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Coping strategies for extreme weather in dryland agriculture

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सार – खादय फसलों के अंतर्गत सूखें ग्रस्त क्षेत्रों का 48 प्रतिशत और अखादय फसलों की कृषि के अंतर्गत 52 प्रतिशत भारत में खादय अनाज का उत्पादन का लगभग 42 प्रतिशत योगदान है मौसम की चरम परिघटना के फलस्वरूप सूखा पडता है और वह न केवल सूखाग्रस्त क्षेत्रों को बल्कि समूचे देश के सामाजिक ढॉचे को प्रभावित करता है सूखे के मानीटरन की विभिन्न तकनीकों और प्रक्रियाओं का उद्देश्य विभिन्न स्थानिक पैमानों पर सूखे के दुष्प्रभाव को कम करना है। विभिन्न समय श्रृंखला पर मौसम की विसंगतियों से तालमेल बिठानें की रणनीतियों के बारे में यहॉ संक्षेप में विवेचन किया गया है। वे जिले जो सूखाग्रस्त इलाके में आते है, वहॉ ओला पड़ने की घटनाओं को भी देखा गया है और कृषि से जुडे नुकसान को कम करने के बारे में भी चर्चा की गई है।

ABSTRACT. Dryland areas account for 48% of area under food crop and 52% under non-food crop cultivation and contribute about 42% of total food grain production in India. Drought is the predominant weather extreme influencing the socio-economic structure of not only dry land regions but also the entire country. Various drought monitoring techniques and mechanisms aim at mitigating the drought impacts at different spatial scales. They are discussed briefly here with strategies to cope up this weather anomaly at different time scales. Dry land districts that are prone to frequent hail episodes are identified and measures to minimize damage to agriculture are also discussed.

Key words – Dryland agriculture, Extreme weather, Drought, Hailstorms, Coping strategies,

1. Introduction

Drylands are found in climate regimes that are arid and semi-arid and have severe constraints for successful crop production. They are typically characterized by low annual rainfall (300-750 mm per annum) and higher potential evapotranspiration (PET). In dry lands, moisture induced droughts are frequent at any stage of crop growth and length of growing period ranges from 75 to 120 days only. Soils in dry land areas are often coarse textured, characteristically low in fertility, organic matter and water holding capacity and highly vulnerable to wind and water erosion. In India, 68% of the total net sown area comes under dry land cultivation, spread over 177 districts. Most dry land areas in India have more than 7 months rainless period with essentially no or very little precipitation. In certain areas the total annual rainfall does not exceed 500 mm (Guhathakurta and Rajeevan, 2008). Crop production, consequently, in such areas is primarily rainfed as there is no facility to give any irrigation, and even protective or life saving irrigation is often difficult.

The dryland areas of the country account for as much as 48% of the area under food crop cultivation and 52% under non-food crop cultivation and contribute to about 42% of the total food grain production and are generally dominated by low value and low yield crops. Most of the coarse grains like sorghum, pearl millet, finger millet and other millets are grown in dry lands only (Rao, 2004). However, the drought prone districts also cultivate commercial crops such as oilseeds and cotton, but they are subject to high instability both in respect to yield and prices (Nadkarni, 1985). The farmers in the dryland areas generally cultivate multiple crops and do not specialize in a particular crop due to the high risk involved in the cropping pattern (Mohanti and Padhi, 1995; Pathy, 2003). Mixed cropping and multiple cropping are also strategies for crop protection from pests and it helps to prevent the spread of the risk (Pionetti and Reddy, 2002).

Due to high temporal and spatial variability in rainfall and wide variations in physiographic and climatic conditions in the country, droughts are experienced in varying intensities (moderate or severe) almost every year irrespective of a good monsoon. Since 2001, the country has experienced three major droughts, in the years 2002, 2004 and 2009, severely affecting the various sectors and overall economic development of the country. India is the amongst the most vulnerable and drought prone countries in the world (Mishra and Singh, 2010). Considering the importance of moisture in dry land farming, a detailed understanding on drought which is the dominating climate

TABLE 1

Probability of occurrence of drought in different meteorological subdivisions of India

Meteorological sub-division	Frequency of deficient rainfall
Assam	Very rare, once in 15 years
West Bengal, Madhya Pradesh, Konkan, Bihar and Odisha	Once in 5 years
South interior Karnataka, Eastern Uttar Pradesh & Vidarbha	Once in 4 years
Gujarat, East Rajasthan, Western Uttar Pradesh,	Once in 3 years
Tamil Nadu, Jammu & Kashmir and Telangana	Once in 2.5 years
West Rajasthan	Once in 2 years

(*Source:* National Rainfed Area Authority, 2009)

extreme and strategies to mitigate its impacts on agriculture is required. In this backdrop an effort has been made to study the drought and its types, different drought monitoring indices, real time assessment of drought, adaptation and mitigation strategies to cope the drought situation across the dry land regions of the country. Apart from the drought impacts, regions in the country experiencing frequent hailstorms and those districts wherein a rise in maximum and minimum temperatures is happening are presented together with strategies to be adopted to overcome these biophysical stresses.

