Role of Drought Early Warning Systems for Sustainable Agricultural Research in India

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Abstract

Agricultural drought is a complex phenomenon. Its impacts vary greatly since they depend not only on the magnitude, timing, duration, and frequency of rainfall deficits but also on the differing responses of various soils, plants, and animals to water stress. The essence of good drought management is to use this range of responses to best advantage.

In recent years, because of growing human population, soil degradation, decreases in water resources, and future projected climate change scenarios, sustainable agriculture has become an important area of research. Agriculture is probably the most weather-dependent activity. Thus, an early warning system for sustainable agriculture is very important. Although early warning for weather parameters other than precipitation has improved considerably, precipitation forecasts on a medium-range scale of 3 to 10 days and long-range forecasts on a smaller spatial scale are still unreliable. The government of India and its various agencies have taken steps for drought management, but drought forecasting has not been developed for various growth stages of the crop. The advisories regularly issued by the India Meteorological Department (IMD) and the National Centre for Medium Range Weather Forecasting (NCMRWF) can be made more user-oriented and a better feedback mechanism may evolve. Proper validation of remotely sensed data in coordination with IMD scientists, scientists from other agencies, and policy makers for proper and timely monitoring of drought in smaller areas has been emphasized. Better communication between farmers, policy makers, and researchers to improve the nature and quality of information provided to the users also has been stressed.

This chapter provides an overview of drought early warning systems in India, including various feedback mechanisms presently in vogue. A brief description of related drought research and management options is included. Future action regarding sustainable agriculture in India has also been highlighted.

Introduction and Background

Drought is universally acknowledged as a phenomenon associated with scarcity of water. Although droughts are still largely unpredictable, they are a recurring feature of the climate.

Drought varies with regard to the time of occurrence, duration, intensity, and extent of the area affected from year to year. It is broadly classified into three categories.

Meteorological drought indicates the deficiency of rainfall compared to normal rainfall in a given region. Hydrological drought indicates the scarcity of water in surface and underground resources. Agricultural drought occurs when the rainfall and soil moisture are inadequate to meet the water requirements of crops.

According to the India Meteorological Department (IMD), meteorological drought is defined as occurring when the seasonal rainfall received over an area is less than 75% of its long-term average value. It is further classified as moderate drought if the rainfall deficit is 26-50% and severe drought when the deficit exceeds 50% of normal. A year is considered to be a drought year for the country if the area affected by drought is more than 20% of the total area of the country.

In dryland areas where irrigation facilities are almost nonexistent, rainfall is the main source of water for various crops. It is well known that the supply of water through rainfall in drylands cannot be as regular as it can be through irrigation. The major challenge in dryland agriculture is to establish ways to minimize reductions in agricultural production through efficient soil, water, and crop management practices during the drought years. Thus, research in dryland agriculture should be aimed at generating management skills required for adjusting cropping patterns and cultivation practices as the situation demands, depending on the occurrence of rain/drought. In India, almost 20% of the total area of the country lies in the dry farming tract where annual rainfall is between 40 and 100 cm without any irrigation support. Thus even after full exploitation of irrigation potential in the country, it is estimated that in India about 70 million ha of cultivable land will be under rainfed agriculture, spread over some parts of Haryana, Rajasthan, Uttar Pradesh, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka, and Tamil Nadu.

In the places where long-term average rainfall is less, year-to-year variability is greater and so the likelihood of drought is greater. However, because the farming options in the driest region are limited, the major impact of drought is felt in semiarid and subhumid regions, where the incidence of drought years is fairly high, but intensive, diversified farming is profitable in years of good rainfall. However, such years are usually few.

There have been many attempts to link drought to sunspot number, meteor showers, volcanic activity, changes in composition of the atmosphere, and other possible causes, but their effect, if any, is masked by the pronounced spatial and temporal variability in drought duration, intensity and extent. Droughts result from anomalies in large-scale circulation of the atmosphere and oceans. The El Niño phenomenon in the Pacific Ocean may provide fairly short-term prediction of drought in certain areas, but cannot account for all droughts worldwide, and the basic question of what causes the El Niño phenomenon is still controversial. Even if accurate long-term forecasts of drought materialize, they will not do away with droughts, and the need for skilled drought management for sustainable agriculture will remain.

