MAUSAM, **67**, 1 (January 2016), 155-168

631.151 : 551.583 (540)

Agricultural disaster management and contingency planning to meet the challenges of extreme weather events

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सार – भारत के आर्थिक विकास में जल-मौसम विज्ञान प्रकृति की प्राकृतिक विपदाएं प्रमुख भूमिका निभाती हैं। भारत में कृषि उत्पादन ग्रीष्म मानसून वर्षा के निष्पादन पर अधिक निर्भर करती है। कई बार आकाशीय एवं अस्थाई विविधताओं के अलावा कई जलवायुवीय विषमताएं/प्रतिकूलताएं विपदा का रूप ले लेती हैं जो देश के कृषि उत्पादन को प्रभावित करती है। भारत में लगातार होने वाले जलवायुवीय विषमताओं की प्रकृति एवं विस्तार सहित उनके इतिहास एवं प्रभावित क्षेत्रों का विवरण प्रस्तुत किया गया है। सूखा एवं बाढ़ की प्रधानता पाई गई है। हाल के ओला वृष्टि, शीत एवं ग्रीष्म लहर की परिस्थितियों ने भी कृषि एवं बागवानी फसलों को अत्यधिक प्रभावित किया है। प्रतिकूल घटनाओं की प्रवृत्तियों, उनकी बारंबारता एवं फसलों पर पड़ने वाले प्रभावों पर विचार-विमर्श किया गया। देश में मौसम प्रतिकूलताओं का सामना करने वाले प्रबंधन अनुकूलताओं एवं आकस्मिक योजनाओं को स्पष्ट किया गया है। राष्ट्रीय जलवायु समुत्थान कृषि पहल (निक्रा) के अंतर्गत प्रतिकूल मौसम घटनाओं से क्षेत्रीय स्तर पर सामना करने के लिए अपनाई गई सफल अनुकूलताओं पर अध्ययन किए गए कुछ मामलों को प्रस्तुत किया गया है।

ABSTRACT: Natural disasters of hydro-meteorological nature are playing a key role in the economic development of India. Agricultural production in India is largely dependent on the performance of summer monsoon rainfall. Apart from its spatial and temporal variability, several climatic anomalies / extremes attaining disastrous form at times were found to influence the country's agricultural production. Nature and magnitude of climate extremes that frequent India are presented with their history and region of occurrence. Droughts and floods are found to be paramount. Of late, hailstorms, cold and heat wave conditions are also exerting considerable influence on field and orchard crops. Trends in extreme events, their frequency and effects on crops are discussed. Regions in the country prone to be sensitive to the various weather extremes are presented. Management strategies and contingency planning to be adopted to cope-up the weather extremes are elucidated. Few case studies on the successful strategies adopted at the field level to cope-up extreme weather events under National Initiative on Climate Resilient Agriculture (NICRA) program are reported.

Key words – Natural disasters, extreme weather events, agricultural production, management strategies, contingency planning.

1. Introduction

Natural disasters can be classified in to hydro-meteorological and geophysical disasters. The hydro-meteorological disasters include landslides/avalanches; droughts/famines; extreme temperatures and heat waves; floods; hurricanes; forest/scrub fires; windstorms; and others (insect infestation and waves/surges). The geophysical disasters include earthquakes and volcanic eruptions. During the period 1900-2014, the number of occasions in which large Indian population got affected from drought were more than any other natural disaster. There were 14 severe drought events that claimed on an average more than 3 lakh lives, affected 75 million people and resulted in US$ 0.17 million loss. If number of natural disaster events are considered riverine flood tops the list (143) closely followed by tropical cyclones (104) (CRED, 2015). An increase in the frequency and intensity of disaster events in south Asia over the period 1970-2010 was observed. The increase is large given by a greater number of hydro-meteorological events as flood and storm events have become increasingly common despite relatively consistent rainfall patterns (GFDRR, 2013).

Agricultural production in India is closely linked to the performance of summer monsoon (June to September) which contributes about 75% of the annual precipitation. Thus, an understanding of the variability of monsoon rainfall is of great relevance as they have a direct impact on total food grain production. Apart from the inter-annual variability in summer monsoon rainfall, occurrence of many of the hydro-meteorological events are found to influence Indian agriculture at different spatial scales. The data on climate anomalies, extreme and disastrous weather events in respect of the Indian sub-continent lie scattered in published literature. De *et al*. (2005) compiled the information on the extreme weather events for over 100 years (1901-2004) and highlighted their socio-economic impacts. Goswami *et al*. (2006) made a comprehensive study of trends in three different intensity classes such as moderate (5<R<100 mm/day), heavy (R>100 mm/day) and very heavy (R>150 mm/day) of Indian Summer Monsoon Rainfall (ISMR) and found that moderate intensity ranges show a decreasing trend while heavy and very heavy intensity ranges show significant increasing trend over Central India. Guhathakurta and Rajeevan (2008) studied the long term trends of rainfall using 103 year data set over the Indian meteorological sub-divisions and found that three sub-divisions (Kerala, Jharkhand and Chhattisgarh) are showing decreasing trends and eight meteorological sub-divisions showed increasing trend. In a more recent study, Hamza *et al*. (2013) showed that number of rainy days over major parts of India are decreasing and increasing over northeastern region in the high (15-20 mm) and very high (> 20 mm) rainfall classes, respectively. Over the west coast, a significant decreasing trend was found. In the northeastern region, days with less than 10 mm rain showed a slight decreasing trend but days with above 10 mm rain showed significantly increasing trend.

Apart from the summer monsoon rainfall, India receives precipitation during the winter months of December to March which is about 15% of the annual precipitation. This precipitation is very important for *rabi* crops. Yadav *et al*. (2012) noticed increased variability in winter precipitation during the most recent three decades with more excess and deficient years. Productivity of *kharif* rice and *rabi* wheat in Indo-Gangetic Plains (IGP) was found to be influenced by monthly distribution of rainfall, which accounted for 44% yield variability in rice and 21% yield variability in wheat (Subash and Ram Mohan, 2010).

Though rainfall and its distribution has profound influence on the Indian food grain production, climatic elements like radiation and temperature are also exerting considerable effect. For instance, Pathak *et al*. (2003) observed negative trends in solar radiation and an increase in minimum temperature, resulting in declining trends of potential yields of rice and wheat in the IGP of India. Mall and Singh (2000) observed incidence of intense fog events curtails the photosynthetically active radiation; intense spell of high temperature during grain filling and ripening stage of most of field crops resulted in low yields. Revadekar *et al*. (2012) studied the frequency indices of hot events at 121 stations that fairly represented the entire country and found increasing trend in hot events and decreasing trend in cold events at majority of the locations.

TABLE 1

Years of phenomenal All-India droughts (1877 to 2014)

Year	Departure of Average monsoon season's rainfall (%) ≤ -20%	Area (%) under deficient monsoon seasonal rainfall ≥ 47.7%
1877	-29.1	66.8
1899	-26.2	83.0
1918	-23.9	68.2
1972	-23.3	49.5
1987	-19.3**	64.3
2002	-19.0	29.0*
2009	-23.0	59.0

(*Source* : Kulshreshtra, 1997; Attri and Tyagi, 2010)
* 52% of the total districts were drought affected
** Marginal case

Considering the influence of extreme weather events on Indian food grain production and the likely chance of increase in their frequency in future, we present here a review on the type and frequency of different extreme weather events that occurred and research results on their impacts on crop production. Management options and contingency planning for different weather extremes are discussed with a few case studies.