2. Drought - An extreme weather event

Farming in dry land areas often encounters constraint in development in the form of moisture stress as a result of drought. Drought is a normal, recurrent feature of climate in dry land regions of India. It occurs in virtually in all climatic zones, but its characteristics vary significantly from one region to another. It originates from a deficiency of precipitation that persists long enough to produce a serious hydrologic imbalance. Droughts are categorized as meteorological, hydrological, agricultural and socio-economic (Nagarajan, 2003).

2.1. *Meteorological drought* - It is period of prolonged dry weather condition due to below normal rainfall. According to the India Meteorological Department (IMD) there are three different types of meteorological droughts based on the rainfall deficit from normal.

Mild	-	0-25%
Moderate	-	26-50%
Severe	-	> 50%

2.2. *Agricultural drought* - Impacts caused due to short-term precipitation shortages, temperature anomaly that leads to increased evapotranspiration and consequently to soil water deficits and ultimately adversely affecting crop production. According to National Commission on Agriculture, agricultural drought is defined separately for both *kharif* and *rabi* seasons.

Kharif - At least four consecutive weeks receiving less than half of the normal rainfall (>5mm)

Rabi - Six such consecutive weeks.

2.3. *Hydrological drought* - It is a result of an effect of precipitation shortfall on surface or sub-surface water sources like rivers, reservoirs and groundwater.

2.4. *Socio-economic drought* - This is the socio-economic effect of meteorological, agricultural and hydrological drought in relation to supply and demand of the society.

3. Drought prone regions in India

On an average, 28% of the geographical areas of India are vulnerable to drought. 971 blocks of 183 districts covering an area of about 74.6 million hectares were identified as drought prone areas of the country. Droughts in the Indian region are mainly due to various kinds of failures of rains from southwest monsoon. Based on the analysis of long series of yearly data, probability of occurrence of drought in different meteorological sub-divisions is given in Table 1. Most of the drought prone areas lie in the arid, semi-arid and sub-humid regions. The spatial probability (per cent) of occurrence of severe drought in India is presented in Fig. 1.

4. Drought monitoring techniques

A uniform method to be adapted for monitoring drought conditions and quantifying the severity of drought

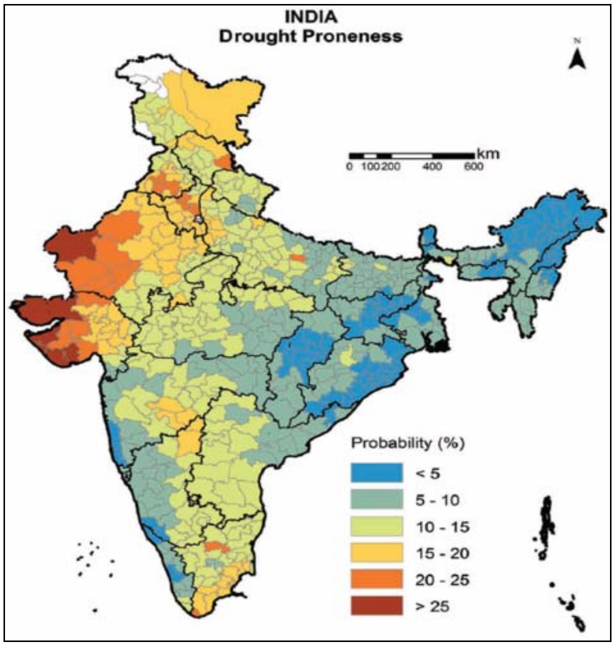


Fig. 1. Probability (per cent) of occurrence of drought across India (*Source* : Rama Rao *et al*., 2013)

is arduous. Drought is a complex phenomenon that is difficult to accurately describe because its definition is both spatially variant and context dependent. As a result, there are a large number of tools that have been developed to monitor moisture conditions. The most common tool for monitoring drought conditions is a drought index. Drought indices have been used for identifying droughts and their triggers (Steinemann, 2003), assessing drought status (Kao and Govindaraju, 2010), forecasting droughts (Agha Kouchak, 2014), performing drought risk analysis (Hayes *et al*., 2004) etc. Some of the indices that are widely used include:

4.1. *Aridity Anomaly Index (AI)* - IMD monitors the incidence, spread, intensification and cessation of agricultural drought (near real time basis) on a weekly timely scale over the country based on AI. It also issues weekly drought outlook, based on this index, which indicates the impending drought scenario in the country in the subsequent week. It can be computed using the following formula:

$$AI = \frac{PE - AE}{PE} * 100$$

where, PE is called potential evapotranspiration and AE is the actual evapotranspiration.

