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Extreme weather events – impact on agro-horticultural sector in Himachal Pradesh

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Abstract

Weather extreme could be any weather parameter be it rainfall or temperature that lies outside a locale's normal range of weather intensity. The negative or adverse impact of extreme weather events could be significant whether directly or indirectly inducing stress on plant growth and performance. Enlisting extreme weather events is highly useful to ascertain their occurrence and probable impact in future. The highest single day rainfall (amount of rainfall received in 24 hours' time) was as high as 381.7 mm at Dharamshala in district Kangra, while the other stations in Himachal Pradesh received the lower single day rainfall. The longest dry spells were more frequent with higher variation during October to December which coincided with sowing of the rabi crops than March to May corresponding to grain filling and maturity of the rabi crops and flowering and fruit development stage in mango, apple and stone fruits. In the recent past, the highest recorded maximum temperature was 48.5°C at Dhaulakuan, district Sirmaur while the lowest minimum temperature was -9°C at Salooni, district Chamba. There was decline in number of cold waves, severe cold waves and total number of days with minimum temperature below normal. The occurrence of extreme weather events showed no pattern or periodicity but they continued to affect sowing, flowering, fruit development and maturity in field/ horticultural crops in the state.

Key words: Highest single day rainfall, dry spells, cold waves, field crops, vegetable crops, horticulture crops.

An unexpected, unpredictable, unusual, unseasonal and severe weather condition is known as an extreme weather event. In the most obvious sense, extreme weather lies outside a locale's normal range of weather intensity. By definition, they are infrequent or rare (Srivastava, 2013). It is extreme of the historical distribution and the range that has not been seen in the past. Listing of chronological weather events is of great value if one wishes to make some certainty about the occurrence of any extreme weather event in future. Thus, a firm grasp of the past events might be a key to know the future weather. At regional scale and for individual extreme event, global or national statistics and thermodynamic arguments may no longer apply since the occurrence and evolution of climate extremes in a particular place is influenced largely by the regional or local atmospheric circulation (Stott *et al.* 2016).

The Northwest Himalayan region is highly vulnerable to extreme weather events due to its extremely intricate topography and altitude-dependent climate, consequently leading to sharp weather fluctuations in different sectors of mountains which could be both unpredictable and harsh (Bharti, 2015). Geologically the Himalayas are considered to be the youngest mountains and are still in the building phase which makes it environmentally fragile and ecologically vulnerable. There are considerable variations in the distribution of rainfall and temperature due to the varying aspects and altitudes. Himachal Pradesh is a small hilly state of the North-western Himalayas. Precipitation declines from west to east and south to north. Highest annual rainfall to the tune of 1000 mm at 75% probability was noticed in 16 (with 6 located in the Kangra district alone) out of 40 rain gauge stations (Prasad and Sharma, 2016). Temperature decreases from west to east and January is the coldest month, whereas highest temperature recorded is in June (State of Environment Report Himachal Pradesh, 2009). Extreme rainfall events are one of the serious challenges society face with a changing climate at present. The increased pressure on the mountain environment has contributed to the occurrence of extreme events such as landslides, land subsidence, removal of vegetation and soil erosion. Considerable losses are also caused to various crops. Undoubtedly, the adverse impact of weather aberration in agriculture and allied sectors is required to be minimized through contingency measures. It was absolutely necessary to document the extent and magnitude of extreme weather events and their probable impact. The information on this aspect in the state is practically nil; hence the present investigation was undertaken.

Materials and Methods

Data on extreme weather viz., highest single day rainfall, dry spells, highest maximum and lowest minimum temperatures and hail events of different data durations have been utilized (Table 1). The extreme rainfall indices and their trends including maximum one day rainfall and the extreme temperature indices of temperature were worked following the method given by Zhang and Yang (2004). The data on hail events was available only from Palampur Station. For working out cold wave and severe cold wave conditions, the criteria of India Meteorological Department (IMD) were used. Under this, number of spells with maximum days with minimum temperature must be below normal by $\leq$-4.5 to -6.4 ^{o}C for cold wave and $\leq$-6.5 ^{o}C for severe cold wave. Total number of spells and total number of days with such spells for cold wave and severe cold wave were worked out using Spell Estimator software developed by CRIDA, Hyderabad and categorized as the longest spell, total spells and total days with spells. For sake of uniformity data sets of extreme weather events for 11 years (2005-15) were presented under relevant sections. Unlike plains, the weather data in hills of Himachal Pradesh is very sparse due to inaccessible and harsh (extremely low temperature) environmental conditions. The available data is though scarce but extremely valuable even if the data duration is <30 years. The impact of extreme weather events was assessed (under All India Coordinated Research Project on Agrometeorology being operated in the Department of Agronomy, Forages and Grassland Management) through Agro-climatic Field Surveys and partly from the Weather Watch Reports of Department of Agriculture, Government of Himachal Pradesh.