2. Extreme weather events over India: Historical perspective

2.1. *Drought prone regions of India*

IMD classified agricultural drought as the period when weekly rainfall is less than half of its normal (> 5 mm) consecutively for a four week period during May to October. Sikka (1999) compiled the occurrences of droughts during the period 1276 to 1870 AD. There were eight instances during which the entire country was affected and on 16 occasions drought prevailed in different regions. During the period 1873-2009 there were 24 drought years of different magnitudes.

Mostly north and north western parts of the country witnessed more frequent of drought years compared to other parts of the country. Severe to phenomenal drought affecting more than 50% of areas were observed in 1877, 1899, 1901, 1918, 1972, 1987 and 2009.

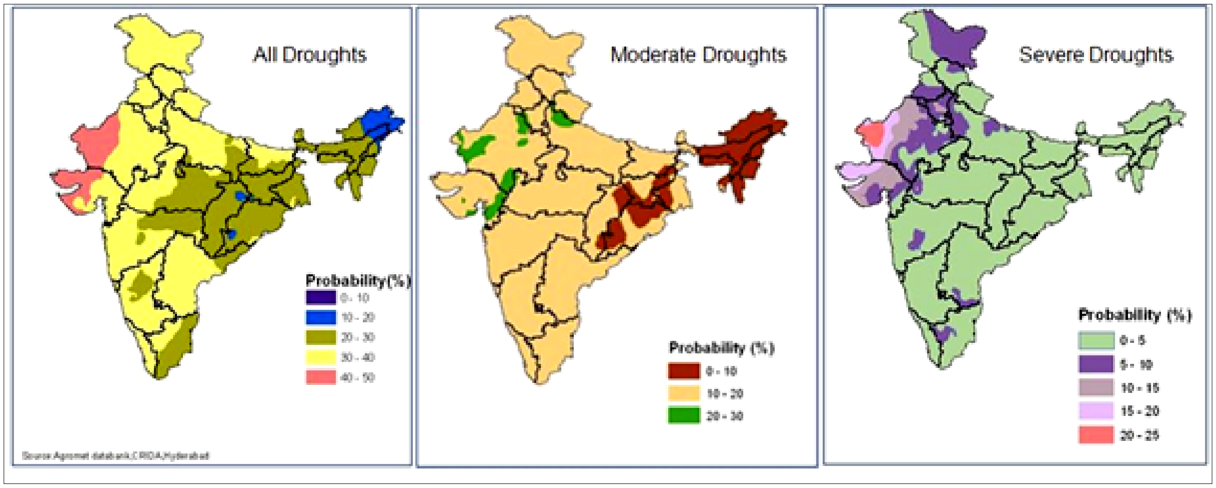


Fig. 1. Probability of different intensities of drought in India (*Source* : Rao *et al*., 2008)

The departures of per cent average monsoon rainfall and area affected under the phenomenal droughts from years 1872 to 1990 compiled by Kulshreshtra (1997) and updated for the period 1991-2010 by All India Coordinated Research Project on Agrometeorology (AICRPAM) are given in Table 1.

The spatial distribution of probability of occurrence of various categories of meteorological droughts were computed using more than 1100 stations rainfall data across India by AICRPAM and is shown in the Fig. 1. At national level, irrespective of the kind of drought, major part of the country can experience 3 to 4 drought years out of every ten years. The probability of occurrence of moderate drought is about 10 to 20 per cent indicating the chances of one to two droughts for every 10 year period over large part of the area. The probability of experiencing severe drought is very low (less than 10 per cent) and mostly confined to northwestern parts adjacent to Indian desert.

TABLE 2

***Kharif* output in drought years**

Year	SWM rainfall departure (%)	July month rainfall departure (%)	*Kharif* food grain production (% decline)
1972-73	-24	-31	-6.9
1974-75	-12	-4	-12.9
1979-80	-19	-16	-19
1982-83	-14	-23	-11.9
1986-87	-13	-14	-5.9
1987-88	-19	-29	-7.0
2002-03	-19	-49	-19.1
2009-10	-23	-4	-7.0

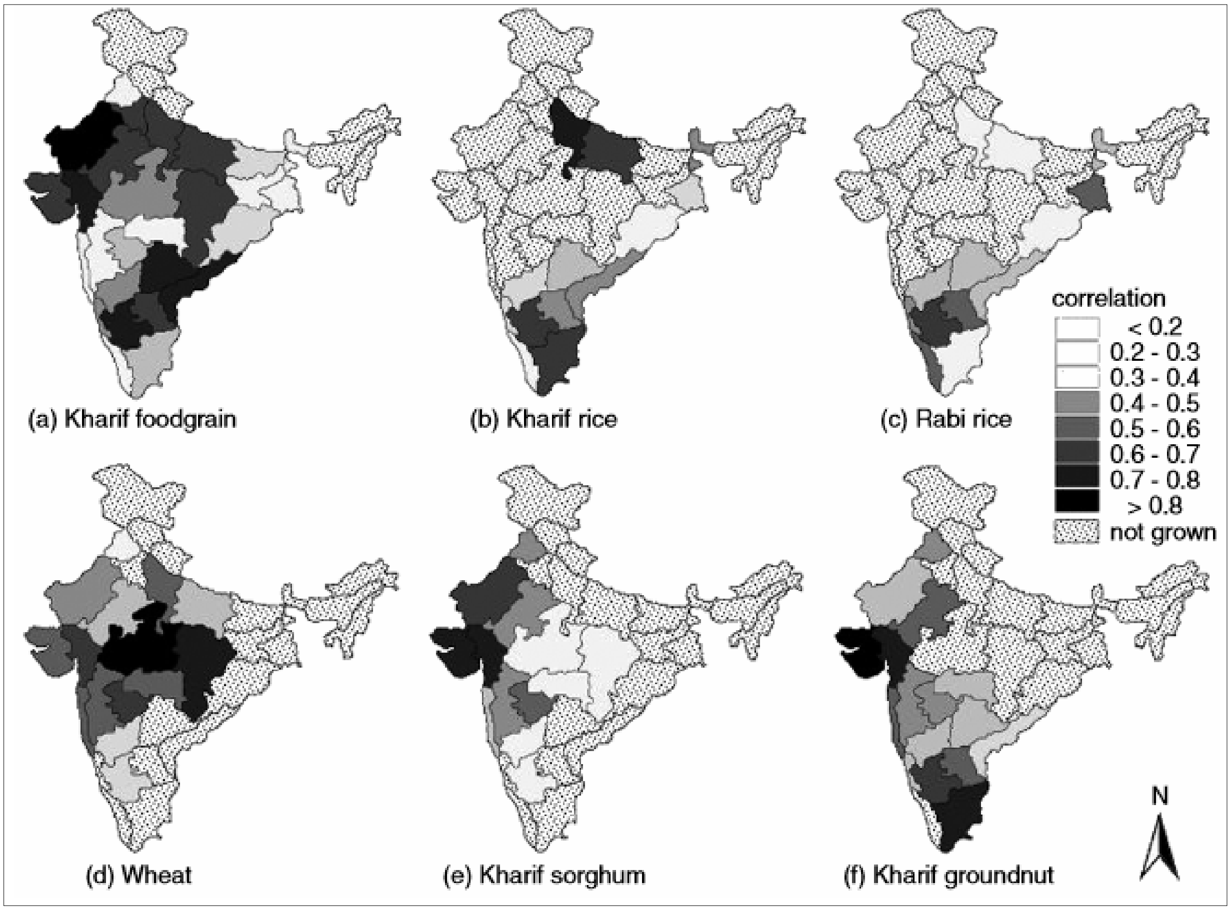
(*Source* : DAC, Ministry of Agriculture)