Normal values of this index for successive weeks during the monsoon for stations representing different agroclimatic zones of the country are to be worked out. Every week the actual aridity at the place is computed from the weekly total rainfall and antecedent soil moisture conditions. The intensity of the drought can be inferred by calculating the anomaly (actual-normal) of the AI. Depending on the value of the anomaly, drought can be categorized as :

Anomaly of AI	*Agricultural Drought Intensity*
≤ 0	Less
0-25	Mild
26-50	Moderate
>50	Severe

4.2. *Standard Precipitation Index (SPI)* - SPI developed by McKee *et al*. (1993; 1995) based on statistical probability was designed to be a spatially invariant indicator of drought. It is produced by standardizing the probability of observed precipitation for any duration (durations of weeks or months can be used to apply this index for agricultural or meteorological purposes, and longer durations of years can be used to apply this index to water supply and water management purposes). The SPI can be calculated for any location that has a long-term precipitation record. The precipitation record is fit with a probability density function and subsequently transformed using an inverse normal (Gaussian) function. This insures that the mean SPI value for any given location (and duration) is zero and the variance is one. Positive values of the SPI indicate greater than median precipitation, while negative values indicate less than median precipitation. An SPI value of less than -1 indicates that a drought event is taking place and drought intensity can be calculated by summing the SPI values for all months within a drought event.

SPI Value	*Category*	*Probability (%)*
> 2	Extremely Wet	2.3
1.5 to 1.99	Very Wet	4.4
1.0 to 1.49	Moderately Wet	9.2
-0.99 to 0.99	Near Normal	68.2
-1.0 to -1.49	Moderately Dry	9.2
-1.5 to -1.99	Very Dry	4.4
< -2.0	Extremely Dry	2.3

4.3. *Drought indices based on satellite data* - Unlike point observations of ground data, satellite sensors provide direct spatial information on vegetation stress caused by drought conditions. The crop/vegetation reflects high in the near infrared due to its canopy geometry, the health of the standing crops/vegetation and absorbs high in the red reflected radiance due to its biomass and accumulated photosynthesis. Stressed vegetation has a higher reflectance than healthy vegetation in the visible (0.4-0.7 microns) region and lower reflectance in the near infrared (0.7-1.1 microns) region of the electromagnetic spectrum. Vegetation indices take the advantage of this differential response in the visible and near infrared regions of the spectrum. Using these contrast characteristics of near infrared, red and middle infrared bands which indicate both the health and condition of the crops/ vegetation, different types of vegetation indices developed by several workers are listed below.

- Difference Vegetation Index
- Ratio Vegetation Index
- Infrared Percent Vegetation Index
- Perpendicular Vegetation Index
- Soil Adjusted Vegetation Index
- Weighted Difference Vegetation Index
- Greenness Vegetation Index
- Atmospherically Resistant Vegetation Index
- Normalized Difference Vegetation Index
- Normalized Difference Wetness Index
- Enhanced Vegetation Index

Among the various vegetation indices that are widely used, Normalized Difference Vegetation Index (NDVI) is an universally acceptable index for operational drought assessment because of its simplicity in calculation, easy to interpret and its ability to partially compensate for the effects of atmosphere, illumination geometry etc. NDVI is a transformation of reflected radiation in the visible and near infrared bands of NOAA AVHRR and is a function of green leaf area and biomass. It is given by the relation:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}$$

where, NIR is the Near Infrared Red and Red is the reflected radiations in these two spectral bands. The severity of drought situation is assessed by the extent of NDVI deviation from its long term mean which is given by the relation:

$$\mathrm{NDVI}_{dev} = \mathrm{NDVI}_i - \mathrm{NDVI}_m$$

where, NDVI_i is the NDVI in the i^{th} month and NDVI_m is the long term average for the same month. Maps that are produced using relative greenness are handy in assessing the drought situation and thus this indicator is being used widely. NDVI is also a useful tool for measuring and monitoring of environmental conditions such as crop condition simulation, yield estimation, land degradation, dryland studies etc. (Aboelghar *et al*., 2010; Kundu and Dutta, 2011; Barati *et al*., 2011; Mohamed *et al*., 2013; Kundu *et al*., 2014a; Kundu *et al*., 2014b; Mondal *et al*., 2014).