Results and Discussion

Highest single day rainfall

Highest single day rainfall often results from a cloudburst which is a rain gush/gust, a sudden heavy downpour over a small region. It specifies a rate of rainfall equal to or greater than 100 mm per hour featuring high-intensity localized rainfall affecting an area not exceeding 20-30 km^2 over a short period, strong winds and lightning (Das *et al*. 2006).

The station wise (Fig1) perusal of data (2005-2015) given in Table 2 shows that Akrot received 203.6 mm rainfall, Arki 272.2 mm, Bajaura 112.8 mm, Banjar 90.7 mm, Berthin 256 mm, Bhoranj 314.3 mm, Chachiot 160 mm, Dehra 245 mm, Dharamshala 290 mm, Dhaulakuan 293.2 mm, Hamirpur 169.3 mm, Jogindernagar 224 mm, Jubbal 105.5 mm, Kandaghat 212 mm, Kangra 200.1 mm, Karsog 94 mm, Kasauli 135.6 mm, Keylong 72 mm, Kotkhai 105.2 mm, Kumarsain 198.4 mm, Malan 227.3 mm, Mashobra 134 mm, Nadaun 270 mm, Nahan 267 mm, Nurpur 156 mm, Pachhad 175 mm, Palampur 268.7 mm, Rohru 84.4 mm, Salooni 375 mm, Sangla 210 mm and Sarkaghat 245.7 mm as the highest single day rainfall (Table 2). However, over the entire database period, Pachhad station in district Sirmaur also received 12.2 mm on 02nd November, 2002 as the highest single day rainfall during the year which was lowest among all the stations and Dharamshala in district Kangra 381.7 mm on 07th October, 1998 which was the highest recorded rainfall at any station in the state. The other stations following Dharamshala were Salooni, Bhoranj, Dehra, Sarkaghat, Kandaghat, Dhaulakuan,

Table 1. Database utilized

Sr. No.	Parameter	No. of Stations	No. of years
1.	Rainfall & dry spells	31	12-45
2.	Temperature	8	12-42
3.	Hail events	1	28

Fig. 1. Map showing stations with district boundaries in Himachal Pradesh

Table 2. Highest single day rainfall events at different stations in Himachal Pradesh