Drought has multidimensional effects in dry farming areas. The drought conditions may lead to (1) shortages in food production due to failure of crops; (2) shortages of fodder and drinking water for cattle, migration of livestock populations, and even a decrease in the animal population; (3) shortages of resources for agricultural operations during the subsequent year as a result of decreases in the animal population; and (4) deforestation to meet the fuel shortage for cooking in rural areas because of nonavailability of agricultural wastes and crop residues.
The other socioeconomic implications of droughts include increases in prices of essential commodities, import of foodgrains, distress sales of cattle, rural unemployment, malnutrition, health hazards, and depletion of assets at the farmers' level. Drought impacts are long lasting, at times lingering for many years. Human and social factors aggravate the effect of drought, as it takes several years for small and marginal farmers in dryland areas to recoup the losses.

In the vast semiarid and arid regions of the world, years of below-average rain are more frequent compared to the years of normal/excess rainfall. Every farmer in these areas should recognize the inevitability of drought and prepare for it by equipping himself with coping strategies.

Moreover, drought management should be an integral component of sustainable agriculture. Thus the threat of instability inherent in recurring drought must be counteracted as far as possible.

As the basic requirement for managing drought in dryland agriculture is to generate the management skills required to adjust crop cultivation plans/practices depending on the time of occurrence of rain/drought, it is necessary to characterize the different types of droughts likely to be encountered in drylands.

Five distinct categories of drought affecting crop production in the drylands were clearly distinguished in India, depending on the time of occurrence of drought and general climatic conditions of the region.

Early season drought

The early season droughts occur in association with the delay in commencement of sowing rains.

Characterization of early season droughts in any agroclimatic region requires precise information on (1) optimum sowing periods for the different crops and their varieties grown in the region under rainfed conditions, (2) amount of rainfall needed to complete the sowing in a given region, and (3) the initial amount of rainfall required for safe germination and establishment of the crop stand to minimize the adverse effect of dry spells immediately after sowing.

Mid-season drought

Mid-season droughts occur in association with the breaks in the southwest monsoon. If the drought conditions occur during the vegetative phase of crop growth, it might result in stunted growth, low leaf area development, and even reduced plant population. Mid-season droughts for crops grown under rainfed conditions can be characterized by (1) the relationship between leaf area index and water use of the crop, depending on the water availability to the crop, and (2) the relationship between the actual leaf area index and effective leaf area index of the crop under moisture stress conditions.

Late season or terminal drought

If the crop encounters moisture stress during the reproductive stage because of early cessation of the rainy season, there may be an increase in temperature, hastening the process of crop development to forced maturity. Therefore, late-season droughts have to be characterized on the basis of the relationship between water availability to the crop during the reproductive stage of crop growth and grain yield.

Apparent drought

Rainfall in the region may be adequate for one crop but not for others. Therefore, apparent drought conditions are encountered because of mismatching of the cropping patterns to the rainfall/moisture availability patterns in some of the regions.

Permanent drought

Drought is a recurring feature in arid regions, as it is in virtually all climate regimes. Even the drought-resistant crops grown in these regions are likely to be subjected to moisture stress, even during years with above-normal rainfall. Alternate land use systems have to be introduced in these regions for sustainable agriculture.

Overview of the Drought Early Warning System in India

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 2 weeks can create plant water stress, leading to low productivity of crops. These breaks cannot be predicted in advance. The agricultural droughts resulting from prolonged breaks in the monsoon rains can be of different magnitudes and severity and affect different crops in varying degrees. Meteorological information, in terms of the frequency and probability of these breaks, can be used 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.