5. Drought coping strategies

Drought can be mitigated by two kinds of measures, either by adopting preventive measures or by developing a preparedness plan. Preparedness refers to pre-disaster activities to increase the level of readiness, or improve operational and institutional capabilities for responding to a drought. National Initiative on Climate Resilient Agriculture (NICRA) launched by Indian Council of Agricultural Research (ICAR) in 2011 is a nationwide project aimed to enhance resilience of Indian agriculture to climate change and climate vulnerability through strategic research and technology demonstration. The project identified 100 districts across the country based on the climatic vulnerability. The intervention of the project in to the dryland regions gives different adaptation techniques with respect to early season drought with delayed onset of monsoon and normal onset followed by early, mid-season and terminal drought. The three important and most commonly observed aberrations in the monsoon behavior in India are:

(*i*) Early or delayed onset of monsoon,

(*ii*) Prolonged 'breaks' or 'dry spells' during the rainy season, and

(*iii*) Rains may terminate earlier or may continue beyond the normal rainy season

5.1. *Delayed onset of monsoon* - During some of the years the onset of the south-west monsoon gets delayed by 2, 4, 6 & 8 weeks. Consequently the farmers, particularly in rain fed regions would not be able to sow the crops timely. Delayed sowing of the crops can lead to reduced and even uneconomical crop yields. Under such circumstances management strategies available are as follows.

5.1.1. *Transplantation* - In the event of late onset of monsoon, community nurseries may be raised for some of the crops at a point where water is available and transplantation can be undertaken with the receipt of rains. Though, transplanting is a labour intensive operation, but it is a way out for compensating the expected losses due to delay in the commencement of sowing rains. Studies in finger millet indicated that both long and medium duration varieties of should be transplanted for maintaining yield levels whenever sowing is delayed. For instance, finger millet transplanted at Bengaluru during the month of September yielded as high as 2.56 t/ha whereas the directly sown crop yielded 0.75 t/ha only. Under delayed conditions, transplanting of pearl millet was found to be advantageous as the transplanted crop gives equal or at times more grain yield than the direct seeded pearl millet (Rana and Bana, 2012). Cotton seedlings can be raised as a contingency measure in polythene bags for transplanting. When sufficient moisture is available after receipt of rains, transplanting can be practiced to compensate loss in plant stand with seedlings of similar age.

5.1.2. *Alternate crops and varieties* - Certain crops and their cultivars are more to perform under drought efficient either due to their shorter duration or capacity to produce better yields even under relatively unfavourable moisture regimes when sown late in the season. Therefore, selection of crops and varieties is very crucial. Crops/varieties have to be chosen depending upon the date of occurrence of sowing rains. For example, it is now well established that castor (c.v. Aruna) produces more yield in the red soils of Telangana region compared to pigeonpea under late sown conditions. In western Rajasthan, short duration crops like green gram and cowpea were found to perform better than pearl millet under late sown conditions. Crops and varieties that can be sown depending upon the date of sowing were identified for dry farming tracts of India (Bana *et al*., 2013).

5.2. *Dry spell immediately after sowing* - During some of the years, a dry spell may occur immediately after sowing of the rainy season crops. Prolonged dry spell of two weeks or more just after sowing may result in poor germination and emergence due to soil crusting, withering of seedlings and poor establishment of crop stand. The small seeded crops which are sown at a shallow depth of 1 to 3 cm such as millets, sesame etc. are affected more followed by beans and sorghum, which are sown at a depth of 3 to 5 cm. Germination failure is more common in lighter soils than in heavy soils. Under such conditions, the following strategies can be adopted.

5.2.1. *Re-seeding* - It is always necessary to maintain proper plant stand to ensure desired yields. Therefore, if a severe dry spell and consequent moisture stress occur at a very early stage, *i.e*., within a week to 10 days after sowing, it is better to re-sow the crop than to continue with inadequate plant stand to persist and yield a poor harvest.

5.2.2. *Land configurations* - Appropriate land configurations like broad beds and furrows, graded border strips, inter-row and inter-plot water harvesting systems etc. hold great promise for *in situ* moisture conservation. Conservation furrows at 10 to 15 m intervals or ridge and furrow across the slope can be best adopted for effective conservation of soil moisture as well as rainwater in bold seeded, dibbled and wide spaced crops (>30 cm) such as cotton, millets, maize and pigeonpea. In medium deep black soils, compartmental bunding (bunds of 15 cm height formed on all the four sides to form a check basin of 6 m × 5 m size) is good option for better retention of soil moisture.

