DROUGHT ASSESSMENT AND MANAGEMENT IN ARID RAJASTHAN

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CENTRAL ARID ZONE RESEARCH INSTITUTE (ICAR), JODHPUR AND
***NATIONAL CENTRE FOR MEDIUM RANGE WEATHER FORECASTING, NOIDA**

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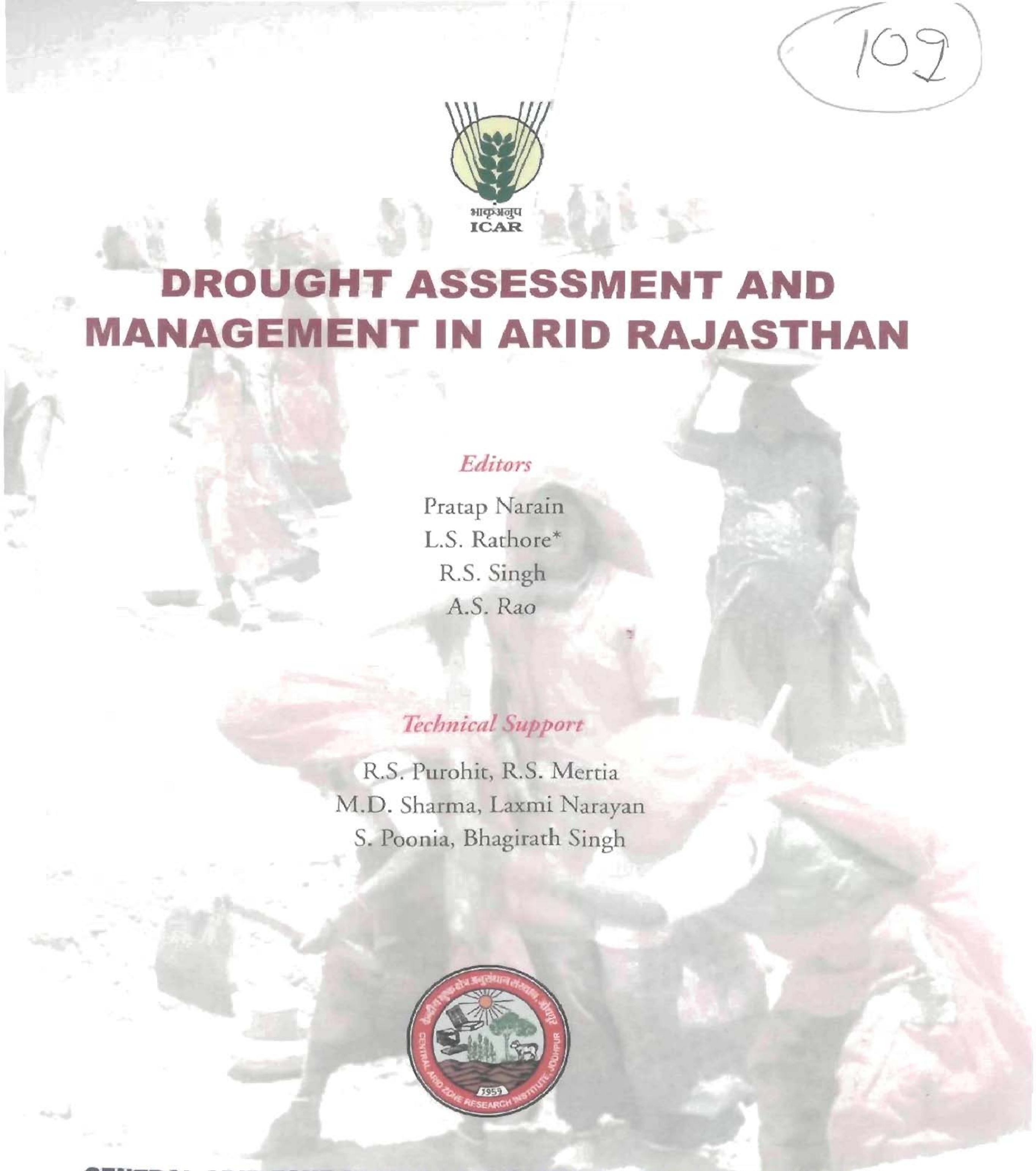

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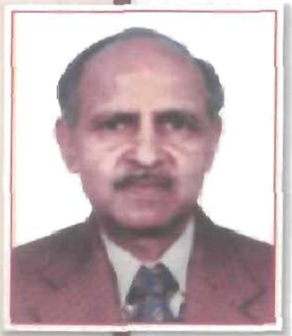
FOREWORD



Drought is the most complex and least understood natural hazard affecting more people than any other hazard, Drought should not be viewed merely as a physical phenomenon or natural event as it results in significant socio-economic impacts, regardless of level of developments, although the character of these impacts tend to differ. Drought impacts are more severe in arid and semi-arid climatic regions. Its impacts on society result from the interplay between a deficiency in water supply affecting fodder, fuel and food availability. Being normal feature of climate, its recurrence is inevitable, but meteorologists always find it difficult to predict the drought well in advance to pre-empt drought preparedness.

Good attempt has been made to document information on different aspects of drought including its definition, classification, causes, monitoring, prediction and early warning system in India. Historical perspective of drought on occurrences and spread has been synthesized through analysis and assessment of past rainfall records. Micro-level assessment and monitoring of drought through networking systems and using cumulative weekly rainfall has been made besides presenting a kaleidoscopic view of drought over western Rajasthan. Analysis of recent drought events has been incorporated along with its impact on crop and grassland productivity. Detailed account of drought proofing and management in chronically drought prone regions, medium range weather forecasting and agrometeorological advisory services is also given

Aspects of drought contingency planning, drought preparedness and drought impact assistance policies as to their future effectiveness under long-term climate change need to be urgently considered. Drought contingency plans on paper are required to be translated into an effective policy covering range of activities required to address short and long-term consequences. Also, effective and interactive management systems need to be set in place. Public-private partnership approach need to be further explored in order to 'mainstream' drought risk management. Involving the development of risk management tools and approaches within the context of overall rural livelihood strategies, integrating risk arising from markets and threats to the natural resource base is quite important. It also involves communicating risk management knowledge through functional, existing communication networks of farmers and other landholders.

I wish to express my appreciation for the authors who have been able to put the information on many of above mentioned issues into clear and concise form. I am sure the publication will be valuable to meteorologists, agricultural scientists, farmers at large and those dealing with planning and managing the droughts.

(Dr. P. S. GOEL)

PREFACE

Weather particularly the monsoonal behaviour over the Indian continent holds the key to agricultural productivity in rainfed areas, their drinking water availability and ultimately their survival of animals and human beings in these areas. In this context, an understanding of weather, its forecasting preparedness to meet unforeseen eventualities and contingent planning is vital for stabilizing agricultural production and socio-economic development. Role of Agrometeorological Advisory Services in organization of different operations relating to crop production and irrigation of field crops is of great relevance. In order to avoid adverse effect of weather, the need for an operational guide on drought assessment and management in western Rajasthan was felt to provide required information for drought proofing. This monograph is an attempt in that direction and has been prepared to cater to the need of researchers and technical manpower involved in drought management.

A general misconception is that drought occur only in arid and semi-arid regions is not correct - since droughts are departure from long-term annual average, it may also occur in high rainfall regions of Meghalaya or Assam or Kerala as was the case in the year 2006. This is becoming more frequent due to phenomena of climate change. In these areas too deficient rainfall affects vegetation, crops and water availability. Since these regions have less experience of coping drought, their preparedness is poor and hence the impact of drought may be more severe in high rainfall regions than in dry regions, which are assured with time tested traditional wisdom of drought management.

The present publication deals with drought prone areas of western Rajasthan. Modern concepts of drought, its definitions, classification of drought, drought prediction in India, drought monitoring indices and early warming systems in India, improving early warming system for drought preparedness and mitigation, rainfall analysis and drought assessment, importance of micro-level assessment and monitoring of drought, contingency planning, drought proofing and management, medium range weather forecasting of NCMRWF and Agro-advisory services and their economic benefits have been discussed in detail.

We express our heartfelt appreciation to all the staff members of the Agrometeorology Section for their dedicated work in collection and computation of data for the preparation of material for this bulletin. Thanks are also due to NCMRWF and DST, New Delhi for financial support for this publication.

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L.S. Rathore
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1. INTRODUCTION

Droughts are attributed to temporal as well as spatial variability in rainfall of a location. Drought is the most disastrous natural hazard causing innumerable miseries to living beings sometimes leading to near famine like situation or even historical famines. Although the onset, persistence and termination of drought are gradual processes, its impact may be far more disastrous than that of flood or other natural calamities. Droughts in succession, when prolonged for more than one year which is often the case, has a devastating effect on natural resources and availability of water, production of food and fodder. Consequently, an unfavourable year of drought has immediate impact on the economy of a agrarian country like India where food grain reserves have narrow edge over the demand. With the increasing demand for the growing population, there may be more frequent imbalance between food supply and requirement leading to depletion of food grain reserves, malnutrition and political unrest. Calamities like drought accentuate miseries.

Indian agriculture continues to be a gamble of the vagaries of monsoon, rainfall being most critical because nearly 70% of the net sown area is still rain dependent. Aberrant behaviour of monsoon such as low and poor rainfall distribution, delayed onset and prolonged dry spells during the cropping season, often results in water stress conditions at different growth stages causing decline in productivity and sometimes crop failures in the country. Food production particularly in the state of Rajasthan nose dives during the years of drought and aberrant weather. Severe drought reduced the food grain production in western Rajasthan by 70 percent during 1987-88, 50 percent during 2002-03 and again by 57 percent during 2004-05 against previous good monsoon year. Such reduction in food grain production was also noticed at state as well as at country level during drought years (Table 1).

Table 1. Food production in India in years of aberrant weather/drought

Year	Food grain production (in million tones)		
	Western Rajasthan (Total for 12 arid districts)	Rajasthan state	India
1964-65	1.95	5.46	97.92
1965-66	1.27 (35)[*]	4.01 (27)	78.75 (20)
1971-72	2.20	6.58	114.25
1972-73	1.50 (32)	5.44 (17)	104.17 (09)
1978-79	3.00	8.33	142.00
1979-80	3.59 (00)	5.49 (34)	118.44 (17)
1983-84	4.57	11.15	165.06
1987-88	1.38 (70)	6.03 (46)	153.00 (07)
1999-2K	4.42	14.00	230.52
2000-01	4.24 (04)	12.00 (14)	214.32 (07)
2001-02	6.88	17.13	232.33
2002-03	3.44 (50)	9.28 (46)	187.86 (19)
2003-04	6.52 (05)	10.90 (57)	212.05 (09)
2004-05	2.96 (57)	5.53 (68)	204.60 (12)

[*] Figures in parenthesis shows per cent decrease in food production due to drought against previous good monsoon year.

The severity of drought depends on the duration, frequency, intensity and geographical distribution of rainfall as well as on corresponding water demand of human, animal, crops and vegetation cover of a region. Seasonal temperature, wind velocity, sunshine, density of vegetation and moisture retaining capacity of soil and soil moisture balance in surface, sub-soil and ground water influence water demand during the drought years.

Arid region of Rajasthan is a frequent victim of disastrous droughts, resulting in huge economic losses and degradation of natural resources of the region. Droughts have always engaged attention of society reflected by legendry worship of the Rain God, sometimes animal and human sacrifices are performed to please the Rain God for saving society from the miseries of drought.

The Indian economy has been described as a 'gamble of monsoon'. The coefficient of variability of SW monsoon rainfall over drought prone and chronically drought prone area range from 15-40 per cent and 41-65 per cent, respectively (Sikka, 2004; Singh *et al.*, 1991 and 2001; Rao and Vijendra, 2004). Although no part of India is immune to drought, but the arid and dry semi-arid regions of the country are vulnerable and experience droughts of varying frequency and intensity often crippling national economy.

About 62 per cent of arid zone in India (covering an area of about 20 million ha) lies in western Rajasthan, thus forming the principal arid zone of the country. The region is endowed with plenty of sunshine and favourable temperature during the rainy season, but is not well placed with regard to water availability for crop production. Low annual rainfall, which varies from 450 mm in the eastern part to less than 100 mm in the westernmost part (Fig.1) and its ill distribution results in widespread and recurring `droughts in many parts of the region with variation only in its magnitude from year to year. To reduce the adverse effects of drought on the economy and to mitigate sufferings, identification and monitoring of drought severity and its geographical distribution helps in drought proofing, drought preparedness and execution of relief programmes to reduce impact of drought on society.

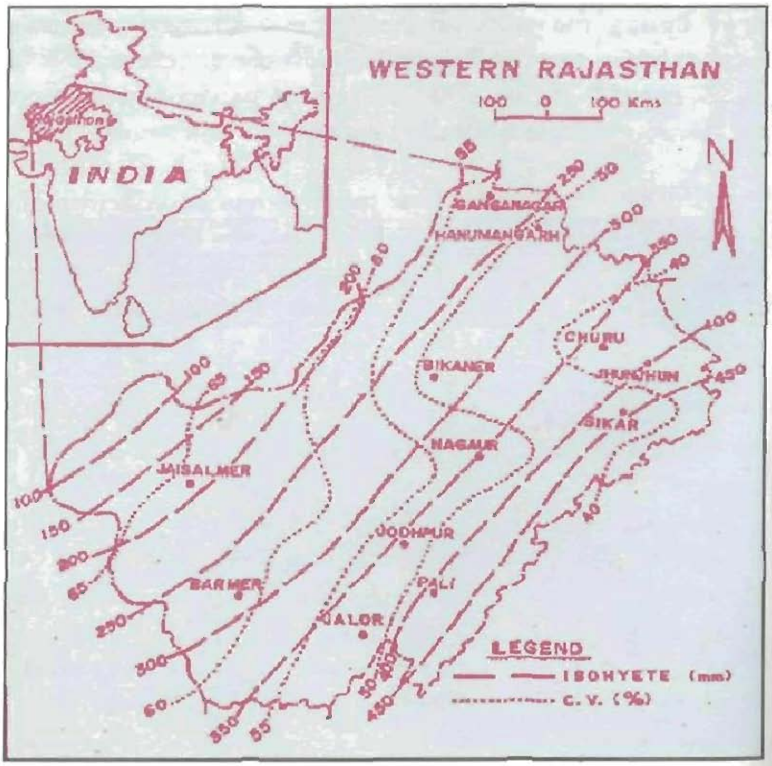


Fig.1 Annual rainfall distribution and coefficient of variation in western Rajasthan (1901-2004)

2. CONCEPT AND DEFINITIONS

Drought has different connotations and meaning to different people depending upon its perception. Drought is defined as 'prolonged dry weather', in a meteorological term a rainfall deficit expressed on a long-term basis. Drought is generally acknowledged as a normal feature of any climate associated with scarcity of water. It is recognized as one of the natural calamities though not quick in onset like floods, earth quacks, typhoons Katrina and Rita hurricane. Drought is considered by many to be the most complex, but least understood of all natural hazards such as flood, tropical cyclones and earthquake (Hangman 1984) affecting more people. Drought may creep at any time, attain many dimensions of severity and last indefinitely. The impact of drought often accumulates slowly and may linger on for years after termination of the event. From agriculturists point of view, drought can be regarded as the condition of insufficient water availability to meet the requirements of plants, animals and human being of the region. It may occur in high as well as in low rainfall areas. Operational definitions are formulated in terms of drought indices, which help developing drought policies, monitoring systems, mitigation strategies and preparedness plans.

3. CLASSIFICATION OF DROUGHTS

Droughts are classified into four major categories.

*(i) **Meteorological drought*** : India Meteorological Department (IMD) defines drought as a situation when the seasonal rainfall over the area is less than 75% of its long-term average. It is further classified as "moderate drought", if the rainfall deficit is between 26 and 50% and "severe drought" when it exceeds 50%. Meteorological drought can be local, regional or on an extensive scale, varying in extent from a few clusters of districts to several meteorological sub-divisions. In temporal scale, a drought can last for a few weeks or longer in the season or succession in a row.

*(ii) **Hydrological drought*** : Prolonged meteorological drought can result in hydrological drought with marked depletion of surface water and consequent drying up of reservoirs, lakes, decline in flow of streams and rivers as also fall in ground water table.