2.1.1. *Impacts on cropped area and production*

Droughts have considerable impact on agricultural production and continuous droughts during 1965-66 and 1966-67 forced the country to import food grains. Similarly, all the drought years have recorded a decline in production over the previous years. However, no other drought in the past led to such a drop in food production as the 2002 drought (Table 2). Food grain production dipped by 29 MT (183 MT compared to 212 MT in 2001). Over 18 million hectares of cropped area were left unsown during the *kharif* season. The percentage fall in *kharif* crop acreage, as compared to the normal, was the highest in Kerala (-59%), followed by Rajasthan (-41%), Tamil Nadu (-27%) and Uttar Pradesh (-19%). During the *rabi* season also, the acreage was reduced by 52% in Rajasthan followed by Gujarat (-28%) and Tamil Nadu (-25%).

2.1.2. *Changes in cropped area*

Area sown to different crops can be affected by the incidence of drought. These changes in area and in productivity as affected by drought together result in changes in production of different crops (Rama Rao *et al*., 2013). The changes observed in area, yield and production of major dryland crops during 1970-2011 periods are



Figs. 2(a-f). Correlation between monsoon rainfall (sub-divisional) and state-level production of different crops. The correlation coefficients shown in (e) for Maharashtra are with the post-monsoon (October-November) rainfall of the sub-divisions in that state (after Krishna Kumar *et al*., 2004)

presented in Table 3. There were 10 drought years during the period of analysis out of which four were severe droughts. Less area was sown to pearl millet during drought years. Area sown to castor was adversely affected by drought and this adverse effect was more severe during 2000-2011 compared to earlier periods. The yield effect in case of sorghum was most significant (-15.8%) during 1986-2000 which was about 9% during the initial period (1970-85) and during the long term (1970-2011). Yield of pearl millet was most sensitive to drought throughout as most of its cultivated area is in low rainfall regions. In case of pulses, sensitivity of yields to incidence of drought was found to be increasing over time as is evident from the yield effects of pigeonpea, chick pea and green gram. Thus, significant changes were observed in the sensitivity of production of major dryland crops to drought over time.

2.1.3. *Changes in production*

The impact of deviations in rainfall during the monsoon period (June to September) on productivity of

TABLE 3

Impact of drought on area sown, yield and production of major dryland crops (%)

Crop	1970-2011		
	Area sown	Yield	Production
Sorghum	2.88	-9.54	-7.73
Pearl millet	-8.31	-27.43	-36.02
Foxtail millet	-2.22	-11.96	-13.25
Maize	-1.56	-11.86	-11.93
Pigeonpea	-3.57	-0.7	-4.77
Chickpea	-5.8	-6.37	-11.45
Greengram	-3.1	-9.57	-11.6
Blackgram	-0.36	-7.36	-7.58
Groundnut	-7.06	-19.05	-25.28
Castor	-7.75	-22.86	-29.11
Sesamum	-6.07	-11.72	-18.6
Soybean	-5.25	-19.04	-11.18
Cotton	-2.67	0.45	-0.34

(*Source*: Rama Rao, *et al*., 2013)

TABLE 4

Flood affected areas and damages in India (1953-2004)

S. No.	Item	Unit	Average during (1953-2004)	Maximum Damage	Year
1.	Area affected	Million Hectare	7.63	17.50	1978
2.	Cropped area affected	Million Hectare	3.56	10.15	1988
3.	Value of damage crops	Rs. in Billions	7.09	42.47	2000
4.	Value of total damage to houses, crops and public utilities	Rs. in Billions	18.17	88.64	2000

(*Source* : Ministry of Home Affairs, 2011)

crops was regressed on the deviations in monthly rainfall and time trend using all India data on production and productivity for the period 1976-2010. The analysis showed that rainfall during July was more critical to the productivity of crops. A one per cent increase over normal in the rainfall during July was found to increase productivity of pearl millet by about 2.25 kg/ha.

Conversely, one per cent decrease in the rainfall would be accompanied by a productivity fall of about 2.25 kg/ha. Similar rainfall-productivity relationship was observed in case of soybean, cotton and groundnut. Deviations in September rainfall were also found to have a positive significant relationship with productivity of sorghum, pigeonpea and soybean. It was also found that rainfall during September also had a significantly positive effect on productivity of *rabi* crops like chickpea, rapeseed and mustard

Dependence of *kharif* food grain production, productivity of crops like *kharif* rice, *rabi* rice, wheat, *kharif* sorghum, *kharif* groundnut on the monsoon rainfall was amply demonstrated (Krishna Kumar *et al*., 2004) (Fig. 2). *Kharif* food grain production in most states [Fig. 2(a)] has a strong association with regional monsoon rainfall. It is also interesting to note that, within Bihar, *kharif* food-grain production is strongly correlated with monsoon rainfall in the northern Bihar Plateau, but only weakly correlated with monsoon rainfall in the plains. Similar spatial variability is also apparent in Maharashtra (*kharif* food grains and *kharif* sorghum) and Karnataka (*kharif* rice, wheat and *kharif* groundnut). Wheat shows a strong response to local rainfall in Madhya Pradesh, Uttar Pradesh, Gujarat, Maharashtra and Rajasthan, but had a poor correlation with local rainfall in Punjab, a major wheat-producing state [Fig. 2(d)]. The strong influence of monsoon rainfall on sorghum observed in Gujarat, Rajasthan and Punjab is not seen in the major sorghum producing state of Maharashtra, where a significant correlation with rainfall during the months of October-November was noticed [Fig. 2(e)]. *Kharif* groundnut production is strongly related to sub-divisional monsoon rainfall in all of the groundnut-producing states [Fig. 2(f)]. Auffhammer *et al*. (2011) recently confirmed that drought and extreme rainfall negatively affected rice yield in predominantly rainfed areas during 1966-2002, with drought having a much greater impact than extreme rainfall.

2.2. *Floods*

Twenty-three of the 36 states and union territories in the country are subject to floods and 40 million hectares of land, roughly one-eighth of the country's geographical area, is prone to floods. Floods occur in almost all river basins in India. The main causes of floods are heavy rainfall, inadequate capacity of rivers to carry the high flood discharge, inadequate drainage to carry away the rainwater quickly to streams/rivers. Ice jams or landslides blocking streams; typhoons and cyclones also cause floods. Flash floods occur due to high rate of water flow as also due to poor permeability of the soil. Most of the floods occur during the monsoon period and are usually associated with tropical storms or depressions, active monsoon conditions. The extent of area affected and damage caused to agriculture due to floods that occurred during 1953-2004 is given in Table 4.