5.2.3. *Intercropping* - Breaks in the monsoon rains can be of different durations. Breaks of shorter duration like 5 to 10 days may not be of serious concern. But prolonged breaks of more than 15 days can create plant water stress leading to reduction in crop productivity. It is difficult to predict these breaks well in advance. The agricultural droughts caused due to prolonged breaks in the monsoon can be of different magnitudes and severity, and affect different crops to varying degrees. Application of meteorological information in terms of the frequency and probability of these breaks can be made to select a combination of crops of different durations in such a way that there is a time lag in the occurrence of their growth for appropriate intercropping systems.

5.2.4. *Soil moisture conservation measures* - Thin out the plants in small seeded crops which are closely planted, to maintain the proper plant population and to reduce crop stand for soil moisture conservation. Gap filling is also required if the plant stand is too thin and the operation may be taken up when the crop stand is less. When germination is less, re-sowing may be taken up with a closer plant to plant spacing. Interculture is advocated to break soil crust, control weeds and create soil mulch to conserve soil moisture. Use of organic mulches such as biomass of weeds, tree leaves, straw and other available crop residue or organic manures to conserve soil moisture. Under moisture stress conditions it is advised to avoid or withhold top dressing of fertilizers till sufficient moisture is available in the soil. In sorghum, pearl millet and groundnut etc. foliar spray of 2% urea during prolonged dry spells is recommended. Wherever ground/surface water is available and irrigation is possible, apply life saving irrigation with drip for wide spaced crops such as cotton, maize, chillies and vegetables and sprinklers for groundnut, maize and vegetables.

5.3. *Mid - season drought* - In the event of long dry spells during the rainy season, the following agro-techniques may be adopted depending up on the situation.

(*i*) Thin out of 20-25 % plants with in the row to reduce the transpiration losses. The thinned out plant biomass can be a useful source for either mulching the soil surface or can be used as herbage to feed the bovine population.

(*ii*) Timely weeding and hoeing is advised to break soil crust, control weeds and create soil mulch to conserve soil moisture. Spray of thiourea @ 500 ppm or urea or MOP @1-2% in pearl millet, mung bean, moth bean, cluster bean and groundnut to minimize the drought effect on the crop.

(*iii*) Nutrition helps the crops to guard against drought by encouraging development of a root system which will utilize soil water more efficiently. During dry spells foliar spray of 2% KNO_3 or 2% urea solution or 1% water soluble fertilizers, like 20-20-20, 21-21-21 etc. is advocated for supplementing crop nutrition.

(*iv*) Withhold top dressing of urea till sufficient moisture is available in the soil. Use 10-15 kg N/ha at optimum moisture, after relief of dry spell to gain lost vigor.

(*v*) Spray Planofix (2 ml / 9 lit of water) at 45 and 55 days after sowing (DAS) to prevent shedding of squares and small sized bolls in cotton grown in medium deep soils. Practice topping to bring down transpirational water losses or restrict excessive vegetative growth by spraying growth regulator such as NAA (4 ml/15 lt of water) in cotton cultivated in medium to deep black soils.

(*vi*) Organic/green mulch in crop rows is also an useful measure against mid-season drought. Adopt surface mulching with crop residues or tree loppings of *Glyricidia* wherever possible. In vertisols, if farm waste is not available, use blade to form a thin layer of soil mulch to avoid cracks.

(*vii*) Apply life saving irrigation, wherever ground/surface water is available and irrigation is possible, with micro-irrigation and/or sprinkler irrigation.

(*viii*) In case of failure of *kharif* crops, harvest the available biomass of ephemerals for fodder and on conserved soil moisture take up the sowing of early season *rabi* crops such as toria, mustard, taramira and chickpea once adequate rains are received.

5.4. *Late season or terminal drought* - In some of the years, the event of terminal drought occurs and in such cases, coping techniques, strategies may be addressed as:

(*i*) Wherever possible, arrange life saving irrigation with harvested rain water in farm ponds or any other source by adopting micro-irrigation (sprinklers).

(*ii*) Take up repeated intercultural operations to remove weeds and create soil mulch to conserve soil moisture. Make conservation furrows for moisture conservation. Prepare shallow furrow while hoeing by tying ropes to prongs, which will provide soil support to plants and conserve soil moisture. Open alternate furrows in row crops or furrows for every 6-8 rows of wide spaced crops in medium to deep soils. Open conservation furrows at 10-15 m interval in shallow to medium deep red and black soils.

(*iii*) During dry spells foliar spray of 2% KNO_3 or 2% urea solution or 1% water soluble fertilizers, like, 20-20-20, 21-21-21 etc. can be practiced for supplementing crop nutrition.