*(iii) **Agricultural drought*** : An agricultural drought occurs when soil moisture and rainfall are inadequate during the growing season to support a healthy crop growth till maturity causing extreme crop stress and drastic reduction in yields.

*(iv) **Socio-economic drought*** : It is a situation, where water shortage ultimately adversely affects the economy of the region. It combines the impact of meteorological, hydrological and agricultural droughts on society, especially in terms of supply and demand of commodities and purchasing power of the people. Severe societal drought may even lead to mass migration in search of food, fodder, water and work, leading to famine, death and social unrest. The worst hit sections of the society during drought are the landless people and people below poverty line. In an agriculture dependent country like India, once the agricultural production declines due to drought, it sets in a chain reaction leading to lower availability of commodities, lower purchasing power and lower economic growth down the poverty spiral, hunger and survival of poor people.

Agricultural drought in dry land regions of India :

Drought has multi-facets of implications in dry farming areas of the country expressed as shortages in food and fodder production and drinking water etc. leading to migration of livestock and decline in animal population, degradation of natural resources, scarcity of seeds for coping in subsequent years. Increase in prices of essential commodities, distress sale of cattle, rural unemployment, malnutrition, health hazards, and depletion of assets at the farmers' level are quite apparent during drought years. There are several kinds of agricultural droughts.

Permanent drought : when drought is a recurring phenomena and a permanent feature a situation common in arid regions. Even the drought-resistant crops are subjected to moisture stress hence alternate land use systems have to be introduced in these regions for sustainable agriculture.

Early season drought : It is due to delayed monsoon, which alters optimum time of sowing, growing season of crops, incidence of insect, pest and diseases and crop productivity.

Mid-season drought : It is caused by breaks in the southwest monsoon during crop growing season. Drought during vegetative phase of a crop results in stunted growth, low leaf area development, and even reduced plant population. It can be characterized by leaf area index vs. water use of the crop under moisture stress.

Late season or terminal drought : Early cessation of rainy season causes terminal drought at reproductive stage leading to hastening crop development and forced maturity.

Apparent drought : It is due to mismatching of the cropping patterns with rainfall distribution and moisture availability. Situations of rainfall in a region may be adequate for one crop but not for others is a common phenomenon.

Contingent drought : It is encountered due to irregularity of rainfall in any definite season.

Invisible drought : This type of drought occurs even in humid regions when rains do not supply enough water to counteract water loss by evapotranspi-ration of humid region vegetation.

4. CAUSES OF DROUGHT OVER INDIA

Drought is a regional manifestation of a general climatic fluctuations associated with the abnormal atmospheric circulation patterns caused by extra-terrestrial or terrestrial factors.

(a) In extraterrestrial forces, there is a 11-year cycle in the variation of annual mean sunspot number, but evidence of such a cycle in the energy output of the sun are lacking. If such cycle exists, the atmospheric circulation would be in a state of constant re-adjustment in accordance with the greater or lesser amount of solar energy reaching the earth causing drought first in one region then in the another.

(b) Terrestrial factors pertain to changes on the earth and following attributes lead to large-scale drought.

(i) ***Volcanic activity*** : Injection of large amounts of ash and dust into the atmosphere by violent volcanic activity may alter the earth's radiation balance and, thereby, create compensating circulation adjustments, which includes climatic fluctuations.

(ii) ***Composition of atmosphere*** : Water vapour, carbon dioxide and ozone would modify the heat balance of the earth and in-turn produce fluctuations in large-scale circulation pattern resulting in drought. The timing, intensity and frequency of meteorological extremes such as drought may be increased and influenced by the enhanced concentration of atmospheric green house gases, such as CO_2, methane and nitrous oxide resulting into global warming (Shukla, 1991 and 1998).

(iii) ***Interaction in Earth-Ocean-Atmosphere complex*** : The enormous heat-storage capacity of the ocean and energy exchanges which take place between the atmosphere and the ocean, make air-sea interaction likely cause of climate fluctuations. The biggest natural climate fluctuations occurring globally on time scales of a few years are the Southern Oscillation and associated El Nino phenomenon (ENSO). Major ENSO episodes lead to massive displacement of rainfall regions of the tropics, causing drought or torrential rains. ENSO has an irregular period, but normally occurs once in every 2 to 7 years. ENSO shows strong link with droughts over India, Indonesia, Australia and torrential rains over coastal areas of Ecuador and northern Peru.

The monsoon rains over the Indian sub-continent is a global phenomena associated with large-scale hemispherical movement of air masses. Therefore, identification of the major atmospheric phenomenon that influence the monsoons over Indian sub-continent is essential in drought forecasting. Sea-surface temperature anomaly around the Indian sub-continent in relation to atmospheric circulation and largescale pressure oscillation in atmosphere over southern Pacific Ocean are of great significance. The *El Nino* has profound influence on the monsoon activity over Indian sub-continent. The Southern Oscillation Index (SOI) is one important parameter amongst eight to ten parameters used by IMD for long-range forecasting. The study of Indian summer monsoon over the country by IMD showed that all the drought years are *El Nino* years, whereas, all the *El Nino* years are not drought years indicating that some other factors influence the monsoon over the Indian sub-continent. The winter circulation over the sub-continent, occurrence of western disturbances late in the season, strengthening of heat low over NW India in summer and shifts in zonal cells over India are some of the important parameters that influence monsoon system over the country. The sea-surface temperature anomaly in the monsoon path is more important in predicting the monsoon rather the pressure difference at far off places in the globe. Therefore, successful prediction of monsoon over different parts of the country will help in forewarning the occurrence of droughts.

The immediate cause of drought over *Thar* desert and adjoining area of western Rajasthan is the predominant sinking motion of air (subsidence) that results in compressional warming or high pressure, which inhibits cloud formation and results in less precipitation. Regions under the influence of semi-permanent high-pressure during all or major portion of the year are usually deserts, such as Sahara and Kalahari deserts of Africa and Gobi desert of Asia. Even the Indian *Thar* desert falls under the sub-tropical high-pressure belt causing subsidence zone (Rathore 2002). The influence of climatic variability is high in arid ecosystem, any deviation persists over a longer duration bound to trigger the process of desertification/dust storm activity or wind erosion (Narain *et al.*, 2000 and 2001).

Increased deforestation, over grazing of pasture land, indiscriminate mining and unplanned urbanization resulting in silting of water bodies, abuse of traditional water resources further aggravates the drought situation.

5. DROUGHT PREDICTION IN INDIA

Advanced forecasts of the occurrence of drought (time, duration and intensity or severity) is highly variable, but forms crucial for planning, proofing and implement mitigation programmes. Drought prediction is synonymous with the prediction of monsoon rains as 85% of the annual rainfall in India is associated with the southwest monsoon. Several postulations have been advanced by climatologists/ astrologers for prediction of monsoon with no definite conclusions.

Gowarikar *et al.*, (1989) suggested a 16-parameter empirical model, being used by the IMD for annual forecast of monsoon rains for India as one unit, later giving for northwest India, northeast India and the peninsula divisions. Over past 25 years, the key parameter found to provide reasonably good estimate over different parts of the world is the El Nino phenomenon, which represents abnormal warming of sea surface over equatorial eastern Pacific off Peru-Chile coast. IMD studies (Mooley and Parthasarthy, 1983) confirm by and large about 70% of the pacific warming be associated with sub-normal rainfall or the drought though one to one tally between monsoon rainfall and the El-Nino does not exist Drought years of 1965, 1972, 1974, 1982 and 1987 can be cited as notable example of former and that the drought of 1979 of the later. There has been number of cases when the rainfall over India was above normal though El- Nino phenomenon was prevailing like 1976 and 1997.

Methods of predicting rainfall or drought based on trends of weather are classified as: (i) Statistical- A climatic variable is auto predictable from the knowledge of its own past history (ii) Correlation- A climatic variable is statistically correlated with one or more environmental variables (iii) Numerical method integrates the basic equation of motion and thermodynamics of the atmosphere.

5.1 Meteorological factors associated with incidence of monsoon drought :

Large number of planetary and regional factors associated with the prediction of rainfall and weather make the short and long term prediction a difficult task.

(a) ***Planetary factors:*** (i) Negative phase of the Southern Oscillation and the negative Southern Oscillation Index (SOI). (ii) Warm phase of the El-Nino and associated sea surface temperature (SST) anomaly in the equatorial-central Pacific Ocean. (iii) Excessive Eurasian snow-cover in preceding winters and spring seasons (iv) Zonal wind anomalies in the lower and middle stratospheric levels

(b). ***Regional Factors*** : (v). A positive anomaly in the surface pressure over Mumbai in preceding winters and pre-monsoon season (vi) A negative anomaly 500 hpa level sub-tropical ridge position over India (75^{0}E) in April. (vii) Below normal surface temperatures over central India and east coast of India in the preceding pre-monsoon season (viii) A

negative SST anomaly in the preceding pre-monsoon season over the Arabian sea (ix) The excessive presence of Himalayan snow-cover in the preceding winters and pre-monsoon seasons. (x) The southward meridional flow anomaly in the middle and upper troposphere along 60°-70°E during the preceding pre-monsoon seasons. (xi) Northward position of the monsoon trough over India and the number of break-monsoon days over India during the monsoon season. (xii) Less than normal formation of monsoon low and less than normal number of monsoon low days over India during the monsoon season. (xiii) Weaker than normal cross-equatorial monsoon flow over the western Arabian sea during the monsoon season. (xiv) Weaker than normal tropical, easterly jet stream over south India during the monsoon season. (xv) Southward of the normal position of the Tibetan high pressure in the upper troposphere during the monsoon season. (xvi) More northward movement of typhoons in the western Pacific during the monsoon season. (xvii) Longer than normal period of the low frequency (30-40 days) oscillation in the lower troposphere during the monsoon season.

5.2 Predicting drought and long range forecast of SW monsoon :

Long-term prediction of monsoon rainfall is important. Though, the IMD has been able to predict all India southwest monsoon rainfall successfully for 14 years using 16-Parameter Model, but the long-range forecast failed in the year 2002, which witnessed worst drought in the country. Studies on the applicability of all India forecast of summer monsoon in different parts of India brought out that forecast of deficit rainfall is not reliable in any part of India other than the northwestern parts. Therefore, prediction of drought over smaller regions is not yet feasible. Hence, probability of droughts of various duration and intensity based on long-term records is the option for assessing drought vulnerability of different regions, which can be used for land use planning and appropriate management practices that can minimize the impact of drought in the event of its occurrence. New operational Long Range Forecast models for southwest monsoon were introduced by IMD from 2003 and are still being continued.

Statistical models for monsoon prediction : Statistical models are based upon correlations of the monsoon rainfall with certain antecedent atmospheric, oceanic and land parameters. These correlations can never be 100% accurate. These may in fact do change with time and slowly loose their significance. A critical re-evaluation of the existing 16-Parameter Model by IMD revealed that correlations of 10 parameters had rapidly declined in recent years. A new set of 10 stable parameters consisting of these 4 new parameters and 6 out of the earlier 16 parameters have been identified by IMD.

Of these 10 parameters, 8 need data only up to March and 2 need data up to June. IMD has developed two new power regression models, one using 8 parameters up to March and another using the full set of 10 parameters up to June. For both these models, data set of 38 years (1958-1995) were used for model development and data for 7 years (1996-2002) for verification. The new 8-Parameter with ± 5% error and 10-Parameter Power Regression Model with ±4% error have shown a superior performance compared to the original 16-Parameter Model.

IMD has also developed two new peripheral models, which will help in forecast with a higher degree of confidence. A Probabilistic Model using a statistical discriminant analysis technique applied to the same 8 parameters will give the probability of monsoon rainfall for the country in five categories viz., Drought (less than 90% of long period average), Below normal (90% to 97%), Near normal (98 to 102%), Above normal (103 to 110%) and Excess rainfall (more than 110%). This model has proved correct in 8 out of 9 drought years and used by IMD in place of 16-Parameter Model.

Rainfall for the month of July is most critical for agricultural operations and also difficult to predict. Since 1999, IMD has been issuing forecasts for the monsoon rainfall over 3 broad homogenous regions of India (NW India including western Rajasthan, NE India and Peninsular India). Using these new models, it has now become possible for IMD to issue the long range forecast for the southwest monsoon season rainfall for the country as a whole on April 16 which was being issued previously on May 25.

IMD's operational Long Range Forecast for 2005 southwest monsoon was that the rainfall for the country as a whole was likely to be 98% of the long period average (LPA) with a model error of 5 %. The probabilistic model suggested a high (75%) probability for the 2005 southwest monsoon rainfall over the country as a whole to be near normal and above. The forecast for July rainfall for the country as a whole is likely to be 97% of its LPA with a model error of 9 %. Further, rainfall for 2005 southwest monsoon was likely to be 97% of its LPA over northwest India, 95% over northeast India, 102% over central India and 97% over south peninsula, all with a model error of 8 %.

El Nino condition during 2005 : Over the Pacific ocean, sea surface temperatures (SST) have remained above normal but below the El Nino thresholds. Trade winds over the Pacific ocean were stronger than normal. Southern oscillation index (SOI) showed substantial increase and it became positive.

New initiatives : Under a collaborative research programme with the Indian Institute of Science, Bangalore, a dynamical prediction system was installed at the National Climate Centre, Pune. The seasonal forecast model of Experimental Climate Prediction Center (ECPC), Scripps Institution of Oceanography, USA was adopted. The predictions based on sea surface temperature data of May suggested above normal rainfall over the country as a whole during 2005 monsoon.

5.3 Drought prediction and medium range weather forecast :

Precipitation and temperature are two fundamental parameters for any prediction. The Tropical Ocean Global Atmosphere (TOGA) project suggest that it is possible to predict certain climatic conditions associated with ENSO events more than a year in advance. For those regions whose climate is greatly influenced by ENSO events, TOGA project results may help a reliable meteorological forecasts. In the tropics, empirical relationships exist between precipitation and ENSO events, but few such relationships have been confirmed to 30°N latitude.

The National Centre for Medium Range Weather Forecasting (NCMRWF) runs two global septral models namely., T-80 and T-170 and two meso-scale models namely, MM5 and Eta on operational basis. The global models are run for 7 days, whereas, meso-scale models are run up to 72 hours. The Centre has good computing resources viz., Cray XIE and Cray SVI which are high end computers. In addition, it also has Dec-Alpha, Param Padma (Indigenous high and parallel processing computer system) and Origin 200 (Single CPU and Parallel) systems. Medium range weather forecasts issued by NCMRWF during two monsoon seasons are found to be reasonably correct and useful. The disaster managers have particularly found these predictions useful during two recent droughts of 2002 and 2004. NCMRWF is also preparing extended range weather prediction for each month on an experimental basis.

NCMRWF issues routine weekly forecast in the form of a bulletin to Ministry of Agriculture through Crop Weather Watch Group meeting. The Centre also issues special All India Agro-advisories for farmers to a special television Channel for Farmers namely, Kisan Channel on every Tuesday and Friday taking the expert support from all the 127 Agrometeorological Advisory Units (AAS) placed in different organizations including CAZRI, Jodhpur in western Rajasthan. Monsoon-2004 and onward, a detailed all India Agro-Advisories containing specific information on current monsoon situation, medium range weather forecast, assessment of rainfall prospects in different meteorological subdivisions including western Rajasthan based on medium range forecast and prevailing rainfall scenario, are prepared on every Sunday and issued to several user organizations like Ministry of Agriculture, Ministry of Rural Development, Ministry of Home Affairs, India Meteorological Department, etc.

5.4 Extended range prediction (ERP) system of NCMRWF and drought :

The NCMRWF global model at T80L18 resolution has been modified to update sea surface temperatures (SSTs) during model integration. The model has been integrated for 45 days, starting from observed initial conditions (with data for the middle of a month) and with observed SSTs (with different initial conditions and SST for 15 years) and model output for last 30 days to be predicted for next month. For example, to prepare the climate for June, the model has been integrated for 45 days starting with initial data for May 16 of several years with SSTs of 1986 to 2000. The results for last 30 days correspond to the model climate for June. The model climate thus prepared has taken into account the inter-annual variability of SSTs from 1986 to 2000. Observed SSTs used for this simulation were monthly NCEP (National Centre for Environmental Prediction) analyzed SST (Reynolds and Smith, 1994).