Sr. No.	Station	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1.	Akrot	58.6	130.2	116.2	183.4	127.6	67.6	203.6	77.8	76.0	92.6	121.0
2.	Arki	120.6	84.0	40.5	177.6	49.0	52.0	160.0	110.2	80.5	90.8	272.2
3.	Bajaura	99.2	57.4	99.0	112.8	71.2	56.0	90.8	49.9	43.0	60.0	50.0
4.	Banjar	48.0	63.0	40.0	40.0	25.0	62.2	51.1	73.4	55.4	38.4	90.7
5.	Berthin	80.0	83.4	105.2	111.4	133.2	71.8	243.0	115.1	111.0	82.0	256.0
6.	Bhoranj	68.0	190.0	314.3	95.1	120.6	76.2	201.0	125.4	96.4	158.4	93.8
7.	Chachiot	120.0	102.2	132.0	91.0	25.0	123.2	160.0	76.0	96.0	91.0	95.0
8.	Dehra	82.8	115.0	88.0	152.2	35.4	40.0	144.0	103.2	245.0	78.0	168.0
9.	Dharamshala	218.0	150.2	145.6	212.4	92.0	95.8	213.4	186.4	197.6	290.0	187.6
10.	Dhaulakuan	89.4	293.2	157.6	143.4	108.4	195.6	126.0	132.2	260.8	230.5	132.6
11.	Hamirpur	69.4	70.6	52.4	59.2	158.6	110.0	159.0	164.2	67.4	169.3	110.0
12.	Jogindernagar	224.0	124.0	158.5	94.0	122.0	74.5	142.5	133.5	140.0	81.0	93.5
13.	Jubbal	105.5	85.3	29.5	71.0	40.0	80.0	22.0	47.0	80.0	45.0	58.0
14.	Kandaghat	100.0	67.0	158.0	76.0	115.0	35.0	75.2	72.4	97.2	212.0	122.0
15.	Kangra	45.4	170.6	126.1	188.3	80.0	170.1	90.4	189.4	200.1	71.2	173.4
16.	Karsog	66.0	55.0	76.0	85.0	75.0	75.0	40.0	62.0	94.0	46.0	72.6
17.	Kasauli	65.5	35.5	135.6	127.0	85.0	119.0	92.0	80.0	82.0	113.0	120.0
18.	Keylong	72.0	45.0	43.0	46.0	41.0	40.0	59.0	43.0	38.0	46.0	51.0
19.	Kotkhai	50.6	105.2	105.0	25.0	70.4	35.2	40.5	55.6	54.0	56.3	55.0
20.	Kumarsain	135.0	60.0	72.0	85.0	23.0	44.0	70.0	46.0	107.0	29.0	198.4
21.	Malan	69.2	132.6	105.2	180.8	222.4	213.6	186.0	145.9	227.3	108.4	118.1
22.	Mashobra	87.2	72.8	108.4	72.6	40.0	80.0	57.2	39.0	134.0	77.4	122.4
23.	Nadaun	60.0	100.0	270.0	105.0	176.0	158.0	195.0	157.2	110.0	82.1	148.7
24.	Nahan	109.8	167.2	127.2	127.8	50.5	210.0	210.0	108.0	267.0	43.0	180.6
25.	Nurpur	50.0	75.0	89.0	86.0	75.4	105.8	72.5	102.0	128.2	156.0	102.0
26.	Pachhad	175.0	90.0	145.3	88.0	150.4	27.4	75.0	65.5	65.4	80.0	84.0
27.	Palampur	268.7	201.5	79.7	114.8	124.0	219.0	229.8	185.2	161.0	138.0	141.2
28.	Rohru	31.5	84.4	53.2	46.2	39.2	66.6	54.2	60.4	60.2	28.6	56.1
29.	Salooni	215.0	86.0	99.0	375.0	250.0	120.0	78.8	80.0	85.5	62.0	82.0
30.	Sangla	210.0	65.0	37.0	62.0	85.0	52.0	49.0	20.0	32.0	32.0	60.0
31.	Sarkaghat	132.0	112.0	180.0	98.0	75.0	130.0	149.0	245.7	85.7	149.0	138.0

Kasauli, Palampur, Arki, Nadaun, Nahan, Berthin, Malan, Mashobra, Jogindernagar, Kotkhai, Nurpur, Sangla, Akrot, Kangra, Kumarsain, Pachhad, Jubbal, Hamirpur, Chachiot, Karsog, Rohru, Banjar, Bajaura and Keylong.

The occurrence of highest single day rainfall in the state is inconsistent/ infrequent over the years. The results of various extreme rainfall indices and their trends including maximum one day rainfall amount obtained from observed daily rainfall of 22 stations in the state having data of 45 years (1970 to 2014) showed significant decrease at 14 and increase at 7 stations at 95% confidence level (Prasad *et al.* 2017). This indicated a decreasing trend in highest single day rainfall at majority of stations in the state.

Dry spells

The longest dry spells, their duration (days) at eight rain gauge stations were found to occur more frequently during October to December (15-108 days) and March to May (22-89 days) at different stations for 44 years (1974-2017). A cross section of data set for 2005-2015 is presented in Table 3. The higher variation was obtained during October to December which coincided with sowing of the *rabi* crops than March to May corresponding to grain filling and maturity of the *rabi* crops and flowering and fruit development stage in mango, apple and stone fruits.

Highest maximum and lowest minimum temperatures

During 2005-15, the highest recorded maximum temperature was 45.0°C at Akrot, 44.6°C at Dhaulakuan, 44°C at Kangra, 43.5°C at Berthin, 40.5°C at Malan, 39°C at Salooni, 38.8°C at Bajaura and 38°C at Palampur (Table 4). However during the entire database period, Dhaulakuan station experienced highest maximum temperature (48.5°C) during 1992 and 1998.

Lowest minimum temperature was -9.0°C at Salooni during 1998 and 2008. The lowest minimum temperature recorded during recent past for other station was -3.6°C at Bajaura, -3.0°C at Berthin, -0.5°C at Palampur, 0.8°C at Dhaulakuan, 1.0°C each at Akrot and Kangra. The lowest temperature attained by Malan station was 2.0°C during 2005, 2007 and 2008. In most of the cases, the occurrence of lowest and highest temperatures were neither contiguous nor after a gap of one year or several years.