(*iv*) Adopt surface mulching with crop residues or tree loppings of *Glyricidia* wherever possible. In vertisols, if farm waste is not available, use blade to form a thin layer of soil mulch to avoid cracks.

(*v*) Harvest the crops at physiological maturity with some realizable yield. If damage is severe, harvest the crop for fodder and prepare to take up *rabi* sowing in double cropping areas.

(*vi*) If poor quality of water is available, barley may be sown. On conserved and/or receding soil moisture, prepare for the sowing of early season *rabi* crops such as toria, mustard, taramira and chickpea.

5.5. *Constraints in adaptation and mitigation* - Based on the severity of drought, a variety of adaptation strategies are available to mitigate it's impacts such as changing the crop calendar, using low water consuming crops, no sowing, use of improved irrigation practices, water harvesting and reducing wastage of water. However, there are constraints in the extent of these adaptations. Farmer's preference for rainwater harvesting through various structures and use of modern irrigation practices is low (Udmale, 2014). Costs associated with *in situ* water conservation practices is one such prohibitive factor (Koohafkan and Stewart, 2008). High initial investment, high cost involved in renewing systems and lack of irrigation water source seriously constrain the wide use of modern irrigation practices such as sprinkler and drip irrigation. Their usage is very low as compared with the potential offered. Household income, farm size and power supply are the other constraints identified (Malik and Rathore, 2012). On the administrative front, preparedness with enough quantity of drought resistant varieties or varieties of crops that consume less water is a daunting task. Awareness among the larger farming community about the current and predicted state of the drought and also drought adaptation practices is not effectively being done at present. Television, radio, news papers and social media should be used as tools to disseminate this information to a greater degree. Although, the governments adapt drought relief measures, there are certain shortfalls. Community based effective planning, implementation and management should be done to overcome the failure of the various government relief measures.

6. Drought monitoring mechanism

Monitoring and assessment of drought conditions at different scales and timely dissemination of information constitute the most vital part of a drought management system. The Drought Research Unit was established in 1967 by the Earth System Science Organisation and India Meteorological Department (ESSO-IMD) to conduct studies on various aspects of droughts in India. The ESSO-IMD in collaboration with ICAR has set up 130 Agro-Meteorological Field Units (AMFUs) and providing medium range weather forecast based agro-advisories at district level. The Crop Weather Watch Group at the Central level collects data from monitoring mechanisms of rainfall, water resources, crop growth etc. and assesses the status of these parameters on a weekly basis. The ESSO-IMD monitors rainfall situation throughout the year in different spatial scales (meteorological subdivisions/state/ district and all India on daily, weekly, monthly and seasonal wise) and prepares rainfall reports for different government agencies since 1992. ESSO-IMD uses per cent deviation of rainfall from normal and AI in determining the meteorological and agricultural drought, respectively till 2012. Later, recommendation of the World Meteorological Organization to use the SPI in monitoring all forms of droughts, *viz*., meteorological, agricultural and hydro-meteorological urged the ESSO-IMD to use the SPI to monitor the drought in the districts of India on a monthly scale from 2013.

In order to overcome the limitations of drought monitoring, the National Agricultural Drought Assessment and Monitoring System (NADAMS) was initiated in 1989 to provide near real-time information on prevalence, severity level and persistence of agricultural drought at state/district/sub-district level with participation of National Remote Sensing Center (earlier National Remote Sensing Agency), Dept. of Space, Government of India as a nodal agency for execution, with the support of IMD and various state departments of agriculture. Drought intensity is determined using the NDVI index and drought bulletins were issued biweekly from June to October every year. At present NADAMS covers 14 agriculturally important and drought vulnerable states of the country and provides information on the prevalence, spatial extent and intensity of agricultural drought during