The model climatology for rainfall has been compared with the Global Precipitation for the Corresponding Period (GPCP Version-2 Combined Precipitation Data Set). The model rainfall climate is reasonably good and all the essential features of rainfall pattern over the Indian region are simulated well by the model. It is noticed that the circulation features obtained from the model simulations (climate) are reasonably good, the model simulates a realistic climate, and can be used for extended range prediction.

6. INDICES USED FOR DROUGHT MONITORING

When drought is defined in relation to precipitation or agriculture, the limits of the definition, though arbitrary, are important to scientists, administrators, planners, and policy makers. There are two primary uses for an index of drought, namely for evaluating the drought hazard over a sizable area and for periodic assessments of the current extent and severity of drought over a region. Drought indices are normally continuous function of rainfall and temperature, river discharge or other measurable variables. Rainfall data are widely used to calculate drought indices, because long-term rainfall records are often available. Rainfall data alone may not reflect the spectrum of drought-related conditions, but they can serve as a pragmatic solution in data-poor regions.

Palmer drought severity index (PDSI) : Palmer (1965) developed a soil moisture algorithm (a model), which uses precipitation, temperature data and local available water content (AWC) of the soil, the concept of CAFEC (Climatically Appropriate For Existing Conditions) rainfall, which was the normal value for the established human activities of that place. This parameter can be obtained based on water balance technique. The anomaly (PDSI) which is difference between the actual and CAFEC precipitation is used as a drought indicator. PDSI varies between -6.0 referring to extreme drought conditions and +6.0 indicating adequate moisture conditions.

Index value	Class for drought
- 1.00 to 1.99	Mild drought
- 2.00 to 2.99	Moderate drought
- 3.00 to - 3.99	Severe drought
< - 4.00	Extreme drought

Standardized precipitation index (SPI) : The SPI was defined by Komuscu (1999) and Mc Kee *et al.* (1995) with following classes

$$\mathrm{SPI} = \frac{X - \overline{X}}{\sigma}$$

Where X = Precipitation for the station.

$\overline{X}$ = Mean precipitation

σ = Standardized deviation.

SPI	Drought class
Less than 2.0	Extreme drought
-1.50 to -1.99	Severe drought
-1.0 to 1.49	Moderate drought
-0.99 to 0.0	Mild drought

This method is widely used and becoming popular in some parts of Europe, South America and other continents for drought identification and its severity.

Climatic aridity index **:** The UNESCO Conference on Desertification (1977) defined a climatic aridity index based on precipitation (P) and potential evapotranspiration (PET).

P/PET	Climatic zone
<0.03	Hyper arid zone
0.03-0.20	Arid zone
0.20-0.50	Semi arid zone
0.50-0.75	Sub humid zone

Moisture availability index (MAI) *:* MAI is defined as PD/PET where PD is the 75% probability precipitation based on analysis of long-term precipitation records and PET is the estimated potential evapotranspiration (Hargreaves, 1971).

Moisture availability index	Area classification
0.00-0.33	Very deficit
0.34-0.67	Moderately deficit
0.68-1.00	Somewhat deficit
1.00-1.33	Adequate moisture
> 1.34	Excessive moisture

Cocheme and Franquin method : The matching of duration of crop growth cycle to that of the water availability period is important in agricultural planning. Duration of periods during which rainfall (P) exceeds selected levels of evaporation (PET) is used an index of agricultural potential. Accordingly, in the studies of Cocheme and Franquin (1967) for semi-arid areas south of Sahara in west Africa, the following limits have been chosen:

P > PET	Humid period
P PET/2	Moist period
PET/2 > P PET/4	Moderately dry period
PET/4> P PET/10	Dry period
P < PET/10	Very dry period

Identifying drought and its magnitude in India **:** IMD uses two measures- the first describes rainfall conditions (departures) while the second represents meteorological drought severity.

Excess	+ 20% or more of the normal rainfall
Normal	+19% to 19% of the normal rainfall
Deficient	-20% to 59% of the normal rainfall
Scanty	-60% or less of the normal rainfall

The precipitation is expressed on a weekly and monthly basis.

Severity of meteorological drought : IMD describes meteorological drought from deficient rainfall areas on weekly/monthly basis.

Departure of annual rainfall from normal (%)	Meteorological drought condition
0 or above	No drought
0 to 25	Mild drought
-26 to 50	Moderate drought
-50 or more	Severe drought

This is most accepted measure of drought in India because of its simplicity. When more than 50% of the area in the country is under moderate or severe drought, the country is described as severely affected by drought; and when the affected area is 26-50% of the country, it is described as an incidence of moderate drought.

Aridity index and severity of meteorological drought : Subrahmanyam (1964) developed a concept of drought classification with the help of aridity index (I_a). The aridity index is the percentage ratio of annual water deficit to annual water need or annual potential evapotranspiration.

$$\text{Aridity Index } (I_a) = \frac{\text{Water deficit}}{\text{Water need}}$$

$$= \frac{\text{Actual evapotranspiration Potential evapotranspiration}}{\text{Potential evapotranspiration}}$$

For computing the water deficit, the climatic water balance using the book-keeping procedure of Thornthwaite and Mather (1955) had been used. The climatic drought classification is given below:

Departure of I_a from normal	Meteorological drought severity
0 or less	No drought
0 to $<\frac{1}{2}\sigma$	Moderate drought
$\frac{1}{2}\sigma$ to $< 1\sigma$	Large drought
σ to 1.5σ	Severe drought
$> 1.5\sigma$	Disastrous

Where σ is the standard deviation

Aridity anomaly (I_a) as an index for demarcation of agricultural drought **:** IMD monitors agricultural drought from water balance technique. The monitoring is done during *kharif* for the country as a whole and during *rabi* for those areas which receives rainfall during post-monsoon. The departure of I_a from normal is expressed as a percentage. These values are then plotted on a map and analyzed.

Drought Category	*Anomaly Value*
Mild drought	up to 25%
Moderate drought	26-50%
Severe drought	more than 50%

Moisture adequacy index (MAI) as a measure of agricultural drought **:** CAZRI developed a technique for quantification of agricultural drought by taking MAI during different phonological stages of the crop (Sastri *et al.*, 1981: Ramana Rao *et al.*, 1981). The classification is as follows:

AE/PE (%) during different phenophases	Drought intensity	Phenophasewise Code		
		Seedling (S)	Vegetative (V)	Reproductive (R)
76 to 100	No drought	S_0	V_0	R_0
51 to 75	Mild Drought	S_1	V_1	R_1
26 to 50	Moderate drought	S_2	V_2	R_2
25 or less	Severe drought	S_3	V_3	R_3

Depending upon the values of AE/PE during different phenophases, the drought code varies as S_0, V_1, R_2, S_1, V_2, R_3, etc is a generalized classification with no specification of any crop. At this stage, the crop factor can be introduced and the drought code in three syllables can be unified into a single drought code applicable to one particular crop for a specific region. For example, the average growing season of pearl millet crop is about 14 weeks. The duration of different phenophase of pearl millet crop in this region will be seedling (S) 3 weeks, vegetative (V) 4 weeks, reproductive (R) 4 weeks, maturity (M) 3 weeks. *As the water stress during maturity stage does not have much influence* compared to water stress during other three stages, the maturity stage is eliminated and the three syllable agricultural drought code can be unified into a single code:

1. The agricultural drought situation for pearl millet crop is severe (A_3) when both vegetative (V) *and reproductive (R) stage experience severe drought with any combination of* S_0, S_1 S_2 *or* S_3, *as the water requirement* during seedling stage is usually less. In these circumstances even the natural grasses too suffer from drought conditions.

2. The agricultural drought situation for pearl millet is moderate (A_2) when vegetative (V) and *reproductive (R) stage experience one moderate and one severe drought each with any* combination of S_0, S_1 S_2 or S_3. During this situation short duration crops also suffer from drought.

3. The pearl millet crop escapes drought situation (A_0) even when mild drought prevails in one or *two growth stages with no drought condition in the third stage.*

4. The rest of the situation result in mild drought (A_1) for pearl millet and short duration crop like pulses escape from drought in these circumstances.

Some more distinct categories of drought effecting crop production in dry lands were clearly distinguished (Ramana Rao, 1992) as under in India depending upon the time of occurrence of drought and general climatic conditions of the region.

i. Permanent drought

ii. Early season drought

iii. Mid season drought

iv. Late season or terminal drought

v. Apparent drought

vi. Contingent drought

vii. Invisible drought

7. AN OVERVIEW OF DROUGHT MONITORING AND EARLY WARNING SYSTEMS IN INDIA

Monitoring rainfall is necessary to provide early warning of drought with objective to minimize the impact of drought on human, livestock and natural resources of the region. A strong drought regional information network for sub-continent including the regions having bearing on Indian climate should be established to provide reliable data and interpretation on all aspects of previous and future droughts including time of occurrence, location, intensity, duration and impacts in different sectors. This is an important and challenging task to give an early warning for drought so that the information can be used by planners, emergency managers, policy and decision makers, and others to help drought preparedness and implement programmes and policies that will help to reduce the risk associated with drought.

A comprehensive drought monitoring system would include the collection of meteorological data (e.g., temperature and precipitation), streamflow, reservoir and ground water levels, soil moisture, snow peak and remotely sensed data from satellites, analysis of data, data product in forecasts of agricultural and hydrological drought and communication to decision makers and other users. Monitoring and early warning techniques includes the use of indices to track current drought conditions and to view them in a historical perspective. Inter-disciplinary cooperation and a collaborative effort with policy makers at all levels is required. Participation of a few National and International organizations involved in monitoring and issuing early warning is required to be ensured to strengthening early warning for Indian sub-continent.

- World Meteorological Organization's World Weather Watch (WWW)
- World Climate Program
- Food and Agriculture Organization's Global Information and Early Warning System on Food and Agriculture (FAO/GIEWS)
- USAID's Famine Early Warning System (FEWS)
- South African Development Community (SADC) regional and national early warning system in South Africa.
- African Centre for Meteorological Applications Development (ACMAD)
- National Agricultural Drought Assessment and monitoring system (NADAMS)

7.1 Drought studies by India Meteorological Department (IMD) :

Realizing the importance of weather in agriculture, IMD started the Agricultural Meteorology Division in August 1932 at Pune to lay special attention on the problems connected with the application of meteorology for agriculture in collaboration with the central and state agricultural departments. It has developed a close network of agrometeorological observatories and taken up research problems like water requirement of crops, pests and diseases, rainfall probabilities in dry farming tracts, crop-weather relationship and application of remote sensing techniques in agricultural meteorology.

Weather services for the farmers in India were started by IMD in 1977 and since then Farmers' Weather Bulletins (FWB) are issued regularly from 22 AAS Units located at State/Regional Meteorological Centers. Short range forecasts valid for 24 to 48 hours and then extended to the following 2 to 3 days are used extensively to provide this advice. These bulletins 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 and also daily forecasts of weather. These bulletins are broadcasted through All India Radio (AIR) stations and Doordarshan Kendras as special programs and disseminated through newspapers in different languages for the benefit of farmers.

The Drought Research Unit was set up at IMD in Pune in 1967, which identifies meteorological drought (moderate or severe) for subdivisions and also drought year for the country based on rainfall analysis. Based on past rainfall records since 1875, IMD has identified meteorological droughts (moderate or severe) over 35 subdivisions of the country. Similarly, drought-prone areas and the probability of occurrence of drought were also identified. Suitable sowing dates for Karnataka, Rajasthan, Gujarat, Madhya Pradesh, Uttar Pradesh, and Maharashtra, based on the climatology of daily rainfall data, soil type, and cropping pattern have already been established by IMD. By superimposing results of the analysis on the soil map, areas experiencing different degrees of droughts have been delineated.

IMD also monitors agricultural drought (incidence, spread, intensification, and recession) at fortnightly intervals during *kharif* and *rabi* using aridity anomaly index (AI) of Thornthwaite for 250 well distributed stations over the country.

$$AI = \frac{PET-AET}{PET} \times 100$$

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

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

Aridity anomaly maps indicate crop stress conditions and are used for early warning of drought. The aridity anomaly maps, however, do not indicate arid regions; on the contrary, they give an indication of the moisture stress/drought in any region on the time scale of one or two weeks. Bi-weekly aridity anomaly reports are prepared for the country as a whole during the southwest monsoon season and over 5 sub-divisions (Coastal Andhra Pradesh, Rayalseema, South Interior Karnataka, Tamilnadu, and Pondichery and Kerala) during the northeast monsoon season and these reports are circulated to various users.

The Drought Research Unit also developed crop yield forecast models based on a long series of past crop and meteorological data using the multiple regression techniques and gives pre-harvest crop yield forecasts for 15 states comprising 26 meteorological sub-divisions for *kharif* (rice) and 12 states comprising 16 meteorological sub-divisions for *rabi* (wheat).

7.2 Drought studies by National Remote Sensing Agency (NRSA) :

By suitably integrating surface and satellite remote sensing data, a three-dimensional monitoring systems can be established to monitor drought, precipitation, surface water, soil moisture, crop water requirement, ground water, irrigation and drainage. Drought indices can also be calculated using the data collected from these networks, which when fed to organized delivery system can deliver early warning for effective disaster mitigation. Short breaks in the monsoon for 5 to 10 days, may not be of serious concern, but prolonged breaks of more than 2 weeks can create in crop water stress leading to low productivity of crops. These breaks in monsoon if predicted in advance, the impact of agricultural drought can be minimized. Early warning of climatic parameters to know crop growth, incidence of epidemics etc, trigger responses from government planners and policy makers for an advance action to face a challenge and pre-empt its impact.

Rainfall estimation : Satellite estimation of rainfall is not likely to be better than rainfall measured through conventional raingauges, but is useful to fill in spatial and temporal gaps in ground reports. Nageswara Rao and Rao (1984) demonstrated an approach for preparing an indicative drought map based on NOAA AVHRR derived rainfall estimation at the seedling stage of crop growth.

Soil moisture : Microwave sensors are useful for estimation of surface soil moisture upto 10 cm, as these sensors have a high spatial resolution and can be obtained even at satellite altitudes.

Vegetation status : Satellite sensors are capable of monitoring many physiological changes through spectral radiance measurements and interpreting this information into vegetation indices affected by moisture stress. The visible and near infrared (IR) bands on the satellite multi-spectral sensors allow monitoring of the greenness of vegetation. Stressed vegetation is less reflective in the near IR channel than non-stressed vegetation and also absorbs less energy in the visible band. Thus, the discrimination between moisture stressed and normal crops in these wavelengths is ideal to measure drought by using Normalized Difference Vegetation Index (NDVI).

$$\text{NDVI} = \frac{\text{NIR} - \text{VIS}}{\text{NIR} + \text{VIS}}$$

Where, NIR and VIS are measured radiation in near infrared and visible (chlorophyll absorption) bands.

The NDVI varies with the magnitude of green foliage (green leaf area index, green biomass, or percentage green foliage ground cover) brought by phenological changes or environmental stresses. Moisture stress in vegetation, resulting from prolonged rainfall deficiency is reflected by lower NDVI values.

Remote sensing and PD54 index of vegetation cover : For assessing the extent and causes of degradation in arid rangelands of Shergarh region, Margaret Fridel and Suresh Kumar (2004) developed PD54 index of vegetation cover from satellite data to search for systematic patterns in vegetation cover change related to land use. In grazing lands, cover tends to be higher where grazing and tree cutting activities are less intensive. Cover levels also increase after rainfall and so, after heavy rain. A study was conducted at Shergarh village to illustrate the growth response on a resilient landscape, following monsoon rains. The areas with responses above and below the average response for a landscape were identified by them and the patterns were related to land use effects. To establish a suitable index of vegetation cover, satellite images (Landsat TM, IRS 1 C/1 D/P6 with LISS 3 sensor) were acquired prior to, and following, a minimum of three contrasting wet seasons. All images were geometrically registered and radiometrically calibrated before calculating an index of vegetation cover - PD54. This is a perpendicular vegetation index based on the green and red spectral bandwidths. Environmental, animal production and socio-economic data were required to interpret and verify the analyses made from satellite data and finally combining this data into a GIS to help interpret and display the information.