Long-range seasonal forecast of the India Meteorological Department

The Indian economy is basically an agro-based economy. The nation’s agricultural planning is primarily dependent on the reasonable accurate prediction of the total amount of rainfall from the beginning of June to the end of September. This kind of prediction comes under the category of long-range forecast (LRFs). The first operational LRF for seasonal monsoon rainfall was issued on June 4, 1886. This was based on antecedent Himalayan snow cover (Blanford 1884). Over the last hundred years, there have been many refinements in the LRF techniques, including the multiple regression technique introduced by Sir Gilbert Walker (1910). Presently, IMD issues LRFs based on statistical techniques. In the last 12 years (1988-99), all the monsoon rainfall forecasts have proved to be fairly accurate.

On the basis of LRFs, various precautionary measures can be planned and adopted. For example, if an LRF indicates below-normal rainfall, then food grains could be purchased from the international market well in advance. Also, adequate arrangements could be made for the transport, storage, and distribution of the food grains. The government authorities can work out various plans and schemes to counter the adverse situation well in advance, and the strategies can be used at various levels, such as states, districts, talukas, villages, and so on.

At present, LRFs pertain to the seasonal total rainfall for the entire country. Scientific research is required for the development of LRF techniques for a smaller spatial and temporal scale.

Service rendered by the Agrimet division of IMD

A scientific study of the influence of weather on crops is of vital importance. Any abnormalities in the weather during the season, such as delay in the outbreak of rains, untimely or excessive rains, droughts, or spells of too-high or too-low temperatures, would very seriously affect the growth and final yield of the crops. Analysis of the existing data indicates that at least 50% of the variability of crop yields is related to weather.

Realizing the importance of meteorology in better understanding the crop-weather relationship and thereby increasing the food production in the country, the Agricultural Meteorology Division (Division of Agricultural Meteorology) was started in August 1932 in Pune. After the formation of the division at Pune, the problems connected with the application of meteorology to agriculture began to receive specialized attention. Close and very fruitful contacts have been established with all the central and state agricultural departments.

The Division of Agricultural Meteorology has a wide network of agrometeorological observatories, which generate various kinds of data on agrometeorological parameters. In tune with the changing agricultural scenario in the country, the Division has taken up more specific research problems like water requirement of crops, pests and diseases, rainfall probabilities in the dry farming tracts, crop-weather relationship, and application of remote sensing techniques in agricultural meteorology.

Agrometeorological Advisory Services Unit (AASU)

The Division of Agricultural Meteorology, in coordination with the respective state agricultural departments, is issuing weekly/bi-weekly Agromet. Advisory Bulletins from 17 AAS units located at State Meteorological Centres (MCs)/ Regional Meteorological Centres (RMCs). The scheme was first launched in 1977 from the state of Tamil Nadu. The Advisory Bulletins contain specific agricultural advisories tailored to the needs of the farming community.

The first and foremost aim of the service is to render timely advice on the actual and expected weather and its likely impact on the various day-to-day farming operations. Short-range forecasts valid for 12 to 24 hours and then extended to the following 2 to 3 days are used extensively to provide this advice. Secondly, agrometeorological forecasts extending over a week or 10 days (medium range) are very important from the users' point of view as well as for planning for various agricultural operations and strategies.

The advisories are prepared by taking into account the stage of the crops, agricultural operations in progress, prevalence of pests and diseases, and the immediate impact of weather on crops. They are prepared in consultation with the experts of the State Department of Agriculture and broadcast over All India Radio (AIR) stations in the state and Doordarshan Kendra as special programs for the benefit of the farmers in the state. These bulletins are also sent to various agricultural authorities in the state.

The bulletins contain specific advice for farmers for protecting their field crops from adverse weather or to make best use of prevailing favorable weather to increase production. These bulletins are broadcast in the regional languages from radio stations of the concerned region. They are also telecast over some of the national TV network stations of the specific region. Newspapers, particularly those in regional languages, are also used for the dissemination of weather information.

In addition to this bulletin, the Farmers' Weather Bulletin (FWB) is also regularly issued from all MCs/RMCs. Weather services for the farmers in India were started by the India Meteorological Department in 1945. FWBs indicate the onset of rains, probable rainfall – intensity and duration, weak or a break in monsoon conditions, occurrence of frost, hail, squalls, and other conditions. The bulletins also contain daily district forecasts of weather, including warnings of conditions (such as heavy rainfall and low temperature) that are injurious to plants.