The results of various extreme temperature indices of temperature obtained from 4 stations in the state having data of 45 years (1970 to 2014) showed mixed trends i.e., equal number of stations showing increase and decrease in temperature (Prasad *et al*. 2017).

Cold wave condition

Occurrences of extreme low temperature condition in association with incursion of dry cold winds from north into the sub continent during December to February are known as cold waves. Three indices viz., longest spell, total number of spells and total number of days having temperature below normal for cold and severe cold wave conditions for nine stations showed a mixed picture but a general decline in the longest spell, total number of spells and total number of days with spell at all the stations (except Shimla) indicating general warming in the region (Table 5). The similar pattern was also observed at Salooni station in Chamba district but the number of spells increased considerably from cold wave to severe cold wave category.

Hail events

The number of hail events are on rise at Palampur i.e., in mid hill region of Himachal Pradesh as evident from Fig.2. The number of days with hail is about 6-7 per year (highest over the state) but, decrease to one in two years over adjoining plains (Prasad, 2013). Though the data is available only for one station but it can be safely assumed that the hail storm activity has increased in the state vis-à-vis other states wherein lot of reports of recent hail activity are coming through press and media. Hailing in the state is frequent at the time of flowering of horticultural crops viz., apple, mango, peach, plum etc. and at the time of maturity of wheat and *Brassica* crops during March and April and also at the time of maturity of rice crop during October. Thus, Himachal Pradesh is in high risk zone of hailstorm damage in India (Kumar, 2010). The severity of the damage caused to the various crops depends on the timing of the hail episodes and size of the hail stones (Rao *et al.* 2014). Protection of annual crops is not possible on large fields but in perennials and cash crops such as orchards, hail nets can be used.

Impact on different crops

The state being mostly rain fed (about 80%), rainfall patterns become extremely important for continuous supply of water to carry out various agricultural and domestic activities (Prasad *et al.* 2016). A brief dry spell during different phenophases, though could be very useful for good growth and also a longer dry spell might attract lower incidence of pest and diseases. The negative or adverse effect of extreme weather events could be significant whether directly or indirectly inducing stress on plant growth and performance. When these extremes exceed the tolerance limits and survival capacity, the impacts could be severe, often leading to plant damage and mortality. Many a times, their occurrence in

Table 3. Longest dry spell days and duration at eight rain gauge stations in Himachal Pradesh