In recent years, heavy precipitation events have resulted in several damaging floods in India. Analyzing data from 2599 rain gauge stations (Guhathakurta *et al*., 2011) showed that wet days have increased in Peninsular India, particularly over Karnataka, Andhra Pradesh and parts of Rajasthan and some parts of eastern India, while most parts of central and northern India showed a decreasing trend in frequency of rain days (> 0.1 mm) (Fig. 3). Frequency of heavy rainfall events (> 64.5 mm) are decreasing in major parts of central and north India while they are increasing in Peninsular, east and northeast India. The rate of increase in rainy days has been observed to be around 40-50 days in 100 years in Peninsular India particularly over Karnataka and Andhra Pradesh. Increase in rainy days has also been observed over most parts of Rajasthan, parts of Gangetic West Bengal and adjoining

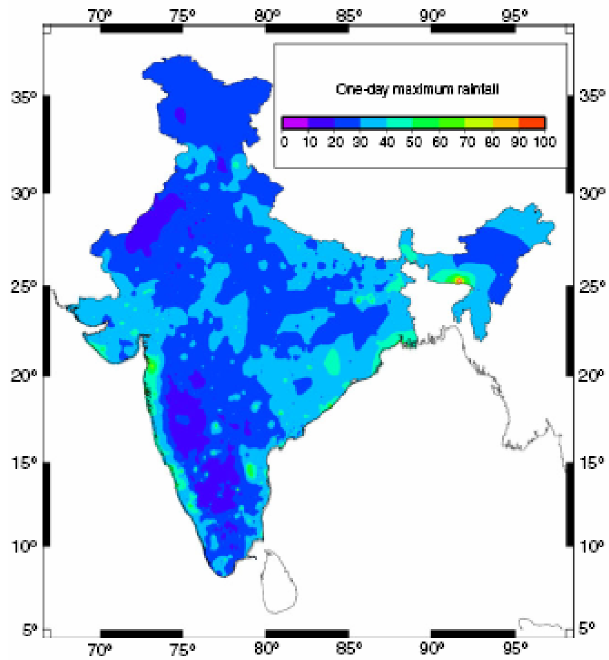


Fig. 3. Highest one-day extreme rainfall in India (after Guhathakurta *et al*., 2011)

areas of Jharkhand. The spatial pattern of India's highest one-day ever recorded point rainfall is presented in Fig. 5. Occurrences of 40 cm or more rainfall has been noticed along the west and east coast of India, Gangetic West Bengal and northeastern parts of India. Trend analysis performed on annual one-day extreme rainfall series showed an increasing trend over south Peninsular region, Maharashtra, Gujarat region, Bihar and some other isolated areas.

2.3. *Cyclones*

The major natural disaster that affects the coastal regions of India is cyclone and as India has a coastline of about 7516 km; it is exposed to nearly 10 per cent of the world's tropical cyclones. On an average, about five or six tropical cyclones form in the Bay of Bengal and Arabian sea, and hit the coast every year. Out of these, two or three are severe.

When a cyclone approaches to coast, a risk of serious loss or damage arises from severe winds, heavy rainfall, storm surges and river floods. Most cyclones occur in the Bay of Bengal followed by those in the Arabian Sea and the ratio is approximately 4:1. The incidence of cyclonic storms, with wind speeds between 65 kmph and 117 kmph and severe cyclonic storm with wind speeds between 119 kmph and 164 kmph, reaching Tamil Nadu and Andhra Pradesh is high during the north east monsoon season *i.e.*, October - December, whereas the highest annual number of storms, severe storms occur in the Odisha - West Bengal coast.

2.4. *Cold and heat waves*

Prevalence of extreme low temperature in association with incursion of dry cold winds from north into the sub-continent is known as cold waves. The cold waves mainly affect the areas to the north of 20° N. In India, a cold wave is considered to be severe when the night temperature drops below its daily normal by 7 °C or more, when normal minimum temperature is 10 °C or more. If the normal minimum temperature is less than 10 °C, then 5 °C or more below normal is called the severe cold wave conditions. The frequencies of occurrence, of cold waves and heat waves in different parts of the country for different periods are given in Table 5. Maximum number of cold waves generally occurs in Rajasthan followed by Jammu & Kashmir and Uttar Pradesh. The frequency of events over different time periods indicates that in recent years the state of Rajasthan is experiencing more cold waves and they were few over Jammu & Kashmir. Depending upon the time of occurrence they are either beneficial or harmful to the field and orchard crops. Cold wave conditions that prevailed during *rabi* 2010-11 and 2011-12 coincided with flowering and seed formation stage of wheat in Punjab resulting in good yields (Samra *et al*., 2012). Average wheat production of Ludhiana district (Punjab) during recent 12 years of heat waves, cold waves and normal years is given in Table 6 along with mean temperature and deviation in minimum and maximum temperature. Below normal deviations in the minimum temperature and maximum temperature in cold wave years of 2010-11 and 2011-12 were statistically significant. Out of 12 years, 8 years (66.7%) were normal, two each (17.6%) were heat and cold waves. On an average, there was a loss of 217 kg/ha (4.5%) in productivity in heat wave year and gain of 356 kg/ha (7.4%) in cold wave year. Among the two recent continuous cold wave years productivity gain in the relatively colder year 2011-12 was higher by 400 kg/ha and total production in the country was highest so far.

During March 2004, heat wave conditions prevailed over different parts of north India coinciding with maturity phase of wheat, rapeseed and vegetables. The temperature increase above normal was of lower magnitude towards eastern and southern India. In 2004 even minimum temperature was higher than normal in several places at Srinagar (Jammu & Kashmir), Palampur, Ludhiana, Pantnagar and Pusa for many days continuously. This has resulted in a loss of 4.6 million tonnes of wheat production. There was a higher incidence of diseases (rusts, powdery mildew) and pests, the wheat

TABLE 5

Frequency of cold and heat waves

State	1901-1910		1911-1967		1968-1977		1978-1999		2000-2008		Total (1901-08)	Total (1911-08)
	Cold waves	Heat waves	Cold waves	Heat waves	Cold waves	Heat waves	Cold waves	Heat waves	Cold waves	Heat waves	Cold waves	Heat waves
Andhra Pradesh	2	-	-	21	-	-	-	3	-	6	2	30
Assam	1	-	1	-	-	4	-	19	1	4	3	27
Bihar	7	-	27	105	8	6	67	23	15	5	124	139
Gujarat, Saurashtra & Kutch	2	-	85	-	6	2	6	-	-	3	99	5
Haryana, Delhi & Chandigarh	-	-	-	-	4	1	15	2	27	15	46	18
Himachal Pradesh	-	-	-	-	4	-	18	-	7	3	29	3
Jammu & Kashmir	1	-	189	26	6	5	15	35	2	-	213	66
Jharkhand	-	-	-	-	-	-	-	-	3	1	3	1
Karnataka	-	-	10	-	-	-	-	-	-	2	10	2
Kerala	-	-	-	-	-	-	-	-	-	1	-	1
Madhya Pradesh	9	-	88	32	7	4	12	15	1	8	117	59
Maharashtra	-	-	60	82	4	4	18	13	2	28	84	127
Orissa	4	-	5	25	-	8	-	18	3	29	12	80
Punjab	3	-	34	-	4	1	19	-	18	17	78	18
Rajasthan	11	-	124	43	7	1	53	7	30	25	225	76
Rayalaseema	-	-	3	31	-	2	-	28	-	-	3	61
Telangana	-	-	5	-	1	-	-	-	-	-	6	-
Tamil Nadu	-	-	-	5	-	-	-	2	-	4	-	11
Uttaranchal	-	-	-	-	-	-	-	-	1	-	1	-
Uttar Pradesh	21	-	51	27	8	3	47	42	23	16	150	88
West Bengal	2	-	14	76	3	9	28	28	12	15	59	128