Farmers' Weather Bulletins are issued throughout the year for broadcast in different regional languages through AIR stations. Initially there was only one broadcast a day, in the evening. A second bulletin was then issued in the morning during the rainy season. Since 1990, FWBs have been issued throughout the year twice a day. These bulletins and the daily weather reports prepared by the centers are also published in the newspapers. At present, 70 radio stations broadcast FWBs in India. The validity of these forecasts is for 48 hours, with an outlook for the subsequent two days. Figure 1 shows the network of Agromet Advisory Services Centres and AIR stations broadcasting FWBs. Contents of the Bulletin are (1) a summary of past weather, (2) a district forecast of weather during the next 48 hours and special weather warnings for cyclonic storms, etc., and (3) an outlook for the subsequent two days.

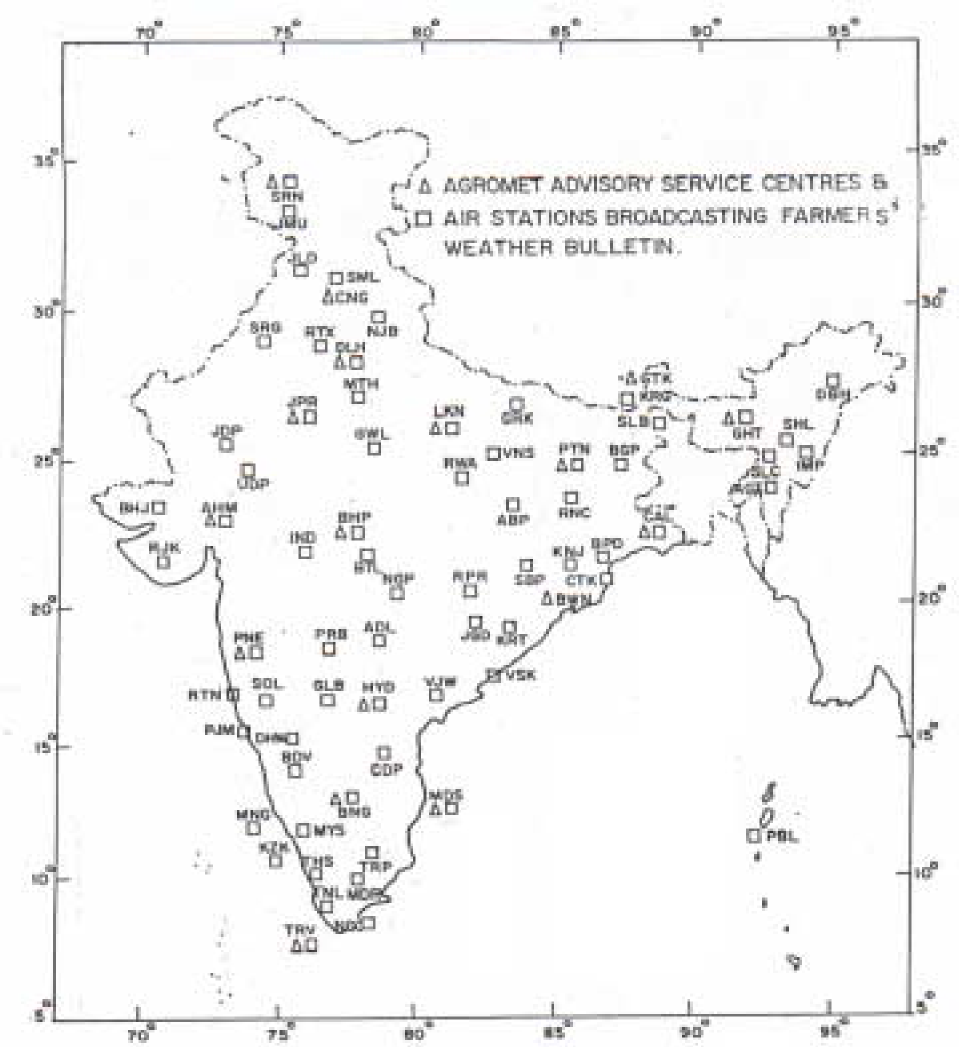

Figure 1. Map indicating - Agromet Advisory Service Centres (△) and Air Stations Broadcasting Farmers' Weather Bulletin (□)