The index was verified by collecting the spectral reflectances of different soil and vegetation features in the visible and near-infrared wavelengths using a spectrometer. Having confirmed that the PD54 data space satisfactorily describes the measured reflectances of dominant land-surface features of the region, ground-based measures of vegetation cover obtained with the wheel point apparatus were compared with the PD54 index values of corresponding pixels. The PD54 index estimated vegetation cover reasonably well on the generally bright sandy soils of the Shergarh region of the Thar Desert (Margaret Fridel and Suresh Kumar, 2004).

Crop condition assessment : Physiological changes in crop alter the spectral properties of leaf/canopy which are better characterized through the use of spectral Vegetation Indices (VI) in comparison to use of individual spectral bands. Commonly used spectral vegetation indices for crop stress monitoring are :

Ratio Vegetation (RVI) = Near IR/Red

$$\text{Normalized Difference Vegetation Index (NDVI)} = \frac{\text{Near IR-Red}}{\text{Near IR+Red}}$$

Greenness Vegetation Index (GVI)=(Weighted sum of reflectance in Near IR bands)- (Weighted sum of reflectance in visible bands)

Where, red and near IR refer to radiance in red and near IR spectral bands, respectively. Crop condition assessment is done on grid-cell basis using spectral Vegetation Index (VI) (Ajai, 1992). The study area is divided into geographically referenced grid cells (sample, segment) of appropriate size. Vegetation Index (VI) for the pixels of the crop of interest are computed for the selected sample segments and VI statistics are generated. Vegetation Index Number (VIN) is computed for each segment for different dates, using computed VI value for each pixel in the cell (segment). VIN profile is generated and stored in a data base to carryout trend analysis.

Crop stress mainly due to water/nutrients, interfere in the portioning of heat energy fluxes within the crop canopy, result in elevated canopy temperature as compared-to ambient air temperature. This forms the basis of remote sensing of emitted thermal IR (8-14 urn) from crop canopy (canopy surface temperature) in assessing crop stress in Stress Degree Day (SDD).

$$\text{Stress Degree Day (SDD)} = (Tc-Ta)$$

Where, Tc and Ta are canopy and ambient air temperatures, respectively. SDD's were monitored by Singh *et al.,* (1998) in rainfed and irrigated pearl millet field to relate the SDD with the crop growth and yield.

AVHRR Thermal data derived SDSI (Satellite Derived Stress Index) is useful for regional crop condition and drought assessment.

$$SDSI = \frac{DT-AT}{DT-NT}$$

where, DT and NT are satellite acquired day and night time temperature, respectively; AT is day time maximum temperature.

Geographical Information System (GIS) can be used in drought monitoring which is a computer-based system for collection, compilation, storage, analysis and retrieval of spatial (map) data like rainfall, crop water requirement, physiography, soil type, soil fertility, depth-to-ground water table, slope of the area, date of sowing and application of irrigation. These maps can be combined (integrated) and analyzed using GIS to find the potentiality of the area for a particular crop and expected crop yield.

Since 1989, National Agricultural Drought Assessment and Monitoring System (NADAMS) has been providing bi-weekly drought bulletins for *kharif* season covering 246 districts in India. These bulletins, which describe prevalence, relative severity level, and persistence through the season at the district level. The drought assessment is based on a comparative evaluation of satellite observed green vegetation cover (both area and greenness) of a district in any specific time period to cover in similar periods in the previous year. The drought interpretation takes into account rainfall and aridity anomaly trends. This nationwide early warning services has been found to be useful for providing early assessment of drought conditions.

7.3 Drought studies by National Centre for Medium Range Weather Forecasting (NCMRWF) :

Since 1988, NCMRWF is 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) to develop weather-based agroadvisory services for the farming community, and (3) to promote and coordinate research in related areas of meteorology and agrometeorology.

NCMRWF, in collaboration with the India Meteorological Department, Indian Council of Agricultural Research, and state agricultural universities, is providing Agrometeorological Advisory Services (AAS) at the scale of agro-climatic zones to the farming community based on location-specific medium range weather forecasts.

To provide numerical weather prediction (NWP) for agrometeorological advisory services (AAS) to farmers, NCMRWF opening agrometeorological field units (AMFU) in each of the 127-

agroclimatic zones of the country. These, AMFUs are located in different Centres of the National Agriculture Research Program (NARP) of ICAR and the SAUs so that research output can be used effectively in formulating the agroadvisories. At present, NCMRWF has established AAS units in more than 107 agroclimatic zones. The remaining zones may be covered in a phased manner. Agrometeorological Advisory Bulletins, with expert advice on crop, soil, and weather are made available to the farming community.

Weather forecast bulletin is disseminated biweekly to AAS units every Tuesday and Friday over a telephone, email and fax. In addition to these bulletins, weather charts are also sent to AAS units. The same communication system is also being used to collect observational data from AAS. Periodic feedback on the success of forecast and advisories is obtained from selected farmers to know how they have adjusted their day-to-day farming operations in response to the advice provided by AAS.

7.4 Agricultural Drought monitoring by Central Arid Zone Research Institute (CAZRI) :

CAZRI is maintaining six agrometeorological observatories spread across the arid Rajasthan at her regional research stations at Jodhpur, Jaisalmer, Chandan, Bikaner, Pali, and Bhopalgarh to collect weather data for drought assessment.

To meet the special requirements for agricultural practices on medium range time scale (i.e. 3 to 10 days), the NCMRWF is providing forecast based on dynamical model out put to meet the requirement for the agricultural community. Under this scheme specialist in dynamical meteorology, agrometeorology, agronomy, plant diseases and pests etc. frame forecast jointly on the scale of cluster of districts and evolve strategies to meet different rainfall situation including drought situation for the benefit of agriculturists. This is being done from 107 centres in India including the CAZRI centre, Jodhpur for arid Rajasthan

Markov Chain probabilities as an aid for drought monitoring:

The Markov Chain probability model (Robertson, 1976) for initial and transitional probabilities of dry and wet spell has been fitted to weekly rainfall (1963-2004) to obtain sequences of dry and wet spells for Jodhpur. Results suggest that pearl millet sown during 27-28th meteorological week (2 to 15 July) has better chances of success as the crop escapes drought during flowering/ milky stage of pearl millet. In arid Kachchh region (1901-1989) occurrence of wet week was found to increase sharply from 25th to 37th standard weeks with highest probability (64.5%) during 29th week (Singh *et al.*, 1991). Longer wet spells are likely only during the beginning of the monsoon period. The analysis was considered a dry week if it receives rainfall less than 10 mm.

8. IMPROVING EARLY WARNING SYSTEMS FOR DROUGHT PREPAREDNESS AND MITIGATION :

Effective drought early warning systems are an integral part of efforts worldwide to improve drought preparedness. An integrated approach preferable based on timely and reliable data for effective drought management policies and plans are required. A few countries have a national drought policy in place. Australia is an exception and progress in South Africa and the United States is also note worthy. It is apparent that other countries are also moving in the direction of a national drought policy. In some instances, sub-national policies were in existence. Comprehensive early warning systems should be the foundation on which national drought policies and plans are built. A national drought policy for India particularly for drought prone area is also required immediately.

Needs and shortcomings of early warning systems :

(i) ***Data networks:*** A wide range of data (i.e., precipitation, temperature, streamflow, ground water and reservoir levels, soil moisture, snow peak) is necessary to adequately monitor climate and water supply status. These data are often not available at the required intensity for accurate assessments. Existing data networks need to be strengthened and data collection needs to be automated by weather stations for accurate assessment.

(ii) ***Data sharing:*** Meteorological and hydrological data are often not widely shared between agencies which restricts early assessment of drought, its use in drought preparedness, mitigation, and response. Sometimes, high cost of data acquisition restricts its free flow for timely assessments and for use in research. Memoranda of understanding between government agencies would facilitate data sharing and use and could bring tremendous societal benefits.

(iii) ***User friendly Early Warning System Products:*** Data and information products produced by early warning systems often are not user friendly. Many products are too complicated and do not provide the type of information needed by users for making decisions. Users are seldom trained on how to apply this information in the decision-making process. User needs should be assessed and products evaluated through permanent feedback mechanisms.

(iv) ***Drought forecast:*** Drought forecasts often do not provide the specific information needed by farmers and others (e.g., the beginning and end of the rainy season, distribution of rainfall within the growing season) to be useful for operational decisions. Greater investments in research to improve the reliability of seasonal forecasts would provide significant economic benefits to society, if these forecasts are expressed in user-friendly terms and users are trained in how these forecasts can be applied to reduce climate risks, risks, it will help combating drought effectively.

(v) ***Drought monitoring tools:*** Tools for detecting the early onset and termination of drought are inadequate effecting the specific mitigation and response actions to over come the drought impact. The Drought Monitor product recently developed in the United States could serve as a model. The Standardized Precipitation Index (SPI) used for drought monitoring in USA needs to be tested and applied in more drought-prone areas. Integrated meteorological, agricultural and hydrological data products are therefore needed on weekly rather than monthly time intervals to accurately evaluate changes in severity and spatial characteristics. Satellite-derived remote sensing data (AVHRR) offer considerable advantages and should be an integral part of drought early warning systems.

(vi) ***Integrated drought/Climate monitoring:*** Integrated approach to climate monitoring should be employed to obtain a comprehensive assessment of the status of climate, its impact on agriculture and water supply in long-term. Too often, drought severity is expressed only in terms of precipitation departures from normal, neglecting information about soil moisture, reservoir and ground water levels, streamflow, snow peak, and vegetation health. Seasonal climate forecasts may also provide valuable information regarding whether conditions are likely to improve or deteriorate in the coming months. Use of multiple climate indices and

parameters provide assortment of tools, each with its own strengths and weaknesses. The experience in the United States with the integrated drought assessment using six different indicators/parameters, including vegetation health, drought severity is potentially a good model for giving a trial in India.

(vii) ***Impact assessment methodology:*** One of the missing links in early warning systems is the connection between climate/drought indices and impacts due to lack of effective impact assessment methodology which needs improvement. Interdisciplinary research including social science on impact assessment could make considerable progress in addressing local needs.

(viii) ***Weak delivery systems:*** Information on drought situation, seasonal forecasts and other products are often not delivered or delivered without regard to its response, thus limiting usefulness. It is critical that delivery systems be improved, location specific, value added using modern technology like internet or website and delivered through electronic and print media, as well as local extension networks to diverse user groups.

(ix) ***Global early warning system:*** A global drought assessment network that relies on one or two key variables like precipitation, vegetation health, would be a valuable tool to provide early warning of areas of potential concern. A National Drought Preparedness Plan (Wilhite *et al., 2000*) should include

- Collection and analysis of drought-related information in a timely and systematic manner.
- Criteria for declaring drought emergencies and triggering various mitigation and response activities.
- An organizational structure and a delivery system that assures information flow between and within different levels of government.
- Defining duties and responsibilities of all agencies with respect to drought.
- Maintenance of a current inventory of mitigation and response programs used in assessing and responding to drought conditions.
- Identification of drought-prone areas and vulnerable economic sectors, individuals, or environments.
- Identification of mitigation actions that can be taken to address vulnerabilities and reduce drought impacts.
- A mechanism to ensure timely and accurate assessment of drought impacts on agriculture, industry, wildlife, tourism and recreation, health and other areas.
- Provision of accurate, timely information to media in print and electronic form (TV, radio, and internet) to keep the public informed of current conditions and response actions.
- A strategy to remove obstacles to the equitable allocation of water during shortages and requirements or incentives to encourage water conservation.
- A set of procedures to continually evaluate and exercise the plan and provisions to periodically revise the plan so that it will stay responsive to the needs of the country.
- A pro-active strategy for drought preparedness as preventive measure will always do better than curative fire-fight when drought has already set in.

9. ANALYSIS OF RAINFALL AND DROUGHT ASSESSMENT

9.1 National level efforts :

Droughts and famines have occurred in India for centuries and have even been mentioned in folklore, however, precise data of these events are not available. Since the establishment of the IMD in 1875, systematic meteorological data generation and its dissemination has made it possible to demarcate areas frequently affected by droughts. A national drought year occurs when less than 75 per cent of the normal rainfall is received. A drought prone area has the probability of a drought more than 20 per cent, while a chronic drought-prone area has greater than 40 per cent. The year 1918 experienced the worst drought of the century witnessed in terms of area affected and rainfall departures (Choudhury *et al.*, 1989, Bhalme *et al.*, 1990). In terms of area affected by droughts, the years 1877, 1899, 1987 and 1972 were in that order for extreme severity drought. During 1877, 1899 and 1918, a large part of the country experienced rainfall departures of less than -60 per cent.

The average seasonal rainfall over the plains of India is widely perceived tool to detect drought and remains the primary factor in determining agricultural production. The principal sources of rain in the Indian sub-continent are the two periodic winds systems known as southwest monsoon (June to September) accounting for 90 percent annual rainfall and the northeast monsoon (October to December) accounting for the rest 10% along the southeast coast. The average annual rainfall of the country is 105 cm with unevenly distribution showing wide variations. The duration of the rainfall varies from 30 to 180 days in different parts of the country. In addition to southwest monsoon, northern India receives some of its rain during the winter while some rainfall in the coastal regions is received from October to December. This large variation in the distribution of precipitation variation across the country creates an array of agroclimatic conditions in combination with different soil types and atmospheric temperatures.

India has been divided into thirty-six meteorological subdivisions that are nearly homogeneous from rainfall point of view. On decadal analysis, number of subdivisions affected by droughts was high during 1871-80, 1891-1900, 1901-10, 1911-20, 1961-70, and 1971-80 (Kulshreshta and Sikka, 1989). They observed that the 1891-1920 and 1961-90 periods witnessed frequent droughts while few droughts occurred during 1930-60. This suggests some kind of low frequency oscillation of the monsoon system on the decadal scale.

Many studies have dealt with monsoon variability and the impact of global- and regional-scale parameters on summer monsoon rainfall. Bhalme and Mooley (1981) prepared a time series of the drought area index defined by the moisture index as the ratio of departure of rainfall from the monthly mean and standard deviation of monthly rainfall. The behaviour 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. Sen and Sinha Ray (1997) have shown a decreasing trend in the area affected by drought in India. Based on the rainfall data of 1875-1999, greatest probability of drought was found in Saurashtra and Kutchch, followed by Gujarat and west Rajasthan. They also studied the effects of El Nino on summer monsoon rainfall of various subdivisions of India.

9.2 Regional efforts for arid western Rajasthan :

Rajasthan state is located in NW India between latitudes approximately 23° N and 30°N longitudes 69° E and 78 ° E. The Aravali mountain range is one of the distinguishing physical features of the state. The state does not have any major river systems. The long term average annual rainfall in western Rajasthan is 330 mm, and 85 per cent of the rainfall (*i.e* 280 mm) is received during southwest monsoon i.e. June to September (Narain and Kar 2005). In west Rajasthan, the variability lies between 35 and 65%. Areas in extreme west Rajasthan (Jaisalmer and Barmer districts), where rainfall is very low (<200 mm) show high coefficient of variation (> 65%), whereas in the eastern region where seasonal rainfall is >400 mm, the coefficient of variation is between 30 and 40 per cent. The vagaries of monsoon causing droughts are perhaps felt more in Rajasthan compared to the other regions, since in a large part of the region, the rainfall is low and the year-to-year variability is high. Analysis of 100 years data (Fig.2) reveals that annual rainfall variability and its long-term trends at Barmer and Nagaur in western Rajasthan, indicated an increase in annual rainfall by about 1.1 mm per year at Nagaur, whereas no such increase is observed at Barmer. As such, there is no evidence of perceptible increase in annual rainfall in arid western Rajasthan.

9.3 Annals of Droughts in Arid Rajasthan

Historical record of droughts and their kind in the region show no definite pattern. Earlier report on drought suggest the major droughts in western Rajasthan between the years 1350 and 1750 were 1362-63, 1648-49, 1659-60, 1747-48 (Sikka, 2004). Archive of severe droughts and famines in Indian arid zone (Narain *et al.,* 2000) reveals fifteen severe droughts (Table 2) in arid region.