(*Source* : De *et al*., 2005; IMD 2000-2008)

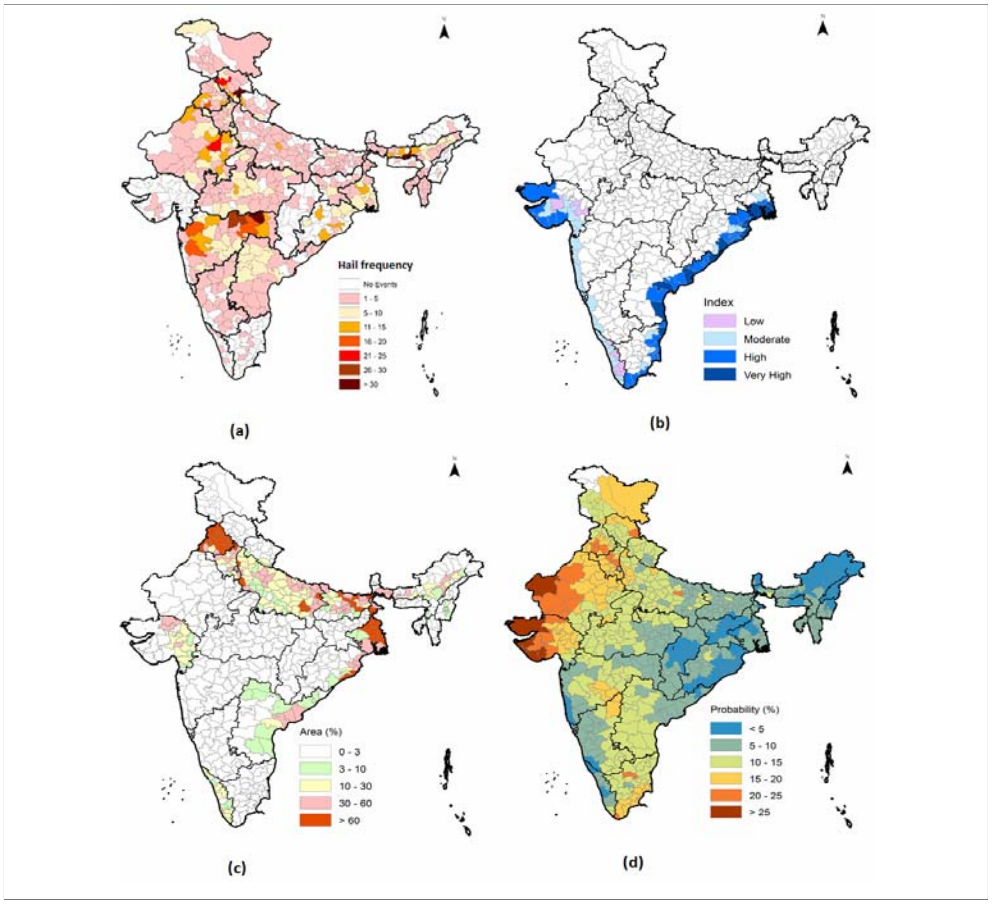
TABLE 6

Influence of heat and cold wave effects on wheat productivity in Ludhiana district

Wheat productivity (kg/ha) during	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	Mean
Non-event year	5169	5073	4498	-	4828	4780	4508	4798	-	4634	-	-	4786
Heat wave year	-	-	-	4747	-	-	-	-	4392	-	-	-	4569
Cold wave year	-	-	-	-	-	-	-	-	-	-	4942	5342	5142

(*Source* : Samra *et al*., 2012)

crop matured 10-20 days in advance of normal period with reduced 1000 grain or test weight. Coconut, banana, cardamom, black pepper, cashew etc. were affected in Kerala due to heat wave induced lower humidity and soil moisture. Milk production was affected slightly due to early disappearance of green fodder. However, castor productivity improved slightly in Gujarat. In Haryana, night temperatures during February and March, 2004 were recorded 3 °C above normal and subsequently wheat production declined from 4106 kg ha^{-1} to 3937 kg ha^{-1} (Ranuzzi and Srivastava, 2012). In a recent study, sensitivity of wheat yields to minimum temperature during post-anthesis period was quantified and it was found that wheat yields in India for the period 1980-2011 declined by 7% (204 kg/ha) for a 1 °C rise in minimum temperature. Exposure to minimum temperature exceeding 12 °C for 6 days and to maximum temperature exceeding 34 °C for 7 days during post-anthesis period are thermal constraints in achieving high productivity levels in wheat (Bapuji Rao *et al.*, 2015).



Figs. 4(a-d). Areas prone to (a) hailstorms, (b) cyclones, (c) floods and (d) drought

2.5. *Hailstorms*

Starting from 26th February, 2014, series of hailstorms struck central India and went on unabated till 15th March, 2014. In Maharashtra, the extended hailstorm activity of 2014 has adversely affected most parts of Marathwada, western Maharashtra, north Maharashtra and Vidarbha. Reports that appeared in the media accounted for damage ranging from Rs.10,000 to 15,000 crores, with all field and orchard crops were put together. In Madhya Pradesh, parts of Malwa and Mahakoshal regions were largely affected. Such an extended period of hailstorm or that matter even thunderstorm activity caught farmers and officials, and people at large, unaware and they were left clueless with this sudden development every day for more than a fortnight. Large sheets of hail were formed over extensive land areas resembling snow hit areas like Kashmir. The hailstones formed into large lumps of irregular shape, in some cases weighing more than 5 kg, after reaching the ground due to agglomeration. It took several hours to 2-3 days for the hails to melt away completely. Crop canopies that came in contact with hails sustained physiological damage which has led ultimately to decay of plants. Apart from this, the crops experienced severe mechanical damage caused the impact of the hails, the weight of which varied from 2g - 200g. The entire episode has brought into limelight the fragility of Indian agriculture to extreme weather situations and the agony of the affected farmers has compelled the State Governments to announce immediate relief measures.

3. Region-wise sensitivity to weather extremes

3.1. *Hailstorms proneness*

Rao *et al.* (2014) used hailstorm data of 38 years for the period 1972 - 2011 (excluding 1977 and 1984, for which data are not available) for mapping areas prone to frequent hailstorms [Fig. 4(a)]. More than 61 per cent of the districts experienced at least one hail event in a 38 year period. Highest frequency is noticed over districts in the northern parts of Vidarbha region of Maharashtra that are adjoining the state of Madhya Pradesh. Rama Rao *et al.* (2013) used various indicators derived from daily gridded data that was aggregated at district level for identifying areas prone to cyclones, floods and drought, and discussed as below:

3.2. *Cyclone proneness*

It is computed by combining number of cyclones crossing the district, number of severe cyclones crossing the district, probable maximum precipitation for a day, probable maximum winds and probable maximum storm surge. Districts of east coastline are more vulnerable to cyclone than west coast [Fig. 4(b)].

3.3. *Flood proneness*

It is based on per cent geographical area prone to flood incidence. According to this index, most parts of Punjab, West Bengal and some districts of Bihar and Uttar Pradesh are most vulnerable to flood (> 60% area) [Fig. 4(c)].

3.4. *Drought proneness*

This index computed by combining the probability of occurrence of severe and moderate droughts with weights of 2:1. Western parts of Rajasthan and Gujarat are highly prone to severe and moderate drought episodes [Fig. 4(d)].