Feedback

To assess the utility and impact of operational weather services to farmers, feedback can be obtained through conferences, workshops of forecasters, agrometeorologists, agriculturists, extension workers, and farmers. Feedback is obtained by various means, such as questionnaires. The questionnaires usually include (1) general information (e.g., name of unit, main crops, and main cultural operations), (2) information regarding farmers' awareness of meteorological forecasts and agromet advisories, and (3) information regarding the language of advisories (e.g., whether the language is easy or difficult to follow), reliability of forecasts, and usefulness of warnings. Regular surveys for this feedback information are essential for the improvement of our forecasting at such a level, so that the user community can correctly interpret the advisories to their best advantage. The feedback information reveals that the use of modern techniques in agrometeorological analysis has increased the credibility of forecasts among the user community. Now with the development of information technology, the feedback may be obtained from farmers and user agencies through the Internet.

Drought Research Unit of the India Meteorological Department

The Drought Research Unit was set up at IMD in Pune under the instruction of the Planning Commission of the government of India in June 1967.

IMD identifies meteorological drought for subdivisions every year based on rainfall analysis. During the last 125 years (1875-1999), IMD has identified meteorological droughts (moderate or severe) over meteorological subdivisions of the country using IMD criteria and also drought years for the country as a whole. Similarly, drought-prone areas and the probability of occurrence of drought were also identified.

IMD monitors agricultural drought once every two weeks on a real-time basis during the main crop seasons (kharif and rabi) of India. For this, an aridity anomaly index (AI) developed on the lines of Thornthwaite's concept is used to monitor the incidence, spread, intensification, and recession of drought. AI is given as

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

where PE is potential evapotranspiration calculated with the help of Penman's formula, which takes into account mean temperature, incoming solar radiation, relative humidity, and wind speed. AE is actual evapotranspiration calculated according to Thornthwaite's water balance technique, taking into account PE, actual rainfall, and field capacity of the soil.

The aridity anomaly is calculated by using the normal Aridity Index for 210 well-distributed stations over the country. The arid areas are demarcated as follows:

Aridity Anomaly	Areas
0 or negative	Non-arid
1 – 25	Mild arid
26-50	Moderate arid
> 50	Severe arid

With the help of aridity anomalies, crop stress conditions in various parts of the country can be monitored during the monsoon season. These anomalies can be used for crop planning and in the early warning system during drought/desertification.

It should be mentioned that aridity is different from drought. Aridity is a permanent climatic situation of a region, while drought may occur at any place and on any time scale. Thus aridity anomaly reports used by the India Meteorological Department do not indicate arid regions; on the contrary, they give an indication of the moisture stress in any region on the time scale of one or two weeks, and they are useful early warning indicators of agricultural drought.

Biweekly aridity anomaly reports are prepared for the country as a whole during the southwest monsoon season and over 5 subdivisions (Coastal Andhra Pradesh, Rayalaseema, South Interior Karnataka, Tamil Nadu, and Pondicherry and Kerala) during the northeast monsoon season. These anomaly reports are widely circulated to various users such as Agromet Advisory Services, the agricultural departments of state governments, agricultural universities, and the National Remote Sensing Agency in Hyderabad. The system is being further refined by supplementing remote sensing data.

The Drought Research Unit also provides Crop Yield Forecasts (CYFs). This unit has developed pre-harvest crop yield forecasting models and issues of monthly statewise crop yield and countrywide total production forecasts for the major crops of kharif (rice) and rabi (wheat), based on the agrometeorological models. Weather parameters like rainfall, temperature, relative humidity, cloud amounts, and improved technology influence crop growth and yield. Based on a long series of past crop yield data and meteorological data of the corresponding period, pre-harvest crop yield forecasting models have been developed using the multiple regression technique. Pre-harvest crop yield forecasts are issued for 15 states comprising 26 meteorological subdivisions for kharif (rice) and 12 states comprising 16 meteorological subdivisions for rabi (wheat) and also for the total rice/wheat production of the country. The forecasts are supplied to India's Directorate of Economics and Statistics, Ministry of Agriculture. The first interim forecast for kharif rice is issued in August and the final forecast is given in November/December. For wheat, the first interim forecast is issued in January and the final in March/April/May.