Table 2. Severe droughts in the Indian arid zone (1792-1900)

Year	Severe drought
1792	Agricultural, Hydrological, and Meteorological
1804	Agricultural and Meteorological
1812-13	Agricultural, Hydrological, and Meteorological
1833-34	Agricultural, Hydrological, and Meteorological
1838-39	Agricultural and Meteorological
1848-49	Agricultural, Hydrological, and Meteorological
1850-51	Agricultural and Meteorological
1853-54	Agricultural and Meteorological
1868	Agricultural, Hydrological, and Meteorological
1869	Agricultural and Meteorological
1877	Agricultural, Hydrological, and Meteorological
1891-92	Agricultural, Hydrological, and Meteorological
1895-96	Agricultural and Meteorological
1898-99	Agricultural, Hydrological, and Meteorological
1899-1900	Agricultural, Hydrological, and Meteorological

(Source : Narain *et at.*, 2000)

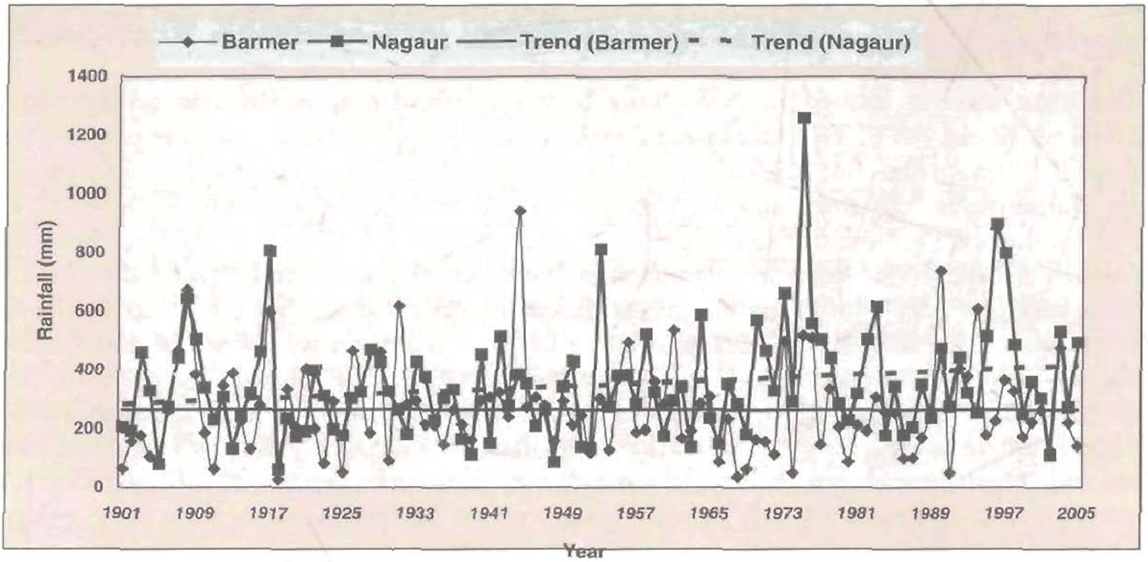


Fig.2 Fluctuations in annual rainfall over two arid stations of western Rajasthan

9.4 Droughts during instrumental period

With improved instrumentation and documentation from 1901, a large number of droughts of varying intensities (Table 3) have been recorded in the region by CAZRI (Rao, 1997; Rao and Singh, 1997; Narain *et al.,* 2000; Narain and Singh, 2002, Narain *et al.,* 2002; Narain and Amal Kar, 2005), the worst in the recent past being that of 1987 and 2002, while the worst in the century was in 1918. Often the drought persists continuously for 3 to 6 years at different intensities, as has been experienced during the period 1903-05, 1957-60, 1966-71, 1984-87 and 1998-2000, causing multiplier effects on crop and fodder production, groundwater and availability of drinking water in the region.

Table 3. Meteorological droughts in the western Rajasthan (1901-2005).

District headquarter	Intensity of meteorological drought		
	Mild	Moderate	Severe
Barmer	1906 1914 1920 1922 1934 1935 1937 1938 1943 1950 1951 1967 1979 1981 1984 1985 1989 1996 2000 2001 2004 2005	1902 1903 1910 1928 1936 1939 1948 1957 1958 1962 1963 1970 1971 1977 1982 1988 1995 1999	1901 1904 1905 1911 1915 1918 1923 1925 1930 1952 1954 1966 1968 1969 1972 1974 1980 1986 1987 1991 2002
Bikaner	1903 1904 1912 1922 1924 1927 1929 1930 1932 1947 1951 1952 1960 1962 1971 1975 1979 1988 1989 1990 1993 2003 2005 2001	1901 1902 1911 1913 1915 1925 1940 1941 1943 1946 1953 1957 1963 1965 1972 1980 1987 1991 1999 2000	1905 1918 1938 1939 1948 1968 1969 1984 1985 2002 2004

Churu (1906-2005)	1906 1907 1913 1914 1916 1922 1928 1929 1931 1932 1937 1940 1941 1947 1948 1953 1954 1955 1957 1958 1959 1960 1962 1963 1967 1971 1973 1974 1981 1982 1986 1991 2002 2004	1910 1911 1915 1920 1935 1936 1938 1939 1952 1965 1968 1969 1972 1984 1987 1999 2000	1918 1921 1951 1979 1989
Ganganagar *(1926-2005)*	1926 1927 1931 1933 1935 1940 1954 1958 1960 1961 1970 1972 1973 1975 1980 1981 1988 1991 1993	1929 1932 1934 1937 1947 1949 1952 1955 1957 1979 1986 1987 2004 2005	1936 1938 1939 1943 1946 1953 1962 1965 1968 1969 1971 1974 2000 2002
Hanumangarh (1906-2005)	1911 1922 1925 1938 1939 1944 1948 1954 1955 1957 1959 1960 1961 1968 1972 1993 1999	1913 1927 1931 1943 1946 1951 1952 1958 1962 1965 1967 1971 1980 1988 1991 2003	1910 1915 1918 1920 1921 1924 1929 1953 1969 1974 1979 1986 1987 1989 1990 1994 2000 2002
Jaisalmer	1910 1924 1927 1932 1935 1936 1942 1945 1952 1967 1980 1982 1997 2000 2003	1902 1903 1913 1915 1919 1922 1928 1934 1938 1941 1949 1950 1951 1960 1964 1965 1966 1971 1977 1984 1989 1990 1991	1901 1904 1905 1911 1918 1921 1925 1930 1939 1943 1946 1948 1963 1968 1969 1972 1974 1985 1986 1987 2002 2004
Jalor	1903 1905 1910 1913 1914 1921 1924 1928 1932 1943 1946 1947 1948 1950 1954 1957 1960 1965 1970 1971 1985 1986 1988 1989 1996 1998 1999 2000 2001 2004	1904 1912 1922 1923 1930 1935 1940 1942 1949 1951 1962 1963 1964 1966 1981 1982 1984	1901 1902 1911 1915 1918 1925 1936 1939 1968 1969 1974 1980 1987 1991 2002
Jhunjhunu	1904 1906 1913 1915 1919 1922 1923 1924 1932 1935 1936 1940 1943 1944 1953 1958 1960 1963 1973 1980 1982 1986 1990 1991 1997 1998 1999 2000	1902 1905 1907 1921 1928 1929 1938 1941 1949 1952 1968 1972 1974 1979 1981 1984 1985 1987 2003 2004	1901 1918 1939 1951 1965 1989 1996 2002
Jodhpur	1906 1907 1919 1928 1929 1936 1937 1940 1942 1947 1950 1951 1955 1957 1959 1961 1962 1965 1981 1988 1989 1993 1999 2003	1901 1910 1913 1914 1920 1922 1930 1935 1938 1939 1941 1946 1949 1963 1971 1972 1974 1980 1984 1985 1991 2000	1902 1904 1905 1911 1915 1918 1921 1925 1960 1968 1969 1986 1987 2002 2004
Nagaur	1904 1910 1912 1915 1923 1926 1927 1930 1931 1936 1937 1943	1901 1902 1906 1911 1914 1919 1921 1924 1925 1932 1935 1946	1905 1913 1918 1920 1938 1939 1941 1948 1951 1952 1963 1966

	1947 1949 1954 1957 1959 1961 1962 1968 1972 1974 1979 1981 1985 1991 1993 2001 2004	1960 1965 1969 1980 1984 1986 1987 1989 1994 1999	2002
Pali	1902 1912 1920 1932 1933 1935 1942 1951 1954 1957 1961 1963 1976 1982 1983 1995 1999 2003	1904 1911 1913 1914 1915 1921 1923 1924 1925 1930 1937 1939 1941 1946 1949 1958 1960 1962 1971 1972 1980 1984 1985 1986 1989 1991 1993 1998 2000 2004	1901 1905 1918 1922 1968 1969 1974 1981 1987 2002
Sikar	1913 1920 1922 1923 1928 1931 1932 1935 1937 1940 1948 1952 1953 1954 1963 1969 1971 1973 1985 1986 1991 1995 2001	1907 1910 1915 1919 1921 1925 1939 1941 1943 1949 1951 1958 1961 1966 1972 1979 1984 1989 1993 2003 2004	1901 1902 1905 1906 1911 1918 1938 1965 1967 1987 1990 1999 2000 2002

The frequency of occurrence of agricultural and meteorological droughts in arid regions is much higher compared to other regions. The arid western Rajasthan comprising of 12 districts experienced droughts in 52 to 62% of the years during last 1901-2004 in one place or the other (Table 4), sometimes occurring in consecutive years like those, which occurred recently in 1984-87 and 1998-2000 which have a multiplier impact on livestock population. Popular saying for arid zone of Rajasthan that in the course of a decade, one year would be a bumper crop (100%), five years of average produce (60-75%), three years of scanty harvest (40-60%) and one year of famine (<25%). An irregular and uncertain rainfall followed by drought and famine is an inevitable, every three years cycle, in the region.

Table 4. Frequency of different intensities of droughts in western Rajasthan

District	Mild	Moderate	Severe	Total
Barmer (1901-2005)	22	18	21	61 (58)*
Bikaner (1901-2005)	22	21	11	54 (52)
Churu (1906-2005)	34	17	05	56 (55)
Ganganagar (1926-2005)	20	13	14	47 (59)
Hanumangarh (1906-2005)	17	16	18	51 (52)
Jaisalmer (1901-2005)	15	23	22	60 (58)
Jalor (1901-2005)	30	17	15	62 (60)
Jhunjhunu (1901-2005)	28	20	08	56 (55)
Jodhpur (1901-2005)	24	22	15	61 (59)
Nagaur (1901-2005)	29	22	13	64 (62)
Pali (1901-2005)	18	30	10	58 (56)
Sikar (1901-2005)	23	21	14	58 (56)
Western Rajasthan	34	20	06	60 (58)

* Per cent of total drought year

Drought differ from one another on account of intensity, duration and spatial coverage which are important for planning management. Intensity refers to the degree of the precipitation shortfall and/ or the severity of impacts associated with the shortfall and is closely linked to determination of impact. Droughts usually require a minimum of two to three months to be perceptible but then can continue for months or years. The areas affected by severe drought evolve gradually. In larger countries, drought would rarely, if ever, affect the entire country. The droughts of 20th century rarely affected 50 percent area of the country excepting in 1918-19, when 73 percent of the country was affected with serious implications. In India, usually some part of the country covering 5-10% is affected by drought.

9.5 Incidence and spread of drought:

Droughts are usually the result of accumulation of a set of weather sequences that require extended period of time to develop. Studies carried out at CAZRI on the pattern of drought incidence indicated that the occurrence and spread of drought is not a sporadic event in western Rajasthan (Rama Krishna and Sastri, 1980). The pattern of drought spread during the severe drought year 1968 was carried out based on the departures of actual monthly water deficiency from annual values, expressed as per cent of water needed. The above analysis revealed that western Rajasthan experienced droughts in 54 per cent of the years confirming the entire western Rajasthan being under chronically drought prone region of India. The zone of maximum drought intensity changed in different months, indicating a sequential pattern of drought spread and decay over the region. Droughts have a general tendency to originate in the northeastern region around Churu and Jhunjhunu during July, spread in a southwesterly direction into Barmer region during August and dissipate with an easterly movement into Pali region during September. The effect of drought is comparatively more in regions of higher rainfall than in regions of lower rainfall within the arid region. This logic may also extends to high rainfall region. Therefore, drought perception is governed by the equilibrium of climate on vegetation, drinking water and coping mechanisms of people. It is the later which has bearing on perception of drought. This type of analysis, when combined with the drought vulnerability provides the necessary confidence for the early identification of drought occurrence and its spread.

Considering a severe drought when more than 50 per cent deficiency in rainfall prevailed in more than 20 per cent of the geographical area, moderate drought when 26 to 50 per cent rainfall deficiency occur in 20 per cent or more and the drought prone area experiencing more than 20 per cent drought years was further divided into low, medium and high intensity drought prone districts facing 30 per cent of total years as drought years, with more than 35 per cent of the total years as drought years. The drought prone districts Jaisalmer, Barmer, Jodhpur and Pali districts have a chance of experiencing drought after every second or third year. The moderately drought-prone Hanumangarh, Ganganagar, Nagaur, Sikar, Jalor and Bikaner districts have probability of drought occurrence once in three or four year's period. The low intensity drought-prone areas are situated in the northeastern parts of the western Rajasthan, which include the districts of Churu and Jhunjhunu having probability of once in 5 years.

A further analysis on probability of occurrence of drought in western Rajasthan (1901-2005) revealed that the entire region experienced drought of either moderate or severe nature at least once in four years. The district-wise probability analysis shows that Churu district has the probability of drought occurrence once in five years, whereas at the other end Jaisalmer and Barmer districts have high probability of drought occurrence, i.e., once in two to three years period (Fig.3)

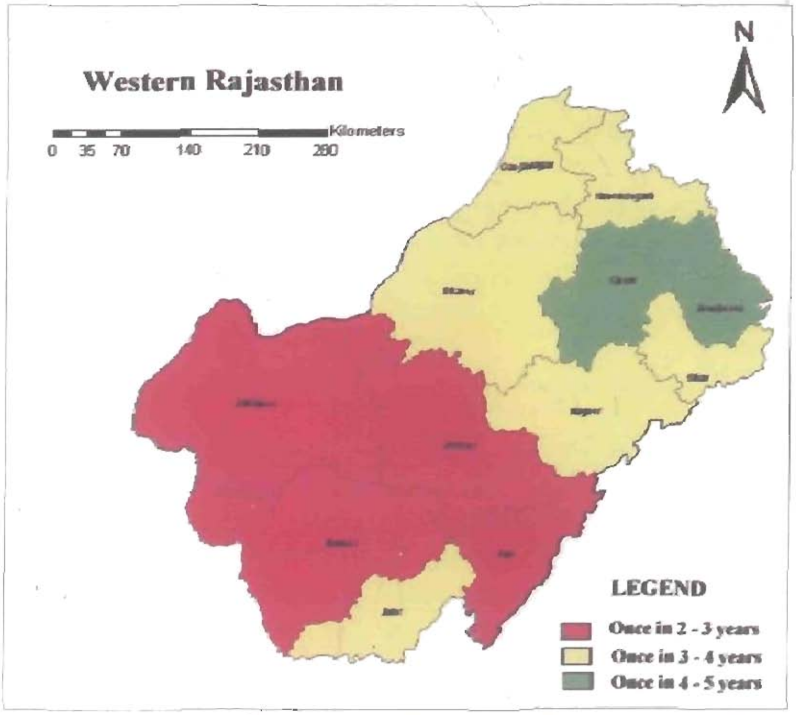


Fig.3 Frequency of drought in different arid districts of Rajasthan

Jaisalmer district is the most prone to drought. During 1901 to 2005, agricultural drought in the region occurred in 70 years, out of which in 45 years it was severe and in 25 years it was moderate affecting considerably the crop and fodder production. Next to Jaisalmer, Barmer district experienced severe drought in 32 years and moderate drought in 18 years. Bikaner district experienced severe drought in 25 years and moderate drought in 23 years. While Jodhpur district experienced severe drought in 19 years and moderate drought in 26 years. The decreasing order of drought intensity in Jaisalmer > Barmer > Bikaner > Jodhpur matches with the proverbial description of drought/famine as having legs in Bikaner, head in Barmer, belly in Jodhpur and stay forever in Jaisalmer (Narain *et al.*, 2000).

The droughts, famines and their consequences have taught many lessons to people of western Rajasthan. The people developed coping mechanism, comparable courage and capacity of endurance in adversaries. The distance, lack of communication and inhospitable terrain make relief works literarily very difficult and expensive in the region. It has now been realized that drought is a regular feature in the areas and all possible efforts should be made by the Government to mitigate effects of drought on a long-term basis. Improved monsoon forecasting on short-, medium-, and long-range scale provides an effective instrument to tackle the drought conditions.