4. Coping with extreme weather events

Targeted research cum adaptation and mitigation of extreme events is at beginning stage and based on the information already generated; these strategies can be broadly categorized into (a) crop based; (b) resource management based and (c) early warning systems.

4.1. *Crop based approaches*

These approaches encompass growing crops and varieties that fit into changed rainfall patterns, use of varieties with changed duration, tolerance for heat stress, drought and submergence. Additionally, varieties with high fertilizer and radiation use efficiency and new crops and varieties that can tolerate coastal salinity and sea water inundation are to be identified / evolved. Inter-cropping is a proven practice of insurance against crop failures due to floods or droughts and facilitates minimum assured returns (Venkateswarlu *et al*., 2009).

4.2. *Resource management based approaches*

Resource management strategies include in-situ moisture conservation, rainwater harvesting and recycling, efficient use of irrigation water, conservation agriculture, energy efficiency in agriculture and use of poor quality water. Watershed management is now considered an accepted strategy for development of rainfed agriculture. Use of anti-hail nets in Himachal Pradesh and J & K to protect the apple orchards from hailstorm is one of the best mitigation strategies adopted by the Indian farmers. The state government is supplying these nets to the farmers at subsidized rates.

4.3. *Early warning systems*

Observation and measurement of meteorological parameters with sufficient density in time and space has led to development of monitoring and forecasting systems with sufficient lead period in India. Successful predictions by IMD on the movement of tropical cyclones (Laila, Thane, Nilam, Phailin, Helen, Lehar and Hudhud) that struck east coast during 2010-2014 resulted in the minimization of human and agricultural losses. Much progress has been made on the agrometeorology front in identification of areas prone to drought, floods, heat and cold waves, frost and hailstorms. Use of remote sensing techniques, crop modelling and GIS are making a head way to gain adequate insights on the crop responses to extreme weather and delineating regions that are likely to get affected.

5. Opportunities to minimize extreme weather impacts

All the above classes of strategies have to be perceived at different time scales short, medium and long-term. Short term measures include contingency crop planning, strengthening input chain and other management aspects. Medium term measures include planning the natural resources addressing the problems and long-term measures mostly involve socio-economic development measures. We present here mostly the short term measures to be adopted for different weather extremes.

5.1. *Droughts*

In-season monitoring of drought through monitoring of rainfall and progress in sowings is crucial for effective management of droughts and minimizing the adverse impacts on crop production. Early season drought due to delay in onset of monsoon is directly responsible for shortfalls in area sown under major crops compared to normal situation. Also, delay in onset often leads to poor inflows into reservoirs, water bodies or poor recharge of groundwater and contributes to delay in sowings.

Contingency crop planning refers to making available a plan for providing alternate crop or cultivar choices in tune with the resource endowments of rainfall and soils in a given location. In rainfed areas, as a general rule, early sowing of crops with the onset of monsoon is the best-bet practice that gives higher realizable yield. Major crops affected due to monsoon delays are those that have a narrow sowing window and therefore cannot be taken up if the delay is beyond this cut-off date for sowing. Crops with wider sowing windows can still be taken up till the cut-off date without major reduction in crop yield and only the change warranted could be the choice of short duration cultivars. Beyond the sowing window, choice of alternate crops or cultivars depends on the farming situation, soil, rainfall and cropping pattern in the location and extent of delay in the onset of monsoon (2, 4, 6 and 8 weeks). Breaks in monsoon cause prolonged dry spells and are responsible for early, mid and terminal droughts. These aberrant situations often lead to poor crop performance and or total crop failure. While early season droughts have to be combated with operations like gap filling and re-sowing, mid and late season droughts have to be managed through crop, soil, nutrient management and moisture conservation measures. Drought also affects livestock/milk productivity due to shortage of fodder. Appropriate location-specific fodder production strategies go a long way in reducing the adverse impact on livestock, which is the major source of livelihood in dryland areas.

5.2. *Hailstorms*

In areas where hailstorm frequency is high all the three strategy categories need to be implemented.

5.2.1. *Protective measures to minimize losses*

The impact of hail damage can be minimized in two ways; one is preventing physically (hail abatement) and the other on the economic front. In the hail abatement, physical barriers such as hail nets or other protective screens can be used to intercept the incoming hailstones. Usefulness of hail nets in protecting the apple orchards in Himachal Pradesh is the best example for this type of protection. The durability and effectiveness of these nets are directly proportional to the quality of material used in their making.

5.2.2. *Change in land use*

Another way of abatement of hailstorm in regions with high frequency is to grow those crops that are less subject to hail damage. In the majority of hail prone districts in India, two or more crops can be grown successfully, but increased net returns from some crops like horticultural might have favoured more area to come under their cultivation. In some of these predominant horticultural areas, which are often subjected to extreme hail damage, wheat or other crops could be grown instead of fruit crops that are more susceptible to hail. This alternative approach is again limited by physical factors like soil, rainfall and temperature apart from differential net returns and farmers choice.

5.2.3. *Risk management*

Another approach to minimize the hail losses to the farmers is through insurance. Various levels of coverage and types of policies are to be made available to farmers at affordable premium rates. In India, the Agriculture Insurance Company (AIC) of India insures against hail damage with add-on premium. Insurers in India may develop products that cover three categories of probability of hail occurrence *viz*., high, moderate and low.

5.2.4. *Management options in the event of hailstorm occurrence*

Top most priority may be given to save the human lives followed by livestock in the event of a hailstorm forecast. Avoiding damage to the infrastructure, including vehicles and other farm machinery/equipment may be taken up given enough time for the commencement of the hail-fall. If the hail event is associated with heavy rainfall, farmers are advised to drain out excess water from standing fields either through land modifications or pumping out the water. Drained water may be collected in farm ponds, if feasible. As a compensatory mechanism for the production losses due to hail damages, the possibilities of making best and timely use of available in-situ soil moisture and surface water (stagnated) to be explored for raising short duration crops including forages and vegetables. Early sowing of greengram/blackgram is better with seed treatment/zero-till sowing after paraquat/glyphosate application. In hail damaged field, orchard crops and vegetables recommended chemicals like fungicides may be sprayed to control spread of diseases due to secondary infection and booster dose of nutrients may be applied apart from growth regulators like NAA to induce fresh flowering, if required.

6. Adoptable technologies for extreme weather-Lessons from NICRA

An important component of the National Initiative on Climate Resilient Agriculture (NICRA), a flagship program of ICAR, deals with demonstration of climate resilient technologies on farmers' fields. This component addresses extreme weather events such as floods, cyclones, prolonged drought, extreme heat/cold wave etc. The demonstrations are being laid out in a farmer participatory mode by Krishi Vigyan Kendras[1] (KVK)

[1] Literally meaning farm science centers, established by the Indian Council pf Agricultural Research in every district of the country to assess and refine agricultural technologies for location specificity.

in 100 vulnerable districts across the country. The initial outcome of demonstrations has shown that there is a great potential in the existing best bet practices to impart resilience to extreme weather events such as the ones mentioned above. Following are some of the specific cases where demonstration of appropriate technologies helped the communities to cope with extreme weather events successfully.