Rainfall Climatology for the Agricultural Planning Unit in IMD

One of the most important pieces of agrometeorological information required by agriculturists is the suitable time for starting the sowing operations in their fields. Sowing dates for the states of Karnataka, Rajasthan, Gujarat, Madhya Pradesh, Uttar Pradesh, and Maharashtra, based on the climatology of daily rainfall data, soil type, and cropping pattern, have been prepared by the India Meteorological Department. Based on such studies, it is also possible to identify areas that may need supplementary irrigation to sustain crop growth. By superimposing results of the analysis on the soil map of the state, areas experiencing different degrees of drought proneness have also been demarcated.

The National Centre for Medium Range Weather Forecasting (NCMRWF)

In January 1988, the government of India approved the establishment of NCMRWF as a constituent unit of the Department of Science and Technology (DST) to help develop suitable numerical weather prediction (NWP) models for medium-range weather forecasts (3–10 days in advance) and prepare agrometeorological advisories for the farming community in 127 agroclimatic zones of India. The main objectives of NCMRWF are (1) to develop location-specific medium-range (3 to 10 days) weather forecasts, (2) develop weather-based agro-advisory services for the farming community, and (3) promote and coordinate research in related areas of meteorology and agrometeorology.

The project has received continued support from IMD since its inception. An exclusive coordination cell, the Agrometeorological Co-ordination Cell, was established in November 1988 in IMD for coordinating activities related to the project. NCMRWF, in collaboration with the India Meteorological Department, Indian Council of Agricultural Research (ICAR), and state agricultural universities (SAUs), is providing Agrometeorological Advisory Service (AAS) at the scale of agroclimatic zones to the farming community, based on location-specific medium-range weather forecasts.

To provide numerical weather prediction (NWP) based AAS to farmers, NCMRWF opened an agrometeorological field unit (AMFU) in each of the 127 agroclimatic zones of the country. These AMFUs are co-located with the National Agriculture Research Program (NARP) Centres of ICAR and the SAUs so that research output can be used effectively in formulating the agro-advisories. At present, NCMRWF has established AAS units in 83 agroclimatic zones (Figure 2). The remaining zones may be covered in a phased manner. Agromet Advisory Bulletins, with expert advice on crop, soil, and weather, are made available to the farming community.

Dissemination and feedback mechanism

NCMRWF's weather forecast bulletin is disseminated biweekly to AAS units every Tuesday and Friday over a telephone, telegram, or satellite-linked Very Small Aperture Terminal (VSAT) communication system. In addition to these bulletins, weather charts are also sent to AAS units. The VSAT has the capability for reliable data transmission, interactive data communication voice transmission, and picture transmission. The same communication system is also being used to collect observational data from AAS.

Periodic feedback on the worthiness of forecasts and usefulness of advisories is also obtained by NCMRWF. Feedback from selected farmers and SAUs indicates whether they have adjusted their day-to-day farming operations in response to the advice provided by AAS; it also highlights their additional requirements.

Central Research Institute for Dryland Agriculture (CRIDA)

CRIDA is maintaining six agrometeorological observatories in their regional research stations at Jodhpur, Jaisalmer, Chandan, Bikaner, Pali, and Bhopalgarh. Data collected at these observatories are also used for drought assessment, which is disseminated to the public and other agencies through the media.

Figure 2. Agromet Advisory Services units of NCMRWF

Remote sensing for drought monitoring

During periods of drought conditions, physiognomic changes within vegetation may become apparent. Satellite sensors are capable of discerning many such changes through spectral radiance measures and manipulation of such measures into vegetation indices, which are sensitive to the rate of plant growth as well as to the amount of growth. Such indices are also sensitive to the changes in vegetation affected by moisture stress. The vegetation index maps are prepared by the National Remote Sensing Agency (NRSA) of the Department of Space and distributed to users for monitoring agricultural drought.