Over exploitation of vegetation for fuel wood during drought years

9.6 Regional position of drought in past century:

The regional picture of drought is analyzed according to its intensity in the district or zone or entire region during the last 105 years, which helps to zonalize the western Rajasthan.

***Severe drought region*:** Severe drought condition prevailed 6 times in the entire arid western Rajasthan. Churu district observed severe drought 5 times, Jhunjhunu 8 times, whereas, Pali and Bikaner districts faced 10 and 11 times drought during the same period. There were 13 severe droughts in Nagaur, 14 in Sikar and 15 each in Jalor and Jodhpur districts. The highest numbers of drought years were observed in Jaisalmer, which faced 22 severe droughts followed by Barmer (21) in this period.

***Moderate drought region* :** Arid western Rajasthan experienced 20 moderate droughts during the last 105 years, Pali district 30 years, whereas, Jaisalmer had 23 years. Nagaur and Jodhpur district observed 22 moderate drought years, whereas, Bikaner and Sikar faced 21 and the remaining districts faced moderate drought in 13 to 20 years.

9.7 Temporal analysis of drought :

During last 105 years, the entire arid zone experienced 26 years of drought. In this period, 20 moderate and six severe droughts occurred which constitutes 19.8 per cent and 5.2 per cent. The six severe drought years were 1901, 1905, 1918, 1969, 1987 and 2002. The year 1918 was considered as highest degree of severe drought, whereas, 1939 was the highest degree of moderate drought. The occurrence of moderate drought is higher than the severe drought. The drought occurred during 1918 and 2002 spread in all the 12 districts of the arid Rajasthan.

The district-wise analysis of drought occurrence reveals that out of 105 years, 16 years were drought-free years, which occurred in a pair of two or three continuous years such as 1908-09, 1916-17, 1944-45, 1975-77 and 1994-97. About 28% of the total number of years experienced moderate drought in only one or two districts. Near about once in ten years, drought sweeps entire arid region of Rajasthan comprising the 12 districts (Table 5).

Table 5. Number of districts and drought years in western Rajasthan

District frequency	Drought years	% of total years
1-3	41	39.5
4-6	20	19.2
7-9	17	16.3
10-11	06	05.8
All 12 districts	04	03.8
Drought free year	16	15.4
Total	104	100.0

The district level decadal analysis of drought shows that a large number of districts were affected by drought condition during 1901-10 and 1961-70. In contrast to these two decades during 1941-50 only a few districts were affected by drought. The 2nd (1911-20), 8th (1971-80) and 9th decade (1981-90) also had an extensive drought in which more numbers of districts were affected by drought during 1911, 1915, 1918, 1972, 1974, 1979, 1984, 1985 and 1987. During these decades, maximum number of districts were influenced by severe drought. The decade 1941-50 is considered to be a good decade for western Rajasthan as far as rainfall is concerned, which did not face any drought condition. The other six decades were characterized by only one or two moderate drought each (Table 6). It seems to have some cyclic pattern in occurrence as well as continuity of drought, which can be perhaps explained with extra-terrestrial as well as terrestrial factors.

Table 6. Decadal-wise distribution of droughts in arid western Rajasthan

Decade	Type and Number of drought years		
	Severe drought	Moderate drought	Total
1901-10	2	2	4
1911-20	1	2	3
1921-30	0	2	2
1931-40	0	2	2
1941-50	0	0	0
1951-60	0	1	1
1961-70	1	3	4
1971-80	0	3	3
1981-90	1	2	3
1991-2000	0	2	2
2001-2005 (5 years)	1	1	2
Total (105 years)	6	20	26

10. IMPORTANCE OF MICRO-LEVEL ASSESSMENT AND MONITORING OF DROUGHT

If district is taken as a unit for assessing drought severity, the real severity of drought prone tehsils may be either under-estimated or over-estimated making strategies for mitigation and relief unrealistic. Non vulnerable tehsils might get more than required benefits and vice versa vulnerable tehsils may not get their due. As an example (Table 8) shows that Osian and Bhopalgarh tehsils are less vulnerable to severe drought situations. An example, the percentage of mild, moderate and severe drought years ranged from 15 to 32, 18 to 27 and 8 to 15, respectively (Table 7). Hence, for realistic assessment of drought severity, monitoring of drought at micro-level is important for appropriate contingency planning.

Table 7. Incidence of meteorological drought in Jodhpur district (1901-2005).

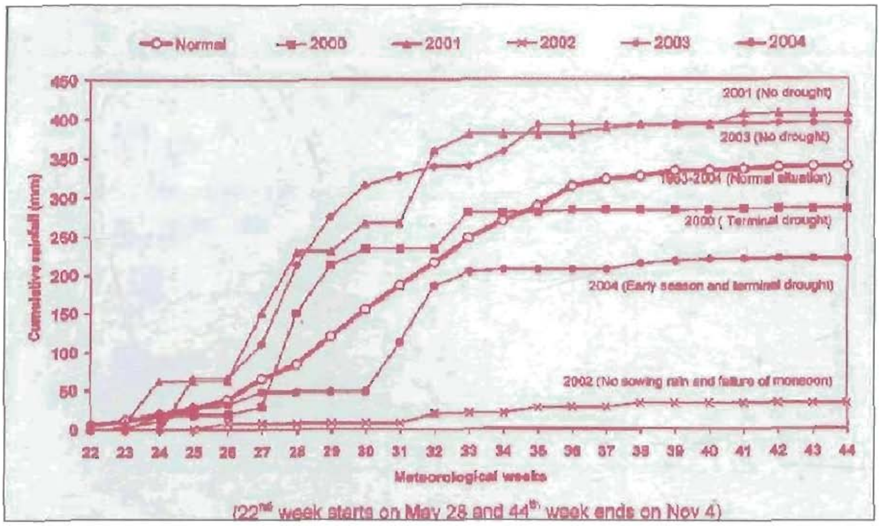
Name of the Tehsil	Mild drought	Moderate drought	Severe drought	Total
Jodhpur	24	21	15	61
Bilara	18	26	13	57
Phalodi	22	22	14	58
Shergarh	17	22	14	53
Osian (1957-2005)	15	27	08	50
Bhopalgarh(1983-2005)	32	18	09	59
District mean	21	23	12	56

10.1 Use of Network system

Though, agricultural drought monitoring system exists at national level, it is necessary for each drought prone state to have its own monitoring system for quick and effective implementation of drought mitigation. CAZRI is equipped with Agrometeorological Advisory Services Unit for daily monitoring of drought taking tehsil level information on weather, crop, ground water etc for issuing drought warning. The inputs required for the analysis are rainfall, potential evapotranspiration (or temperature), sowing date, water holding capacity of respective soils, crop coefficients, etc. The climate water balance model is used to calculate soil moisture status, evapotranspiration etc and will give first signal when drought conditions start. Depending on the duration and severity of drought, it will give alarm about severity of a drought. The main *kharif* crop of pearl millet and pulses of each tehsil in all 12 districts are considered. All the information and model will be processed at drought monitoring unit at CAZRI and message of drought warning will be passed on to ICAR, New Delhi and relevant departments for necessary action.

10.2 Using cumulative weekly rainfall by CAZRI

Analysis carried out by CAZRI, Jodhpur reveals that if enough sowing rain is not received latest by 27th meteorological week (before middle of July), there is a likely chance of occurrence of terminal drought for pearl millet at reproductive phase of the crop as observed during drought years 2000 and 2004. Similarly, if adequate sowing rain do not occur by the end of July, there is no possibility left to grow even short duration *kharif* pulses successfully. It is likely that *kharif* pulses can experience terminal drought at reproductive phase as occurred during 2004. In 2002, when adequate sowing rain did not occur by middle of August, the entire region wiped out under severe drought and there was even acute shortage of natural grasses, fodder, feed and drinking water for animals in the region. Hence, graphical representation (Fig.4) of cumulative weekly rainfall during different *kharif* seasons in the recent past is very simple but can be successfully used as an indicator for early warning of agricultural drought for different crops in the region.



(22nd week starts on May 28 and 44th week ends on Nov 4)

Fig.4 Monitoring of cumulative weekly rainfall during *kharif* seasons at CAZRI, Jodhpur, used as a tool for early warning of drought in western Rajasthan

11. DROUGHT OVER WESTERN RAJASTHAN IN THE BEGINNING OF NEW MILLENNIUM (2000-2004)

11.1 Droughts during 2000, 2002 and 2004

Western Rajasthan comprising of 12 districts is chronically drought prone region and droughts are a recurring feature. Its average frequency over the arid western Rajasthan is once in 1.5-2.0 out of 5 years. New millennium commenced with drought where the region experienced 3 droughts recently in 2000, 2002 and 2004 (Table 8). Severity of drought 2002 has also broken all previous records after 1918.

Table 8. Tehsil-wise rainfall (mm) in drought prone districts of western Rajasthan. (2000-2005).

Name of district	Name of Tehsil	Normal annual rainfall (mm)	Actual annual rainfall (mm)					
			2000	2001	2002	2003	2004	2005
Barmer	Barmer	281	222	264	126	475	220	140
	Siwana	358	249	271	107	609	262	223
	Sheo	223	356	325	81	267	187	176
	Pachpadra	271	226	236	167	506	291	266
	Chohtan	315	254	467	72	474	182	200
	Gudamalani	279	267	272	36	556	156	207
Average		288	262	306	98	481	216	202
Bikaner	Bikaner	255	147	206	32	245	97	313
	Nokha	332	310	270	71	392	205	224
	Pugal	166	264	274	34	121	150	335
	Khajuwala	164	132	165	89	184	254	195
	Loonkaransar	284	564	263	64	326	106	342
	Chattargarh	224		284	63	301	246	252
	Dungargarh	343	283	209	73	442	115	432
Average		252	283	239	61	287	168	297
Churu	Churu	392	230	413	288	570	253	444
	Ratangarh	364	184	297	78	446	250	217
	Sujangarh	410	352	276	130	371	397	370
	Sardarsahar	358	317	336	110	366	151	355
	Taranagar	388	127	429	157	363	300	312
	Rajgarh	406	187	465	210	366	427	432
Average		386	233	369	162	414	296	355
Ganganagar	Ganganagar	293	99	305	98	420	138	191
	Suratgarh	244	138	331	68	201	208	199
	Raisinghnagar	226	60	163	86	208	44	132
	Sri Karanpur	246	182	248	73	205	151	105
	Padampur	263	76	245	50	196	159	157
	Anupgarh	218	202	250	115	217	61	181
	Sadulshahar	310	151	498	140	413	245	241
	Gadsana	172	223	278	100	302	111	191
	Vijaynagar	158	103	301	71	173	95	238
Average		237	137	291	89	259	135	182

Hanumanagrh	Hanumangarh	246	121	264	117	179	208	312
	Sangria	322	222	456	90	494	357	218
	Tibbi	331	252	436	150	216	276	305
	Bhadra	382	137	412	240	328	151	404
	Nohar	373	106	310	157	486	155	340
	Pilibanga	211	214	285	67	166	153	236
	Rawatsar	223	237	243	109	219	136	220
Average		298	184	344	133	298	205	291
Jaisalmer	Jaisalmer	199	145	321	63	178	47.3	221
	Pokaran	206	208	294	49	194	85	149
	Ramgarh	143	34	121	9	212	29	57
	Sam	159	78	79	51	163	77	114
	Fatehgarh	153	368	333	44.5	324	148	190
	Nokh	198	279	155	48	209	91	275
Average		176	185	217	44	213	80	168
Jalor	Jalor	438	311	340	171	661	314	321
	Bhinmal	419	385	296	142	717	335	484
	Sanchore	425	285	238	60	840	249	352
	Jaswant pura	479	285	602	347	631	225	615
	Ahore	406	293	334	126	728	343	440
	Raniwara	436	244	503	187	762	395	457
Average		434	301	386	172	723	310	400
Jhunjhunu	Jhunjhunu	383	249	397	123	270	202	427
	Nawalgarh	470	368	462	131	523	322	379
	Udaipurwati	562	320	369	211	649	404	633
	Chirawa	434	363	475	165	553	364	548
	Khetri	581	400	621	234	693	370	668
	Buhana	499	325	565	133	532	376	458
	Malsesar	427	329	521	188	457	419	530
Average		479	336	487	169	525	351	520
Jodhpur	Jodhpur	386	273	527	91	359	182	283
	Osian	317	192	322	94	483	192	260
	Bhopalgarh	345	303	397	98	398	285	285
	Shergarh	255	232	346	72.8	353	103	109
	Bilara	449	274	336	149	353	496	510
	Phalodi	225	146	251	63	221	79	111
	Luni	300	276	653	38	422	168	514
Average		325	242	405	87	370	215	296
Nagaur	Nagaur	417	361	305	111	532	273	495
	Jayal	380	337	391	96.6	399	287	331
	Parbatsar	414	252	460	157	555	217	317
	Didwana	346	410	329	98	566	308	358
	Degana	462	336	347	194	523	327	469
	Mertacity	399	256	292	157	349	396	355
	Ladnu	405	336	318	77	420	295	459
	Nawa	460	243	443	212	420	345	421
	Khinwsar	276	204	268	82	448	219	250
	Makrana	361	268	481	258	479	283	430
Average		392	300	363	144	469	295	388

Pali	Pali	421	237	500.2	90	337	229	454
	Bali	549	356	536	268	632	416	501
	Marwar Jn.	551	373	577	192	516	560	369
	Jaitaran	454	389	563	234	392	391	352
	Sojat	417	327	440	77	397	321	357
	Raipur	508	304	615	143	477	398	495
	Desuri	632	381	686	350	786	520	573
	Rohat	341	270	492	63	583	296	441
	Sumerpur	510	460	746	167	776	400	464
Average		487	344	573	176	544	392	445
Sikar	Sikar	530	198	657	152	584	205	468
	Srimadhopur	519	278	401	126	466	299	492
	Fatehpur	407	413	609	324	500	203	412
	Laxamangarh	435	228	293	124	501	386	335
	Danta Ramgarh	482	327	554	248	451	253	305
	Neem ka Thana	495	290	350	197	555	446	729
	Ramgarh	331	212	343	205	282	218	410
Average		457	278	458	197	477	287	450
Average for Western Rajasthan		351	243	305	92	384	202	331

Annual moisture indices (Im,%) for western Rajasthan as a whole during last six years (2000-2005) in comparison to long-term (1901-2000) average are given in Table 9.

Table 9. Overall drought scenario in western Rajasthan (2000-2005)

Year	Rainfall	Rainfall Departure (%)	Moisture index, Im (%)	Drought intensity
2000	243.2	-30.7	-85.7	Moderate
2001	305.1	-0.1	-82.0	No drought
2002	92.2	-73.7	-94.6	Severe drought
2003	383.9	+9.4	-77.4	No drought
2004	201.8	-0.4	-88.1	Moderate
2005	331.1	-0.1	-53.7	No drought

11.2 Weekly water balance studies :

Weekly climatic water balance (Thornthwaite and Mather, 1955) of western Rajasthan revealed that the *kharif* crop growing period was 12 weeks in normal rainfall years suitable for pearl millet, clusterbean, cowpea and moth etc. This gets reduced to 8 weeks during moderate drought (Fig.5) allowing only short duration legumes like clusterbean, moth, horse gram etc to be grown, while in severe drought years like 2002 hardly any crop can be taken up and farmers have to make contingency plan accordingly. Between 1901 and 2005, the above normal *kharif* rainfall years (i.e., greater than 20% of the normal) at Jodhpur were 31, normal years (20 per cent of the normal) 25, below normal years (> 20 per cent of the normal) 33 and poor rainfall (> 50 per cent of the normal) years 15.

Analysis of severe drought years, 1918 and 1987 revealed that the seasonal rainfall was 37.0 and 64.4 mm, respectively (Fig.6). The highest one-day rainfall received at Jodhpur was 9 mm on August 9, 2002. Neither single shower nor cumulative rainfall in a particular week was adequate for sowing *kharif* crops. The month of July normally expected to be the wettest month turned out to be the driest in the recorded history since 1877 (Narain and Singh, 2002). Monsoon 2002 was one of the worst since 1987, when all India rainfall for the season was 19% below normal. Rainfall of 12.1 and 6.6 mm received in the first and second fortnight of August, respectively, was of no significance to standing crops. Detailed daily rainfall analysis of twelve districts comprising of 73 tehsils during 2002 showed that drought extended to whole of Rajasthan.