6.1. *Drought mitigation*

6.1.1. *Crop based*

In the southern peninsula, Tumkur district, Karnataka is one of the most drought prone districts of the region. Prolonged droughts cause near complete loss of yields of finger millet, which is the staple food crop of this region, threatening the food security of the rural population. Although finger millet requires very little water for cultivation, distribution of the rainfall determines its yield, as the crop is mostly rainfed. Farmers generally cultivate long duration finger millet in this region. As a result, the crop is more prone to intermittent dry spells. Demonstration of a short duration finger millet variety (ML365) that can be sown late when the onset of monsoon is delayed, helped farmers to minimize their loss due to prolonged drought in 2011. It also ensured the food security of the farm families. The farmers have retained the seeds and are using them in subsequent seasons.

In low lands of Saran district, Bihar aberrant rainfall situation prevailed in five out of previous 10 years and very low rainfall in July has led to delayed transplanting of paddy. Farmers preference for long duration varieties often lead to delayed transplanting and even up to end of August, which severely lowers the productivity. A resilient technology, establishment of community nurseries, for this specific situation was developed. In this technique, staggered community nursery at an interval of two weeks involving varieties of different durations (140, 125-135 and <110 days) under assured irrigation was raised at the village level. During 2013-14, deficit rainfall conditions (-70%) in July and first fortnight of August has led to delayed transplantings. However, farmers who adopted resilient technology were benefitted with an additional yield of 4-5 q/ha (13% yield increase) compared to farmers who transplanted over aged seedlings in August.

6.1.2. *Management based*

Transplanted rice in Punjab requires about 130 ± ha-cm water and an estimate puts 10% of global methane emissions to the flooded rice fields. In case of delay in monsoon, farmers resort to excessive exploitation of ground water which is leading to a decline quality of land and water. Direct seeded rice cultivation is identified as a resilient technology for this situation wherein nursery raising is done away. This allows timely sowing of succeeding *rabi* wheat. It also leads to a saving in water up to 25% compared to transplanted rice. It further saves 27% of diesel used as pumping energy, 35-40 man days per hectare and reduction in methane emissions. Drum seeding technique is another resilient technology in which direct seeding of pre-germinated paddy seeds is done. This technology was found advantageous in the predominant transplanted rice areas of Andhra Pradesh, Telangana and Kerala states that are increasingly facing water shortages due to deficit rainfall, declining ground water table due to insufficient recharge, late and limit release of canal irrigation water due to poor inflows into tanks/reservoirs. Apart from increased benefit cost ratio (0.8-0.9), this technology facilitates about 30% saving in seed, fertilizer and at least two irrigations.

6.1.3. *Resource based*

Furrow irrigated raised bed (FIRB) planting and Broad bed and furrow (BBF) system are some *in situ* soil and water conservation practices that proved beneficial across the country. Zero till drill of wheat is another climate resilient practice to overcome the terminal heat stress as it facilitates early sowing of wheat compared to conventional method. Small scale water harvesting structures like farm ponds at individual farm level enable reuse of harvested water during critical periods of crop growth stage and for providing pre-sowing irrigation to *rabi* crop. Large potential exists for up-scaling this technology for Indian conditions. Even in high rainfall areas like Dimapur, Nagaland, where the annual rainfall is around 2500 mm, a problem persists in the form of unavailability of adequate amount of water during the dry season. Field experiences indicate that this intervention allows farmers to shift to cultivation of vegetables/high value crops, resort to integrated farming system.

Desiltation of existing tanks/water harvesting structures is another smart practice in drought prone regions. This practice was found promising in Namakkal (Tamil Nadu), Kurnool (Andhra Pradesh), Rajkot (Gujarat) and Kullu (Himachal Pradesh), where prolonged dry spells at critical stages during *kharif* often lead to low productivity and some time even to total crop failures. Renovation and up-gradation of existing runoff structures like check dams resulted in improving the cropping intensity, recharge of open/tube wells, crop diversification and increase in crop productivity at several NICRA villages.

Rainwater harvesting in dugout ponds helped farmers in the South 24 Parganas district of West Bengal to harvest fresh water and start cultivating small patches of land after sea water intrusion due to cyclone Aila (23-26 May, 2009). The district situated on the east coast of India is prone to cyclones and sea water intrusion during high tides and often suffers from high rates of out migration of farmers. The KVK of the district demonstrated to the farmers how to harvest rainwater and use the same for cultivating vegetables in a small scale. This prevented en masse migration of farmers from the village by ensuring a reasonable economic activity to earn their livelihood.

6.2. *Flood management*

The district of Srikakulam, Andhra Pradesh located on the East coast is prone to floods. Located in the delta of two minor rivers, it is often prone to inundation of crop lands thereby causing large scale loss to farmers who predominantly cultivate rice in this region. One of the major interventions of NICRA was to first look at the possibility of improving the drainage so that the period of crop inundation can be reduced. Secondly, introduction of submergence tolerant varieties[2] of rice like Indra (MTU-1061) so as to minimize loss to farmers (Plate 1). This strategy proved very successful when cyclone Neelam (28th October to 1st November, 2012) hit the east coast and resulted in wide spread crop damage.

Plate 1 : Use of flood tolerant varieties to cope with cyclonic rains in Andhra Pradesh

6.3. *Socio-economic approach*

In rainfed regions of India because of the rainfall pattern, a narrow window exists for timely land preparation, sowing and other agricultural operations. Contrary to this, in high rainfall regions providing drainage at the right time to remove excess water from heavy rainfall events becomes crucial. Labor shortage at these peak times of agricultural operations is influencing the farm income. Custom hiring centers established under NICRA program enabled farmers to get access to the farm machinery and to implement several climate resilient practices. A typical example of this facility is documented in Umrani village of Nandurbar, Maharashtra in which *in situ* conservation of soil and water and sowing across this flow resulted not only in 11-13% increase in soybean yield but also in conserving valuable top soil from erosion.

Some early lessons from the custom hiring centers in adopting climate resilient technologies are:

- Seed cum fertilizer drills helped in introducing or expanding the intercropping areas.

- Different kinds of crop threshers enabled farmers in timely harvesting operations at a lower cost. This could help avoid crop damage in weather abbreviations such as cyclone, frost etc.

- Zero till drills helped save time, water fuel and escape terminal heat stress besides enabling farmers to make early harvest of *rabi* crops.

- Broad bed furrow technology for wheat, soybean, and maize saved crop damage from excess soil moisture by aiding quick drainage and avoiding water stagnation.

6.4. *Integrating diverse farm enterprises*

Mono-cropping is widely practiced in areas prone to droughts, floods and extreme weather events such as frost/cold stress. In these vulnerable areas, dependence on a single farm enterprise by farmers is making them more vulnerable as they have limited resilience to cope with climatic conditions. Several integrated farming system (IFS) modules with a combination of small enterprises such as crop, livestock, poultry, piggery, fish and duck rearing were demonstrated to farmers in NICRA villages in the eastern, northern and north eastern states were found to increase their resilience. Successful demonstrations with integrated farming systems involving Rice-fish-poultry in Sonitpur, Assam; Apple-fisheries-poultry in Phulwama, J&K; Duckery-fish in Alapuzha, Kerala; Pig-poultry-fish in East Singhbum, Jharkhand, captive rearing of fish seed in Srikakulam, Andhra

[2] Popular slender grain rice varieties are imparted with submergence tolerance by introducing a gene in the rice breeding programmes of national research institutes.