Drought Research in India

Many studies have dealt with monsoon variability and the impact of global- and regional-scale parameters on summer monsoon rainfall. There are also many studies on the prediction of summer monsoon rainfall through numerical models. Studies by Smith and Sikka (1987), Singh and Kriplani (1985), Chowdhury et al. (1988), Singh et al. (1992), and Vernekar et al. (1993) have shown that the 30-50 day mode has strong interannual variability, which may in turn affect the variability of the monsoon season rainfall through active-break monsoon episodes. Bhalme and Mooley (1981) prepared a time series of the drought area index. They defined the moisture index as the ratio of departure of rainfall from the monthly mean and standard deviation of monthly rainfall.

The epochal behavior of drought has been discussed by Joseph (1978), Sikka (1980), and Mooley and Parthasarathy (1984).

Appa Rao (1991) classified the drought-prone areas and chronically drought-affected areas. Most of the drought-prone areas identified above are in either arid or semiarid regions where droughts occur more frequently. Sen and Sinha Ray (1997) have shown a decreasing trend in the area affected by drought in India. Gore and Sinha Ray (1999) made a detailed study of the variability of drought incidence over districts of Maharashtra. Sinha Ray and Shewale (2000) have determined the probability of occurrence of drought on the basis of summer monsoon rainfall data for the period 1875-1999. Figure 3 indicates the probability of occurrence of moderate and severe drought over various subdivisions in India. Probability of occurrence of severe drought was found to be greatest in Saurashtra and Kutch, followed by Gujarat and West Rajasthan. Sinha Ray and Shewale (2000) also studied the effects of El Niño on summer monsoon rainfall of various subdivisions of India.

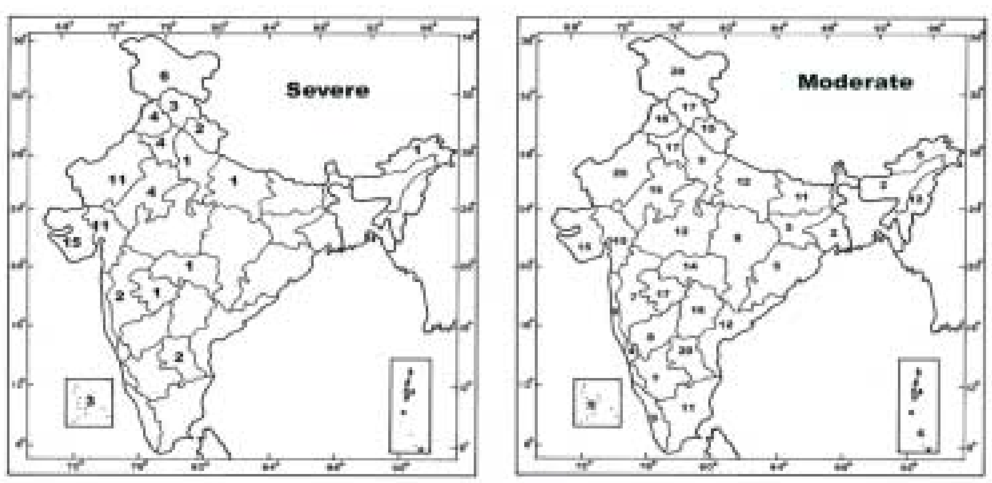

Figure 3. Occasions of moderate and severe drought during 1875 - 1999

Government Efforts

The National Natural Resource Management System (NNRMS) has been set up to monitor the progress of remote sensing applications to natural resources management in the country. To pursue and guide remote sensing application development in the agriculture sector, the Standing Committee on Agriculture and Soils (SC-AS) has been created. The SC-AS is entrusted with the responsibility of examining the role of remote sensing technology in addressing various issues related to management of agricultural resources. They are assessing the present and future capabilities of that technology to develop procedures to retrieve agromet parameters from space-borne systems and disseminate agromet information for farmers' advisory services.