11.3 Possible causes for failure of 2002 monsoon:

The SW monsoon system develops over Indian ocean in the middle of May and touches Kerala coast around 1st June each year. It advances further towards Indian sub-continent into two branches i.e. one through Bay of Bengal and another through Arabian sea. The whole monsoon system is governed by different atmospheric and meteorological conditions as well as formation of low-pressure area over sea and land surface. Severe drought of 2002 was of rare occurrence and its behaviour has been looked into in depth.

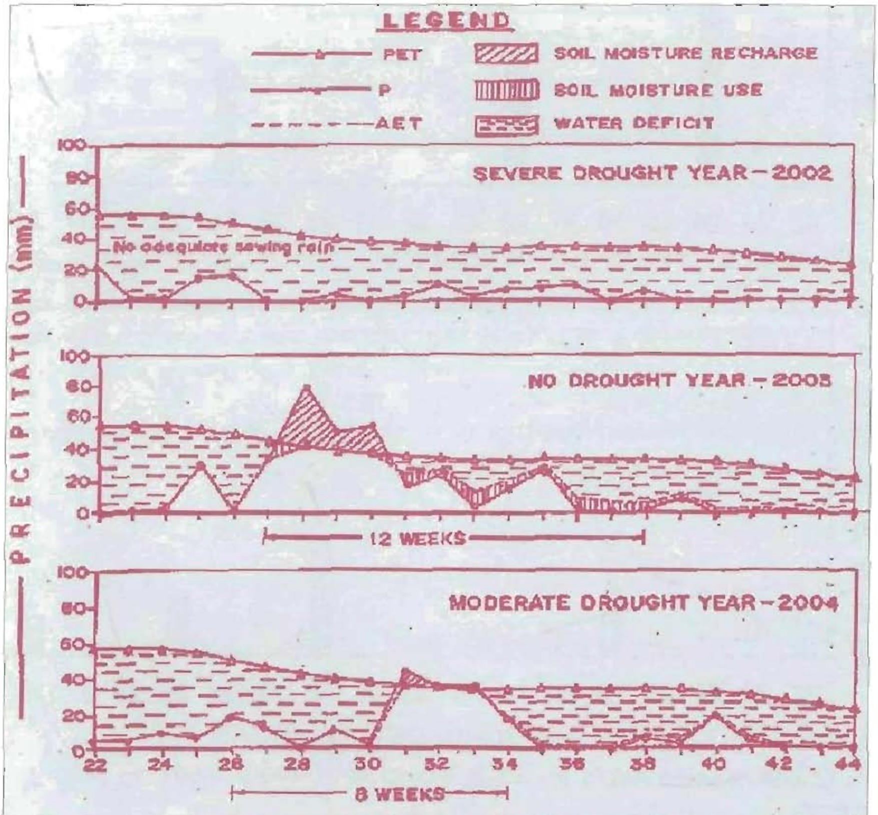
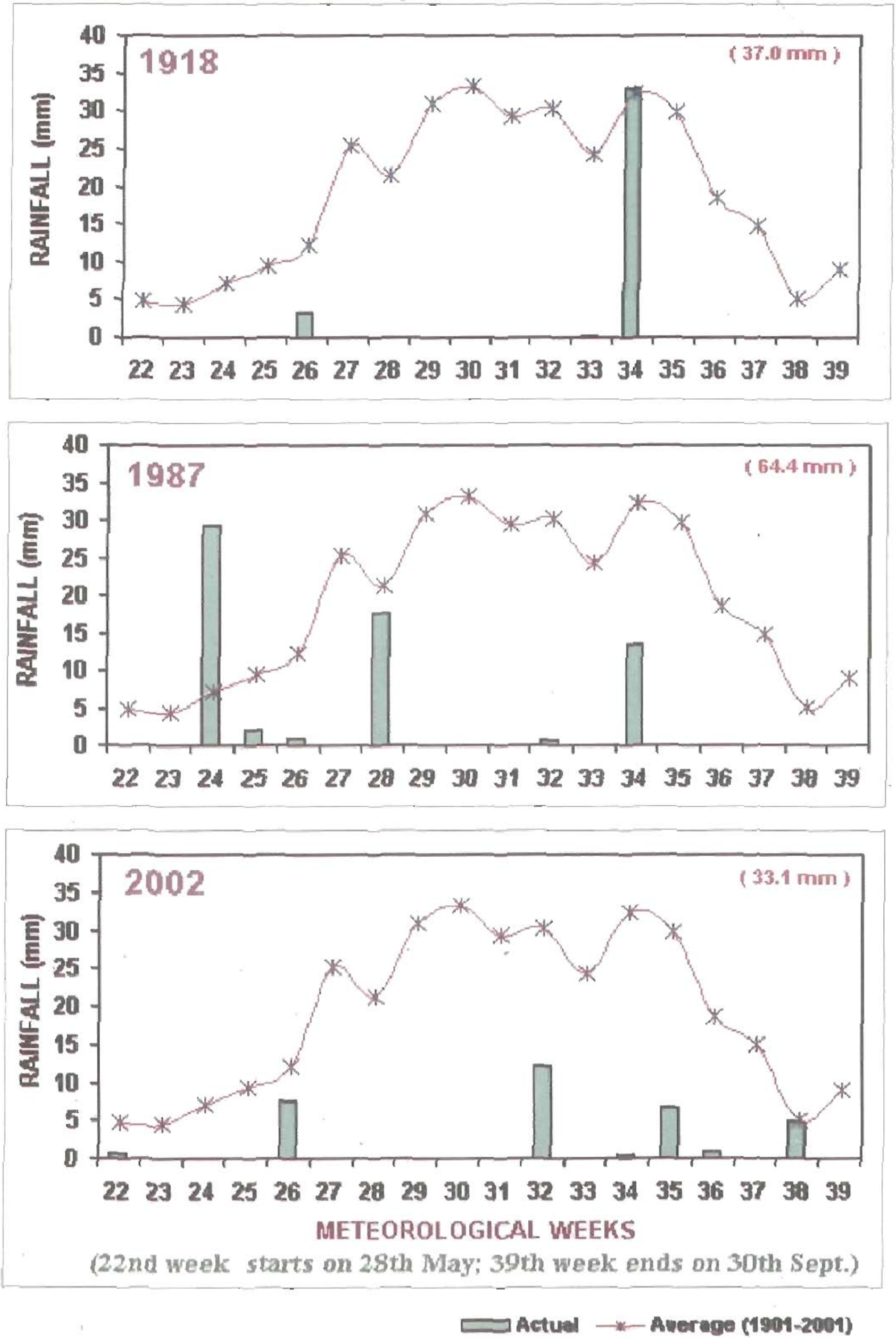


Fig.5 Rainfall pattern and climatic water balance of different monsoon situations in western Rajasthan



(22nd week starts on 28th May; 39th week ends on 30th Sept.)

Fig.6 Weekly rainfall in *kharif* season during drought years at Jodhpur

During 2002, the SW monsoon touched Kerala coast on May 29 i.e 3 days earlier than its usual date. Its subsequent movement and activeness was neither normal nor as per the seasonal forecast particularly for northwest India. Further, advancement and behavior of monsoon over western Rajasthan was much delayed and almost no rainfall received during peak rainy month of July. Later on in the month of August, monsoon wind arrived over the region but due to very low and erratic rainfall, farmers could not start any agricultural activities in the region.

The causes for occurrence of drought in arid Rajasthan from the analysis of SW Monsoon in 2002 were identified in the following weather abnormalities, which can be used for early warning of drought in the region.

1. Presence of strong westerly wind up to the level of 500 mb over NW India during July may possibly be responsible for blocking timely advancement of monsoon over the western Rajasthan. This has resulted into an anomaly in out going long wave radiation (OLR) during July. Higher OLR implies lower rainfall. The high positive OLR anomaly over the Indian region and negative OLR anomaly over the equatorial Pacific region could be the reason for deficit rainfall in India.

2. Absence of Somali jet stream over Arabian Sea which led to scarcity of cloud systems over the Arabian sea.

3. Absence of strong tropical easterly jet stream at a height of 16-20 km over north India, which is associated with deficit monsoon rainfall in the country.

4. Northward movement of monsoon trough from its normal position.

5. Anomaly in SST over large area in Pacific Ocean.

6. Increase in cloud cover across the tropical Pacific Ocean. It is believed that there is competition for convergence of moist air between the atmosphere over the Pacific Ocean and that over the Indian region. Therefore, it is not surprising that increased cloudiness over the Pacific Ocean is associated with deficit monsoon rainfall.

7. The total water vapour in the air column over India decreased markedly in the third week of May 2002 and remained below normal most of the time during July, could be the reason for deficit rainfall.

11.4 Characteristics of weather variables during 2002 :

Droughts are normally associated with high temperature, high wind velocity and low relative humidity and play crucial role in aggravating severity of its impact.

Air temperature: The annual air temperature was warmer by 1.4°C in comparison to long-term (1963-2001) mean annual temperature at Jodhpur and such increase in temperature was up to 2.3°C during *kharif* season due to complete failure of SW monsoon. Maximum temperature (Fig.7) over Jodhpur increased during drought year particularly in monsoon months having long dry spell and clear sky.

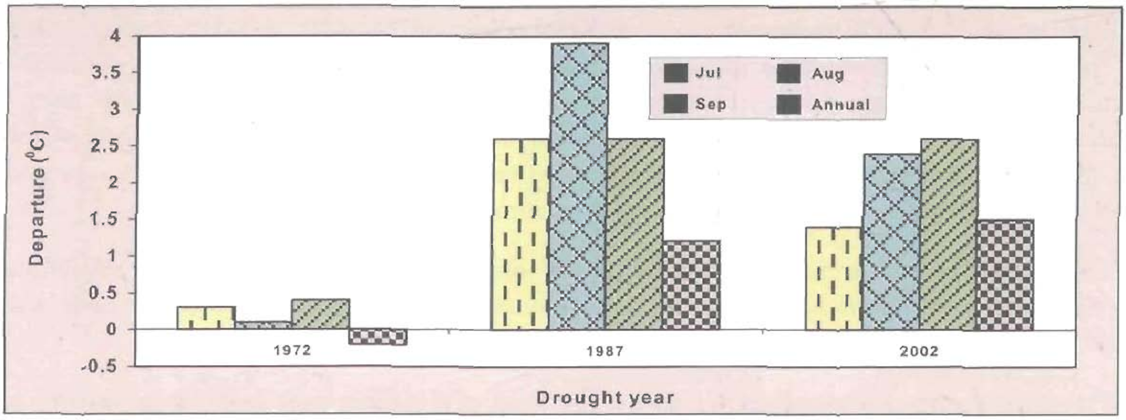


Fig.7 Departure of maximum temperature (°C) from normal over Jodhpur during major drought years in western Rajasthan

Relative humidity Significant increase in relative humidity (Fig.8) was observed in western Rajasthan during drought years compared to normal years. This shows that failure of monsoon is not because of lack of moisture but due to absence of air mass lifting mechanism in the atmosphere.

Wind regime and dust storm activity : Wind regime was up to 13.5 km h^{-1} in July from a low of 2.5 km h^{-1} in October. In general, decreasing trend in annual wind speed was observed at Jodhpur, Pali and Bhopalgarh (Fig 9). However, wind speed was high during all major drought years in comparison to immediate previous year (Fig.9) During 2002, wind speed in July at Jodhpur, Pali and Bhopalgarh was 13.5, 15.1 and 16.7 km h^{-1}, respectively, against normal wind speed of 11.7, 13.1 and 12.4 km h^{-1} during the same month (Fig.9). Generally, intensity of wind erosion and dust storm frequency over western Rajasthan is directly linked with strong wind speed and rainfall during the immediate previous year (Ramakrishna *et al.*, 1994).

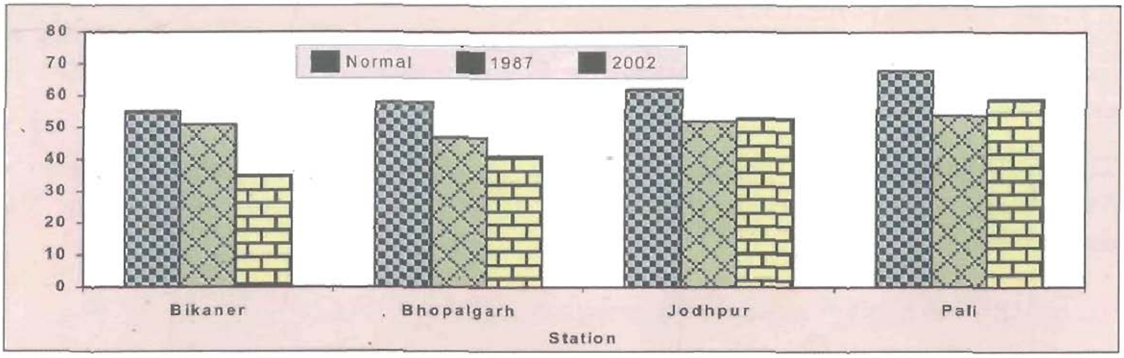


Fig.8 Variation of relative humidity in July during drought years in western Rajasthan

Dust storms affect air temperatures through absorption and scattering of solar radiation. Arid Rajasthan is a zone of loess deposition and dust movement. On an average, 17-19 dust storms per year occur at Ganganagar against 9 dust storms per year over Jodhpur region. May and June are the months with greatest dust activity. This is the period the surfaces are dry, wind velocities high and thunderstorms frequent occur. Dust storm frequency decreased from 18 during 1987 to 3 during 2002 at Jodhpur (Fig. 11). During drought years in the past dust storm frequency was more than the

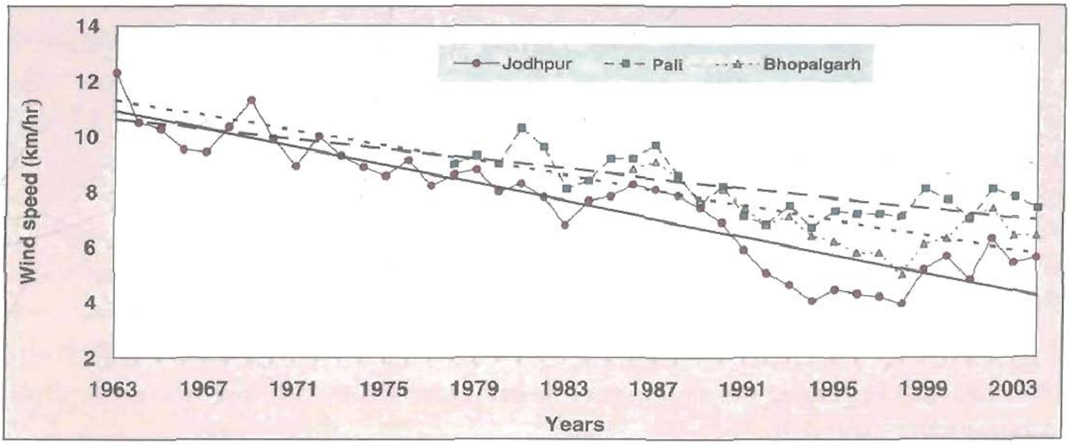


Fig.9 Fluctuation of annual mean wind speed at various stations in western Rajasthan

normal frequency (9/year) of dust storms. Drought enhances wind erosion as a result of low vegetation and dry soil conditions. The increase in dust storm activity is felt not only during drought years but also in subsequent years