Pradesh amply show the potential existing under IFS for climatically stressed regions. Modifications in the design of housing structures to eliminate cold stress effects in backyard poultry in East Sikkim and heat stress/cyclone effect in goats at Namakkal, Tamil Nadu are some resilient technologies that proved successful.

As livestock contributes a major chunk in the total agricultural income, mostly in drought prone regions of the country, meeting fodder requirements in the slack season is a tough task especially in the event of deficit or delayed rainfall conditions. Possibilities to sow fodder crops in uncultivated paddy fields under late kharif situation in lowlands may be explored. In such an eventuality seeds of sorghum, bajra and maize along with legume intercrop (cowpea / horsegram etc) need to be mobilized and made available to interested farmers who own livestock. A catch crop of urd/ mung can be taken up in May with early rains for multiple use as grain / green manure / mulch/fodder depending on subsequent rainfall conditions.

There has been a very encouraging response from farmers and other stakeholders for the technologies developed and on-farm demonstrated. The learning has been valuable in terms of policy formulation and programme development aimed at coping with extreme weather events.

7. Conclusions

To sum up, monsoon activity in the lower atmosphere, position of the monsoon trough, breaks in the monsoon activity are the main determining factors governing the extreme events like droughts, floods, hailstorms, heat waves over the Indian sub-continent. In the decades to come, their study and projections in relation to global climate change would be an important contribution in understanding future scenarios. Research on adaptation and mitigation strategies to extreme weather as well as development of fore-warning systems are to be strengthened to enable Indian agriculture to cope with extreme weather events in future. A multi pronged strategy for scaling up the existing coping mechanisms involving all the stake holders is required to make production systems in India more resilient.

References

Attri, S. D. and Tyagi, A., 2010, "Climate Profile of India", *Met. Monog. Environ. Meteorol.*, 01/2010, IMD, New Delhi.

Auffhammer, M., Ramanathan, V. and Vincent, J. R., 2011, "Climate change, the monsoon, and rice yield in India", *Climate Change*, DOI 10.1007/s10584-011-0208-4.

Bapuji Rao, B., Santhibhushan Chowdary, P., Sandeep, V. M., Pramod, V. P. and Rao, V. U. M., 2015, "Spatial analysis of the sensitivity of wheat yields to temperature in India", *Agric. For. Meteorol.,* **200**, 192-202.

CRED, 2015, "EM-DAT : The OFDA/CRED International Disaster Database", www.em-dat.net - Université Catholique de Louvain - Brussels – Belgium.

De, U. S., Dube, R. K. and Prakasa Rao, G. S., 2005, "Extreme weather events over India in the last 100 years", *J. Ind. Geophys. Union*, **9**, 3, 173-187.

GFDRR, 2013, "Disaster risk management in south Asia: A regional overview", Available at http://reliefweb.int/sites/reliefweb.int/files/resources/Disaster%20Risk%20Management%20in%20South%20Asia%20-%20A%20Regional%20Overview.pdf.

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

Guhathakurta, P. and Rajeevan, M., 2008, "Trends in rainfall pattern over India", *Int. J. Climatol*., **28**, 1453-1469.

Guhathakurta, P., Sreejith, O. P. and Menon, P. A., 2011, "Impact of climate change on extreme rainfall events and flood risk in India", *J. Earth. Syst. Sci.*, **120**, 3, 359-373.

Hamza, V., Krishna Kumar, K. and Babu, C. A., 2013, "Long term trends of seasonal and monthly rainfall in different intensity ranges over Indian subcontinent", *Mausam*, **64**, 3, 481-488.

Krishna Kumar, K., Rupa Kumar, K., Ashrit, R. G., Deshpande, N. R. and Hansen, J. W., 2004, "Climate impacts on Indian agriculture", *Int. J. Climatol.*, **24**, 1375-1393.

Kulshrestha, S. M., 1997, "Drought management in India and potential contribution of climate prediction, Joint COLA/CARE Technical Report No. 1", Centres of the Institute of Global Environment and Society, September 1997, p105.

Mall, R. K. and Singh, K. K., 2000, "Climate variability and wheat yield progress in Punjab using the CERES-wheat and WTGROWS models", *Vayu Mandal*, **30**, 3-4, 35-41.

Ministry of Home Affairs., 2011, "Disaster management in India", Ministry of Home Affairs, Government of India, New Delhi, p234.

Pathak, H., Ladha, Aggarwal, P. K., Peng, S., Das, S., Singh, Y., Singh, B., Kamra, S. K., Mishra, B., Sastri, A. S. R. A. S., Aggarwal, H. P., Das, D. K. and Gupta, R. K., 2003, "Trends of climatic potential and on-farm yields of rice and wheat in the Indo-Gangetic Plains", *Field Crops Research*, **80**, 223-234.

Rama Rao, C. A., Raju, B. M. K., Subba Rao, A. V. M., Rao, K. V. and Rao, V. U. M., Kausalya Ramachandran, Venkateswarlu, B. and Sikka, A. K., 2013, "Atlas on vulnerability of Indian agriculture to climate change", Central Research Institute for Dryland agriculture, Hyderabad, p116.

Rao, G. G. S. N., Rao, A. V. M. S., Vanaja, M., Rao, V. U. M. and Ramakrishna, Y. S., 2008, "Impact of regional climate change over India", 13-48 (In) G.S.L.H.V. Prasada Rao, G.G.S.N.Rao, V. U. M. Rao and Y.S. Ramakrishna (Eds) Climate Change and Agriculture over India. Kerala Agricultural University, Trissur.

Rao, V. U. M., Bapuji Rao, B., Sikka, A. K., Subba Rao, A. V. M., Rajbir Singh and Maheswari, M., 2014, "Hailstorm threat to Indian agriculture: A historical perspective and future strategies", Central Research Institute for Dryland Agriculture, Hyderabad, p44.

Ranuzzi, A. and Srivastava, R., 2012, "Impact of climate change on agriculture and food security", ICRIER, Policy Series, No. 16, May.

Revadekar, J. V., Kothawale, D. R., Patwardhan, S. K., Pant, G. B. and Rupa Kumar, K., 2012, "About the observed and future changes in temperature extremes over India", *Nat. Hazards*, **60**, 1133-1155.

Samra, J. S., Prabhjyot, Kaur and Amrit Kaur, Mahal, 2012, "Spectral density analysis of the cold wave (2010-11 and 2011-12) and its impact on wheat productivity in Indian Punjab", Plenary lecture in the 3rd International Agronomy Congress at New Delhi on November 27, 2012.

Sikka, D. R., 1999, "Monsoon drought in India", Report no.2, Joint Report of COLA/CARE Tech. Report, 270pp. Available at COLA, 4041, Powder Mill Road, Calverton, MD, USA.

Subash, N. and Ram Mohan, H. S., 2010, "Trend detection in rainfall and evaluation of standardized precipitation index as a drought assessment index for rice-wheat productivity over IGR in India", *Int. J. Climatol*., **31**, 11, DOI: 10.1002/joc.2188.

Venkateswarlu, B., Shankar, A. K. and Gogoi, A. K., 2009, "Climate change adaptation nd mitigation in Indian agriculture", In: Proc. National Seminar on Climate change adaptation strategies in agriculture and allied sectors, KAU, Thrissur, December 2008, 109-121.

Yadav, R. K., Rupa Kumar, K. and Rajeevan, M., 2012, "Characteristic features of winter precipitation and its variability over northwest India", *J. Earth Syst. Sci.*, **121**, 3, 611-623.