Recent efforts to combat drought through policies formulated by governmental agencies include:

- crop weather watch groups at the national and state level,
- food security through buffer stocks,
- priority to the most seriously affected areas for "food for work"/National Rural Employment Project and other programs,
- high priority to food production in the most favorable/irrigated areas as compensatory programs,
- optimum input use,
- rural godowns to avoid crash sales, and
- crop insurance schemes.

Most recently, serious attempts have been made to develop areas on the basis of watersheds. The Watershed Development Programmes have brought out the possibility of holistic development of an area. They include:

- soil and water conservation programs,
- choosing production systems based on land use capability classification,
- increased cropping intensity either through harvesting excess rainwater through surface runoff or by improving the ground water recharge through percolation tanks, and
- good crop husbandry.

The space-based National Agricultural Drought Assessment and Monitoring System (NADAMS), which has been operational since 1989 under India's Department of Agriculture, provides scientific information at the district level for most of the states and subdistrict levels in a few states. The NADAMS program needs to be strengthened with interdepartmental support. The Drought Prone Area Development Programme (DPAP) and Desert Development Programme (DDP) should use the action plans prepared on the basis of integrated resource estimation from remote sensing data.

Premier government institutions like the Central Arid Zone Research Institute (CAZRI), Jodhpur; Indian Grassland and Fodder Research Institute (IGFRI), Jhansi; Central Soil Salinity Research Institute (CSSRI), Karnal; and research stations of the Ministry of Agriculture in various states have developed some ameliorative measures. These practices are region specific, and after proper implementation, they have the potential of bringing forth productive green cover on otherwise marginal degraded lands.

Forecasting agricultural output using space agrometeorology and land-based observation (FASAL) is under active consideration at the Ministry of Agriculture for administrative approval and implementation. The pilot FASAL project in Orissa (1999-2000) has demonstrated the combined use of various sources of data in making kharif rice multiple forecasts.

Drought Management

Drought management should not be treated as an isolated problem but as an integral and key factor in sustainable agriculture. Farmers should be encouraged to develop a range of flexible contingency plans that protect the soil, climate, and vegetation. By having numerous contingency plans, farmers can resist the temptation of overextracting these resources. Drought management procedures include:

- community nurseries at points where water is available,
- transplantation,
- sowing of alternate crops/varieties,
- ratooning or thinning of crops,
- soil mulching if the break in the monsoon is very brief,
- weed control,
- in situ water harvesting and/or run-off recycling,
- broad beds and furrows,
- graded border strips,
- inter-row and inter-plot water harvesting systems,
- intercropping systems for areas where the growing season is generally 20 to 30 weeks,
- alternate land use systems,
- development of agriculture on the basis of the watershed approach,
- alley cropping,
- agro-horticultural systems,
- watershed approaches for resource improvement and use,
- water resources development,
- treatment of lands with soil conservation measures,
- alternate land use systems, and
- forage production.

Future Needs

- IMD’s long-range forecasts should be available on a smaller spatial and temporal scale, which will be helpful for sustainable agriculture.
- Agromet parameters estimated from remote sensing data need to be validated with ground-based observation and turned into a usable product.

- The Department of Agriculture and All India Co-ordinated Research Project on Agrometeorology of ICAR and IMD should have a linkage with the NADAMS project of the Department of Space to provide periodic crop/pest/disease information at subdistrict to national levels.
- The Agromet advisory service issued from NCMRWF and AGRIMET of IMD should coordinate the space-based program on NADAMS and use the spatial maps for strengthening the present advisory services on crop pest/disease monitoring.
- The Drought Prone Area Programme (DPAP) and the Desert Development Programme (DDP) require improved management of land and water resources to avoid land degradation like salinity, alkalinity, and waterlogging.

Each state should be equipped with a drought management system, linking district administration with state and national departments that provide services.

Agromet information for farmers' advisory services should be made more user-oriented, and frequent feedback may be obtained from farmers for further improvement. Use of the Internet may be exploited for more efficient feedback.

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