Year	Bajaura	Dhaulakuan	Palampur	Salooni	Akrot	Berthin	Kangra	Malan
2005	98[#] 25th Nov to 31st Dec	94 29th Sep to 31st Dec	80 13th Oct to 31st Dec	80 13th Oct to 31st Dec	99 24th Sep to 31st Dec	94 29th Sep to 31st Dec	16 04th Nov to 19th Nov	108 15th Sep to 31st Dec
2006	27 19th Jan to 14th Feb & 22nd Oct to 17th Nov	43 23rd Oct to 04th Dec	25 24th Oct to 17th Nov	30 13th Sep to 12th Oct	51 19th Jan to 10th Mar	45 21st Oct to 04th Dec	29 21st Sept to 19th Oct	38 19th Jan to 25th Feb
2007	42 09th Oct to 19th Nov	71 30th Sep to 09th Dec	60 02nd Oct to 30th Nov	53 19th Oct to 10th Dec	79 23rd Sep to 10th Dec	44 17th Oct to 29th Nov	77 26th Sep to 11th Dec	63 29th Sep to 30th Nov
2008	34 18th Oct to 20th Nov	53 10th Feb to 02nd Apr	64 17th Oct to 19th Dec	40 25th Feb to 04th Apr	76 17th Oct to 31 Dec	76 17th Oct to 31st Dec	75 18th Oct to 31st Dec	63 17th Oct to 18th Dec
2009	35 06th Oct to 09th Nov	36 06th Oct to 10th Nov	34 06th Oct to 08th Nov	65 05th Sep to 08th Nov	46 16th Nov to 31st Dec	46 16th Nov to 31st Dec	46 16th Nov to 31st Dec	46 16th Nov to 31st Dec
2010	39 21st Nov to 29th Dec	56 24th Feb to 20th Apr	40 20th Nov to 29thDec	40 20th Nov to 29th Dec	47 06th Mar to 21st Apr	89 11th Feb to 10th May	70 11th Feb to 21st Apr	68 23rd Oct to 29th Dec
2011	49 24th Sep to 11th Nov	83 17th Sep to 08th Dec	36 02nd Nov to 07th Dec	45 25th Oct to 08th Dec	66 04th Oct to 08th Dec	64 04th Oct to 06th Dec	68 25th Oct to 31st Dec	68 25th Oct to 31st Dec
2012	56 05th Oct to 29th Nov	71 20th Sep to 29th Nov	35 25th Oct to 28th Nov	55 05th Oct to 28th Nov	36 25th Oct to 29th Nov	43 13th May to 24th June	56 30th Apr to 24th June	56 29th Apr to 23rd June
2013	40 12th Nov to 21st Dec	73 10th Oct to 21st Dec	39 10th Nov to 18th Dec	43 09th Nov to 21st Dec	43 09th Nov to 21st Dec	66 29th Mar to 02 June	43 09th Nov to 21st Dec	52 08th Nov to 29th Dec
2014	35 09th Nov to 13th Dec	47 27th Oct to 12th Dec	35 09th Nov to 13th Dec	35 09th Nov to 13th Dec	44 30th Oct to 12thDec	59 15th Oct to 12th Dec	66 09th Oct to 13th Dec	47 27th Oct to 12th Dec
2015	21 06th Nov to 26th Nov	77 24th Sep to 09th Dec	17 27th Sep to 13th Oct	29 23rd Aug to 20th Sep	46 26th Oct to 10th Dec	29 29th Oct to 26th Nov	21 06th Nov to 26th Nov	18 24th Sep to 11th Oct
Oct-Dec	15-98 days	31-100 days check all	17-83 days	24-89 days	36-93 days	44-94 days	16-99 days	18-108 days
Mar-May	27 days	33-79 days	22-61 days	32-82 days	47-72 days	43-89 days	31-56 days	38-63 days

days

Table 4. Highest and lowest temperatures(°C) at different stations

Year	Palampur	Salooni	Malan	Kangra	Akrot	Berthin	Bajaura	Dhaulakuan
				Highest maximum temperature				
2005	37.0	33.5	40.0	41.5	44.5	42.4	37.5	44.0
2006	34.0	31.0	39.8	39.0	42.2	39.4	38.8	40.5
2007	36.5	36.5	39.0	42.0	41.8	41.4	36.3	43.0
2008	31.7	31.5	37.0	38.5	42.2	39.6	33.8	41.4
2009	36.0	36.0	39.2	40.5	43.0	41.6	38.0	43.8
2010	35.5	35.5	37.8	41.0	43.2	40.8	37.6	42.5
2011	32.0	35.5	37.2	41.0	41.8	39.8	34.4	40.2
2012	38.0	38.5	40.5	44.0	44.8	42.0	37.6	44.6
2013	34.0	39.0	40.4	43.5	45.0	42.5	37.7	41.6
2014	36.0	35.0	38.9	41.5	44.2	43.5	36.0	44.3
2015	33.2	35.0	35.7	39.0	43.5	43.2	35.0	42.6
				Lowest minimum temperature				
2005	0.0	-1.5	2.0	1.0	2.5	0.6	-3.6	0.8
2006	2.5	-1.0	4.0	3.0	2.8	0.8	-1.7	1.0
2007	0.0	-1.5	2.0	1.0	1.4	-3.0	-3.2	1.5
2008	-0.3	-9.0	2.0	1.0	1.0	-2.6	-2.6	1.0
2009	2.0	1.0	5.0	2.0	3.0	0.8	-2.4	1.0
2010	2.0	-1.5	4.4	1.0	2.0	-0.8	-2.9	1.0
2011	-0.5	-4.5	4.0	1.0	1.2	1.0	-1.9	1.0
2012	0.0	0.1	3.2	1.0	3.0	1.0	-1.8	1.0
2013	0.0	-5.5	4.6	1.0	1.8	1.0	-3.4	0.7
2014	1.0	-0.8	4.0	1.0	1.0	1.0	-2.7	0.6
2015	0.0	-9.0	2.3	3.0	2.0	-0.6	-2.9	0.8