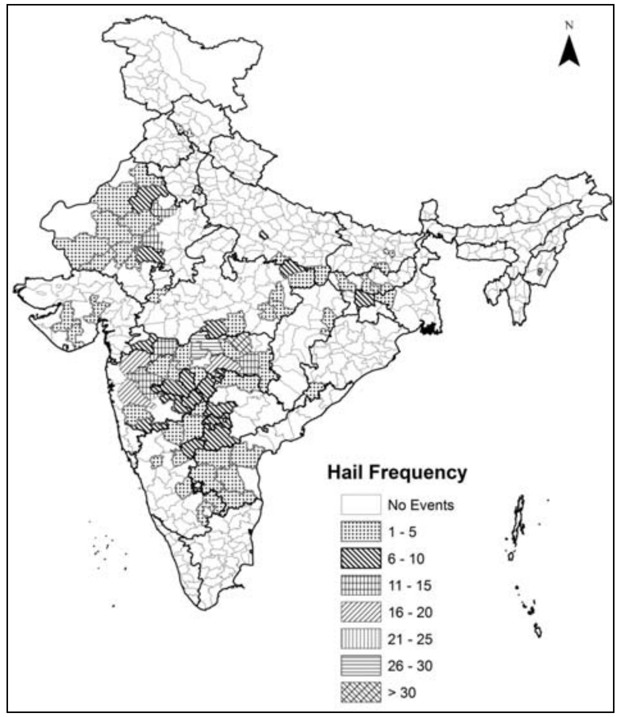
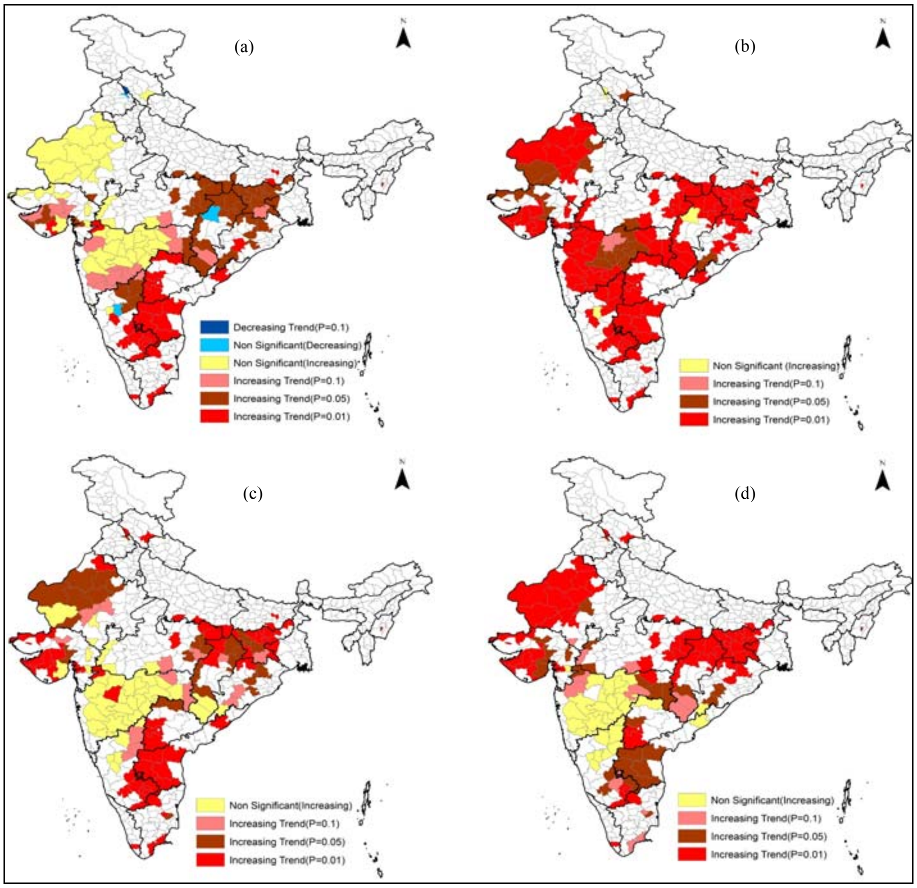


Fig. 2. Dryland districts showing hail frequency during the period1972-2011
(*Source* : Redrawn from Rao *et al*., 2014b)

the *kharif* season. On a fortnightly basis, drought assessment is carried out using daily observed coarse resolution (1.1 km) data and the information to the user departments is provided on a monthly basis. Detailed drought analysis at sub-district level is achieved separately for four states (Andhra Pradesh, Karnataka, Haryana and Maharashtra). The drought warnings and the drought monitoring reports generated by the NADAMS have been used as inputs to review the agricultural situations by the agriculture departments. They have also been used as inputs for developing contingency plans, for estimating relief claims and for relief management.

