R. K., Gupta, A., Singh, R., Singh, R. S. and Rathore, L. S., 2006, "Water resources and climate change: An Indian perspective", *Curr. Sci.*, **90**, 12, 1610-1626.

Min, S. K., Kwon, W. T., Park, E. H. and Choi, Y., 2003, "Spatial and temporal comparisons of droughts over Korea with East Asia", *Int. J. Climatol*., **23**, 223-233.

Naidu, C. V., Durgalakshmi, K., Munikrishna, K., Rao, S. Ramalingeswara, Satyanarayana, G. C., Lakshminarayana P. and Rao, L. Malleswara, 2009, "Is summer monsoon rainfall decreasing over India in the global warming era?" *J. Geophys. Res.: Atmos*., **114**, D24108.

Rajeevan, M., Bhate, J. and Jaswal, A. K., 2008, "Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data", *Geophys. Res. Lett.*, **35**, L18707.

Rao, V. U. M., Rao, A. V. M. S. and Chowdary, P. S., 2015, "Weather Cock 15", All India Coordinated Research Project on Agrometeorlogy, Central Research Institute of Dryland Agriculture, Hyderabad.

Singh, P., Kumar, V., Thomas, T. and Arora, M., 2008, "Change in rainfall and relative humidity in different river basins in the northwest and central India", *Hydrol. Proc.*, **22**, 2982-2992.

Singh, R. B. and Sen Roy, S., 2002, "Climate variability and hydrological extremes in a Himalayan catchment", ERB and Northren European FRIEND Project 5 Conference, Demanovska dolina, Slovakia.

Sinha Ray, K. C. and De, U. S., 2003, "Climate change in India as evidenced from instrumental records", *WMO Bull.*, **52**, 53-59.

Sinha Ray, K. C. and Srivastava, A. K., 1999, "Is there any change in extreme events like droughts and heavy rainfall?", INTROPMET 97, 2-5 December, 1997, IIT New Delhi.

Sinha Ray, K. C. and Srivastava, A. K., 2000, "Is there any change in extreme events like heavy rainfall?", *Curr. Sci.*, **79**, 2, 155-158.

Venables, W. N. and Smith, D. M., 2012, "RClimDex - A Programming Environment for Data Analysis and Graphics Version 2.15.0 (2012-03-30)", University of Adelaide, Australia.

RAJENDRA PRASAD
ANUPAM SHARMA

CSK Himachal Pradesh Krishi Vishvavidyalaya,
Palampur, Himachal Pradesh – 176 062, India
(*Received 28 July 2016, Accepted 24 September2018*)

email: rprasad57@gmail.com