Table 5. Cold wave & severe cold wave observed at nine stations

Decade	Palampur Since 1974-2016			Shimla Since 1984-2014			Bajaura Since 1986-2016			Dhaulakuan Since 1987-2016			Salooni Since 1991-2016			Akrot Since 1999-2016			Berthin Since 2004-2016			Malan Since 2000-2016			Kangra Since 2003-2016		
													Cold wave														
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
1974-1980	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1981-1990	2	3	4	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991-2000	2	2	3	0	0	0	4	15	26	5	4	10	1	1	1	2	1	2	0	0	0	0	0	0	0	0	0
2001-2010	1	3	3	1	2	2	3	4	7	4	3	8	1	1	1	2	4	5	3	10	17	0	0	0	0	0	0
2011-2016	2	5	6	2	10	12	1	2	2	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0
													Severe cold wave														
1974-1980	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1981-1990	3	3	5	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991-2000	0	0	0	0	0	0	3	3	6	0	0	0	25	59	159	1	1	1	0	0	0	0	0	0	0	0	0
2001-2010	0	0	0	0	0	0	0	0	0	2	1	2	25	41	137	0	0	0	4	3	5	0	0	0	0	0	0
2011-2016	0	0	0	1	1	1	0	0	0	0	0	0	7	29	68	2	2	4	0	0	0	0	0	0	2	2	3

1- Longest spell; 2-Total spell; 3-Total days contiguous areas become really devastating. There appears to be an obvious and ample impact based on these environmental conditions. Following are some of the real field examples experienced on crops across the region:

Impact of rainfall, high velocity winds and hailstorm

Sowing rains during June were either scanty or deficient in 10 out of 12 districts in the state during 2012 and 2014 which caused delayed sowing and poor coverage of area sown. Transplanting and intercultural operation of rice and maize were affected due to scanty and deficit rainfall in more than half of the districts during 2016 and 2017, respectively. Grain development in maize and panicle initiation and grain filling in rain fed rice was severely affected due to deficit rainfall in 8 districts during 2013 and 6 districts each during 2014, 2016 and 2017. Harvesting of maize during September-October was affected because of excess rain in 10 districts during 2012. Years 2013 and 2014 proved to be really bad witnessing heavy rain, high velocity winds and hailstorm damaging apple, plum, peach, cherry, apricot and almond. The highest loss was observed in district Kinnaur due to heavy rains associated with cloud burst. Mango and litchi in district Kangra and the summer vegetables in all the districts were damaged. Maize, paddy and vegetables including tomato were damaged in 6 districts (Solan, Kullu, Mandi, Kangra, Hamirpur and Chamba) with premature apple drop in district Shimla.

Heavy rain and associated strong winds damaged standing (ready to harvest) and harvested (ready to thresh) wheat in district Kangra during May, 2013. Hail and excessive rain damaged pea in 5 districts (Kullu, Mandi, Solan, Shimla and Sirmaur) and wheat in Kangra district during April, 2014. Apple, mango and vegetables were severely affected in 5 districts (Mandi, Shimla, Chamba, Kullu and Kangra) during June, 2014. Water logging and flattening of wheat and heavy damage in mango, peach and plums was observed in 4 districts (Kangra, Mandi, Hamirpur and Una) during May, 2017.

Continuous dry spell of about a month during October – November, 2012, affected the sowing of all the *rabi* crops, whereas continuous heavy rains during October, 2013 delayed their sowing. Dry spell for a period of over a month during November- December of 2013, 2014 and 2015 affected the emergence of timely sown wheat. Heavy rain associated with hail during March and April, 2015 affected the crops with the estimated loss of over 20%. The major risk for wheat is either failure of rains during sowing and/ or reduction in winter rains and/or unseasonal rain/hail at harvest, whereas for apple it is decrease in chill hours and high temperature during bloom (Anonymous 2013- 2018).

Impact of temperature

Heat waves and cold waves are such short period climatic aberrations that can cause severe stress on plant survival and performance. Significant losses have been experienced year after year. Both the extremes of maximum and minimum temperatures cause stress to plant productivity (Ramakrishna 2013).