Central Research Institute for Dryland Agriculture (CRIDA) prepared district-wise contingency plans for 528 districts in collaboration with State Agricultural Universities (SAUs) / ICAR Institutes / Krishi Vigyan Kendras. The Central Water Commission, National Centre for Medium Range Weather Forecasting, National Remote Sensing Centre and National Rainfed Area Authority are other key agencies that provide early warning. All India Coordinated Research Project on Agrometeorology (AICRPAM) at CRIDA closely monitor the rainfall situation in the country at the district level and uses map products to forewarn all the stake holders in impending drought. AICRPAM in collaboration with IMD is issuing fortnightly National Agromet Advisory Services (NAAS)



Figs. 3(a-d). Dryland districts showing trend in maximum and minimum temperatures during *kharif* and *rabi* seasons : (a) T_{max} *kharif* (b) T_{max} *rabi* (c) T_{min} *kharif* and (d) T_{min} *rabi* for the period 1971-2009 (*Source* : Redrawn from Rao *et al*., 2014a)

bulletin specifying the management options to cope up the drought conditions. An impact analysis carried out at different centers on the utility of Agromet Advisories gave encouraging results augmenting the necessity to extend these Agromet Advisories to finer spatial scales.

7. Hailstorms in rainfed regions of India

A series of hailstorms struck central India during the period 26th February to 15th March, 2014. Such an extended period of hailstorm and its widespread occurrence is unknown for almost 80 years of recorded history. This has compelled AICRPAM to identify the regions with high hail frequency, describe the nature of damage to agriculture sector, assess current knowledge of hail suppression and to suggest policy actions. Hail prone districts were identified and the frequency in each month during the 38 year period from 1972-2011 documented (Rao *et al*., 2014b). The maps prepared for this work were redrawn considering only the rainfed districts of India. For preparing the maps we considered 143 districts that are set to be dryland districts as per the criteria recently adopted by Raju *et al.* (2014). There are two rainfed districts that experienced more than 30 hail episodes and four districts with more than 20 hail episodes during 38 year period (Fig. 2).

In some of the districts orchard/plantation crops are predominantly grown. In the event of hailstorm damage to field and horticultural crops, actions to be resorted are mostly crop specific. If the hail event is associated with heavy rainfall, farmers advised to drain out excess water from standing crop 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, possibilities of making best and timely use of available *in-situ* soil moisture and surface water (stagnated) to be explored for raising short duration cropsincluding forages and vegetables. Early sowing of greengram/blackgram is better with seed treatment/zero-till sowing after paraquat/glyphosate application. As hailstorms can cause severe damage to arable crops, orchard crops, and farm structures apart from seriously injuring livestock, poultry and humans, there is a need to systematically document the data on temporal and spatial distribution of hailstorms with the consequent damage. This facilitates identification of vulnerable areas more scientifically. There is a need for adequate Doppler Weather Radar (DWR) network in the country to monitor mesoscale phenomena, assimilate RADAR data in numerical weather prediction models to forecast occurrence of hailstorms over larger areas. The mechanism of alerting farmers has to be developed as it is difficult to predict hailstorms well in advance in tropical countries like India. There is also a need formulating a pilot project involving IMD, SAUs, AICRPAM and progressive farmers to undertake studies on suppression on hailstorms and to explore economically viable protection strategies to minimize the losses from hailstorms.

8. Rising temperatures in dryland districts

Apart from rainfall, the role played by temperature on agricultural production on a regional basis is gaining attention of scientists and policy makers alike (Gupta *et al.*, 2010; Lobell *et al.*, 2012). A negative response of global yields in wheat, maize and barley to increased temperatures was clearly established. Warming since 1981 has accounted for a combined loss of approximately 40 million tonnes per year in these three crops (Lobell and Field, 2007). Rainfall and temperature variations play a significant role in crop production in both crop growing seasons in India (Auffhammer *et al.*, 2006).

Any increase in temperature has an associated increase in evaporative demand and it is already shown that increased evaporative demand has considerable affect on crop production across several locations in India (Rao *et al.*, 2012). In an earlier work we reported the rising trends in temperatures at district spatial scales (Rao *et al.*, 2014). We present here the trends in temperatures for dryland districts (categorized by Raju *et al.*, 2014) from the same analysis. There are about 29 dryland districts showing highly significant increasing trend in maximum temperature (T_{max}) during *kharif* [Fig. 3(a)] and rising trend in T_{max} is more widespread during *rabi* with 116 districts out of 143 showing highly significant trend. Similarly, minimum temperatures are also rising in majority of dryland districts. During *kharif* season 58 districts exhibited a strong increasing trend in minimum temperature (T_{min}) [Fig. 3(c)]. As the case with T_{max} a rising T_{min} is widespread during *rabi* compared to *kharif* with 70 districts showing a strong rising trend [Fig. 3(d)]. Since rise in temperatures are likely to reduce the yield, it is imperative that suitable adaptation strategies have to be developed to minimize the adverse impacts. Adaptation options like growing varieties tolerant of thermal stress, changing planting dates, efficient irrigation and fertilizer management and application of additional nitrogen are some of the measures found to be beneficial (Aggarwal *et al.*, 2010; Sarker *et al.*, 2012).

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