The higher maximum temperature in March, 2004 and rainless period of 62 days adversely affected crops like wheat, rapeseed-mustard, linseed, potato, vegetables, apple, pea and tea across the state (Prasad and Rana 2006). The estimated yield loss was

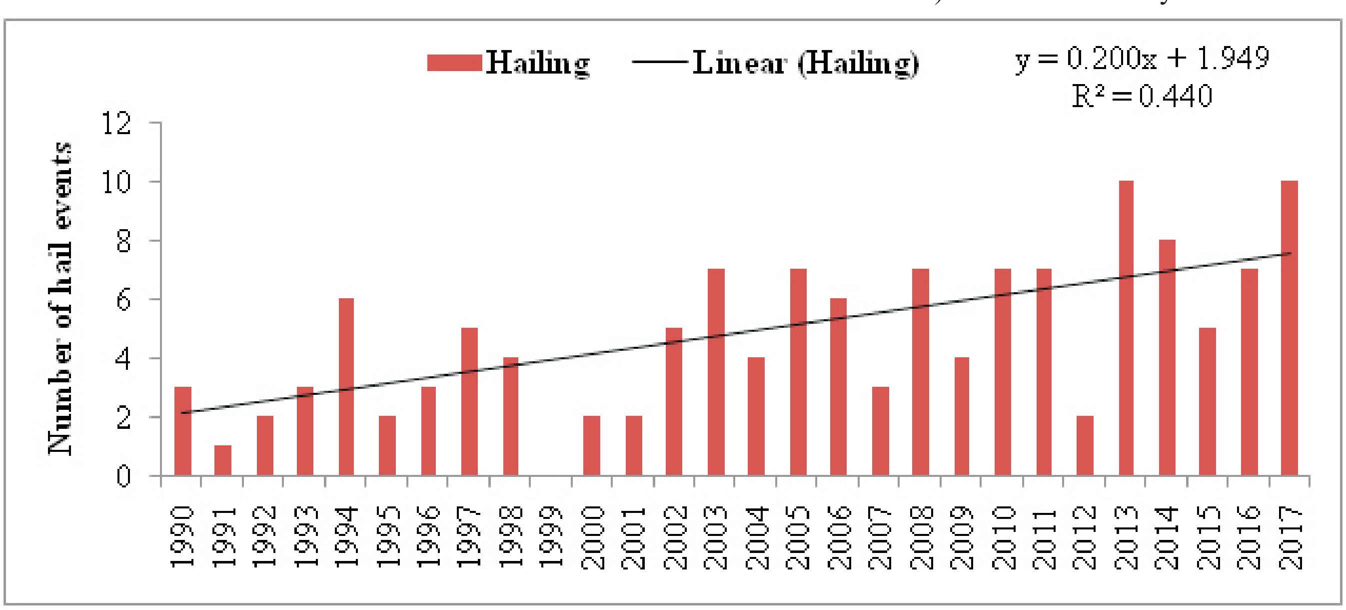

Fig. 2 Increasing hail events at Palampur in mid hills of Himachal Pradesh

between 20-60% depending upon the crop. Wheat and potato harvest was advanced by 15-20 days and the flowering of apple was early by 15 days. The optimum temperature for bloom and fruit set is 24 °C for apple, while it experienced above 26 °C for 17 days. A major part of north western region of India witnessed intense heat wave conditions producing an adverse impact on the productivity of major crops in the region. The observed highest rise in the daily maximum temperature in major cities of the region varied between 8-12 °C. Simulation studies by Aggarwal and Singh (2004) using Infocrop model showed that warming during grain-filling highly negatively impacted the wheat production in North India during 2004.

Analysing the impact of cold wave conditions over North India during December 2002 to January, 2003, Samra *et al.* (2003) observed that the temperatures at several places in north India remained un-usually low continuously for 3-4 week leading to adverse impact over 600 ha of mango and litchi orchards wherein heavy damage in mango (40 -100 %) and litchi (50-80 %) was observed. Heavy damage in tomato (100 %), potato (72-80 %), peas (30-50 %) and marigold (100 %) was also observed during 2005-06 and 2007-08.

Management options of extreme weather events through weather forecast and Agromet Advisory Services

Timely communication of weather forecasts, whether of longer time scale or shorter time validity, is of utmost importance as many critical operations related to economic and food security aspects are based on these forecasts. For the same temporal distribution of weather parameters, different crops react differently. Also, the effects of weather or weather-induced stresses and incidence of pests and diseases is critically dependant on the state and stage of crops. The effects of anomalies of a weather and post harvest processing, as well as for solving other weather related agricultural problems (Bhan 2013). For example, a sample advisory for hailstorm: Cover the orchards with hail nets in Kangra, Chamba, Una, Hamirpur, Bilaspur, Solan, Mandi, Shimla districts as the chance of hailstorms looms large in these districts (Chattopadhyay 2013).

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