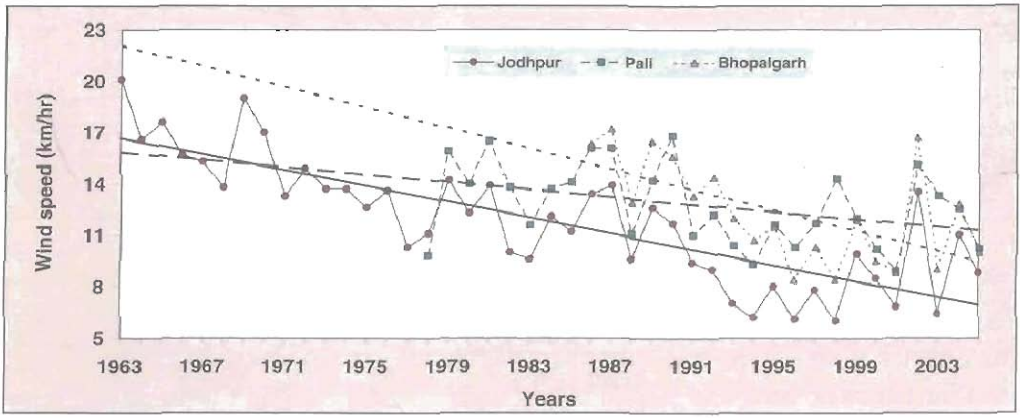


Fig.10 Fluctuation of wind speed in July at different stations in western Rajasthan

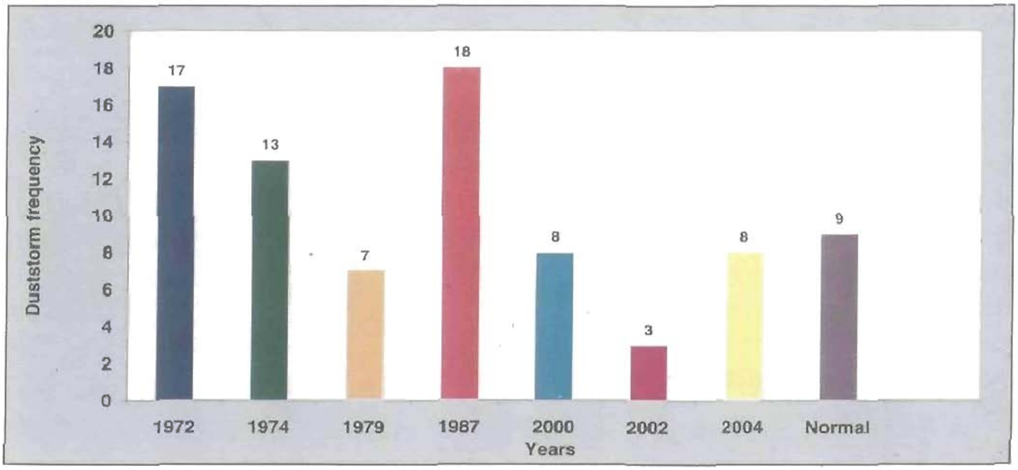


Fig.11 Frequency of dust storm (days) during drought years over Jodhpur

Duration of sunshine and evaporation rates During drought period, higher duration of bright sunshine hours and high evaporation rates are observed. Mean daily sunshine hours were highest (10.1 h day^{-1}) in June and lowest (6.9 h day^{-1}) in August against its normal value of 9.2 h day^{-1} in June and 6.8 h day^{-1} in August. Pan evaporation was highest in May (14.7 mm day ^{1}) followed by June (12.6 mm day ^{1}) and April (11.4 mm day ^{1}) again evaporation during monsoon period ranged between 8.8 and 12.6 mm day^{1}.

Rainfall distribution and comparison with other drought years.

During monsoon 2002, the distribution and quantum of rainfall received (86 mm against normal 280 mm) was extremely poor and much below normal (-69 %) than the other drought years of western Rajasthan (Table.10)

Table 10. Monsoon rainfall (mm) during drought years in western Rajasthan.

	Recent drought years						
Month	1972	1974	1979	1987	2000	2002	Normal
June	36	29	10	26	12	35	29
July	50	126	139	28	180	7	98
August	130	30	47	40	44	23	107
September	4	7	14	3	11	21	46
June- Sept	220	192	210	91	247	86	-
Normal (Jun- Sep.)	280	280	280	280	280	280	280
% Departure	-22	-31	-25	-65	-12	-69	-

Spatial distribution of rainfall during July-September, 2002 compared to normal isohyets showed that rainfall (Fig.12) was between 5 mm (coinciding normal isohyets of 100 mm in western part of Jaisalmer and Bikaner district) and 100 mm (matching with normal isohyets of 400 mm in eastern part of Jalor, Nagaur and Jhunjhunu district). The biggest seasonal rainfall of 187 mm was recorded at Jaswantpura (Jalor district) against the normal of 412 mm followed by Makrana (169 mm) in Nagaur district against a normal of 221 mm and Khetri (129 mm) in Jhunjhunu district against a normal of 390 mm.

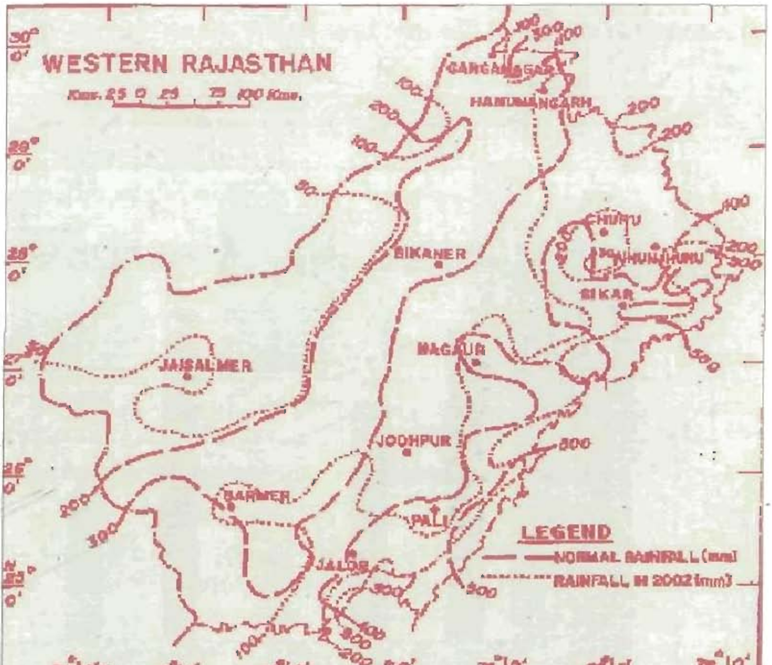


Fig.12 A comparison of annual rainfall during severe drought year 2002 with normal annual rainfall over western Rajasthan

Incidence and spread of drought in arid Rajasthan during two severe drought years 1987 and 2002 were monitored. During 1987, out of 72 tehsils, 54 received scanty rainfall, 17 deficit rainfall and one normal rainfall, whereas, during 2002 out of 90 tehsils, 72 received scanty rainfall, 18 deficit rainfall and none of them normal rainfall (Table 11 and 12). In western Rajasthan, severe drought affected 87 tehsils during 2002, whereas 15 and 32 tehsils, respectively during 2000 and 2004.

During 2004, monsoon rainfall was 13% below all India average rainfall. *Kharif* crops suffered drought conditions at an early stage in July and also in September affecting severely in 32% tehsils, moderately in 35% tehsils and with mild drought in 25% tehsils.. Only 8% tehsils were drought free in western Rajasthan during *kharif* 2004.

Table 11. Number of tehsils effected by severe drought in 1987 and 2002 over western Rajasthan.

	1987				2002			
District	Normal	Deficit	Severe	Total	Normal	Deficit	Severe	Total
Barmer	0	0	6	6	0	2	7	9
Bikaner	0	3	1	4	0	1	6	7
Churu	0	5	2	7	0	2	5	7
Jaisalmer	0	1	5	6	0	0	6	6
Jalor	0	0	5	5	0	3	3	6
Jodhpur	0	1	5	6	0	0	7	7
Jhunjhunu	0	0	4	4	0	0	7	7
Nagaur	0	2	6	8	0	2	8	10
Pali	0	1	6	7	0	1	8	9
Ganaganagar	1	2	4	7	0	3	6	9
Hanumangarh	0	1	4	5	0	0	7	7
Sikar	0	1	6	7	0	4	3	7
Total	1	17	54	72	0	18	72	90

Note: S for Scanty (-60% normal rainfall or less); D for Deficit (-20 to -59% normal rainfall), N forNormal (± 19% normal rainfall) and T for Total
(Source: Singh and Singh, 2002)

Table 12. Tehsil-wise drought assessment in western Rajasthan.

Year	No drought	Mild drought	Moderate drought	Severe drought	Drought intensity for W. Rajasthan
2000	26	22	26	13	Mild
2001	38	31	17	01	No drought
2002	00	01	07	79	Severe
2003	64	14	08	01	No drought
2004	07	22	30	28	Moderate
2005	52	21	09	10	Mild

12. DROUGHT IMPACT ASSESSMENT, RESPONSE AND MITIGATION :

Impacts of drought are economic, social and environmental, which are difficult to quantify because of their non-structural nature. Methodologies or techniques for estimating impacts, and the reliability of estimates are highly variable. Though traditional wisdom exists to reduce impacts, these are not adequately efficient in dealing with large-scale droughts hence some causalities that of livestock becomes inventible. Therefore, policies need to be framed not only to mitigate drought impacts with temporary solutions but also to eliminate its impact on society permanent basis.

Immediate impact of drought is felt on agriculture. With the increased intensity or extended duration of drought prevalence, a significant reduction in food production is often noticed. Drought results in crop losses of different magnitude. The impact depends on the geographic distribution of drought at farm as well as at national level.

Due to severe drought conditions in 1987, food production was reduced by 7 million tonnes and in 2000 again it was short by 9 million tonnes from the previous levels. The recent drought of 2002 has severely affected the agricultural activities in 12 states spread in 524 districts in the country. Out of 36, 27 meteorological sub-divisions experienced deficit to scanty rainfall. Though rainfall received in September brought down the overall deficiencies to 19 percent over the country, the impact of this drought has been severe in many areas of the country. The effect of such severe drought generally is more pronounced on fodder availability as compared to that of food grain. Besides these, scarcity of drinking water for both human and livestock is another serious concern during such drought years. Droughts thus have multiplier effect on agricultural production, their impact is felt during the subsequent years due to deficit ground water recharge, land degradation, fall in investment capacity of farmers, rise in prices, reduced grain trade, and power supply. It indicates that impact assessment of drought should not be limited to the drought year but its residual impact needs to be assessed particularly on national resources like river flow, ground water and perennial vegetation.

12.1 Impact of drought on crop production :

Pearl millet production in western Rajasthan during the drought years of 1998, 1999, 2000 and 2002 decreased by 52, 74, 38 and 86%, respectively from that of recorded during 1997 (Table 13). Maximum reduction of 86-89% in grain production during 2002 confirm the severity of agricultural drought in the arid western Rajasthan.

The drought impact on crop acreage and productivity of pearl millet and *kharif* pulses in Jodhpur district are presented in Table 14 and 15. The crop acreage under pearl millet reduced by 90% during the severe drought 2002 and 40% under a moderate of 2005. Pearl millet grain production also reduced by 76 to 84% during these drought years (Table 15). Drought also influenced in the reduction of crop acreage under *kharif* pulses, but the impact was less felt on the production of the *kharif* pulses compared to that of pearl millet (Table 16).

Drought impact on moth bean in Bikaner district

Moth bean is cultivated as sole as well as in various cropping systems. Evapotranspiration (ET) rates are low and vary between 1.8 and 4.8 mm day^{-1} (Singh *et al*, 2000). Narain *et al.*, (2001) had

Table 13. Impact of agricultural drought on production of pearl millet and *kharif* pulses in western Rajasthan

District/region	Production (metric tons) during good monsoon year 1997	Reduction (%) during drought years			
		1998	1999	2000	2002
Pearl millet					
Barmer	250553	94	92	28	98
Churu	296854	74	91	82	98
Nagaur	273845	30	51	12	83
Pali	54291	96	88	63	100
West Rajasthan	1723083	52	74	38	86
***Kharif* pulses**					
Barmer	105484	99	96	25	98
Churu	88119	57	90	91	100
Nagaur	70723	15	69	28	63
Pali	8713	85	87	29	100
West Rajasthan	462240	65	86	53	89

Table 14. A comparison of crop acreage and productivity of pearl millet in Jodhpur district

Year	Monsoon rainfall	% departure	Pearl millet		
			Area	Production	Productivity
1996	387.5	42.7	626.12 (34.9)	230.10 (76.3)	367.5 (26.0)
1997	345.6	27.2	616.17 (32.8)	239.40 (83.4)	388.5 (33.3)
1998	278.1	2.4	511.28 (10.2)	13.29 (-89.8)	26.0 (-91.0)
1999	250.0	-7.9	480.49 (3.5)	36.53 (-72.0)	76.0 (-73.9)
2000	222.0	-18.3	536.59 (15.6)	65.96 (-49.5)	122.9 (57.8)
2001	355.9	31.0	652.06 (40.5)	444.57 (240.0)	681.8 (133.0)
2002	72.0	-73.5	45.06 (-90.3)	31.62 (-75.8)	701.9 (-)
2003	344.9	26.9	485.00 (4.4)	181.88 (39.3)	375.0 (28.7)
2004	196.9	-27.5	413.50 (-10.9)	41.35 (-68.3)	100.0 (-65.7)
2005	263.3	-3.1	275.00 (-40.7)	20.63 (-84.2)	75.0 (-74.3)
Average	271.6	-	464.12	130.53	291.5

Note : Area in thousand ha, productivity in thousand metric tonnes and productivity, kg/ha
(Source : Krishi Bhavan, State Department of Agriculture, Jodhpur)

carried out the climatic water balance on weekly basis using precipitation and potential evapotranspiration for data during each cropping season (July-September) over the 30 years period (1968-97) as adapted by Thornthwaite and Mather (1955). Ratio of actual evapotranspiration to potential evapotranspiration is computed for each week/growth stage of the crop to know intensity of drought experienced by the crop in the region (Sastri *et al.*, 1982). It has been reported (Table 16) that moth bean (dew bean) experienced severe agricultural drought during 33% years, moderate drought during 23% mild drought during 20% years in the region. In general, the crop suffered with severe/ moderate drought in every alternate year.

Table 15. A comparison of crop acreage and productivity of *kharif* pulses in Jodhpur district

Year	Monsoon rainfall	% departure	*kharif* pulses		
			Area in '000 ha	Production	Productivity kg/ha
1996	387.5	42.7	262.54 (19.1)	78.24 (107.4)	584.8 (81.1)
1997	345.6	27.2	247.96 (12.5)	79.20 (109.9)	642.0 (98.9)
1998	278.1	2.4	203.43 (-7.7)	0.05 (-99.9)	0.8 (-99.7)
1999	250.0	-7.9	188.61 (-14.4)	7.27 (-80.7)	96.2 (-70.2)
2000	222.0	-18.3	215.48 (-2.2)	16.79 (-55.5)	185.2 (-42.6)
2001	355.9	31.0	254.32 (15.4)	61.14 (62.0)	499.3 (54.6)
2002	72.0	-73.5	13.41 (-93.9)	0.58 (-98.5)	120.1 (-62.8)
2003	344.9	26.9	260.00 (17.9)	81.50 (116.0)	700.0 (116.8)
2004	196.9	-27.5	238.50 (8.2)	35.78 (-5.2)	300.0 (-7.1)
2005	263.3	-3.1	320.00 (45.2)	16.80 (-55.5)	100.0 (-69.0)
Average	271.6	-	220.42	37.73	322.8

Table 16. Intensity and frequency of agricultural drought over Bikaner district (1968-97)

No drought years	1975, 1977, 1978, 1983, 1992, 1995 and 1996 (7 years)
Mild drought years	1970, 1973, 1976, 1980, 1982 and 1997 (6 years)
Moderate drought years	1969, 1971, 1984, 1988, 1989, 1990 and 1994 (7 years)
Severe drought years	1968, 1972, 1974, 1979, 1981, 1985, 1986, 1987, 1991 and 1993 (10 years)

On an average, during severe drought, cropped area was reduced to the tune of 12% whereas, productivity reduced to an extent of 85%. Even the moderate drought reduced yield by 55% and cropped area by 8% (Table 17). These figures reveal that even under moderate to severe drought in Bikaner region farmers are convinced to grow moth bean, which is a drought hardy arid legume. Lesser fluctuation in cropped area during drought years confirm preference of farmers to this crop and high degree of adoption of moth bean. Moth bean has a drought coping crop strategy in Bikaner and Jaisalmer. Increasing drought tolerance and production potential of this crop is desired for bringing sustainability in this agro-ecosystem of hot and hostile arid district of western Rajasthan.

12.2 Impact of drought on Grassland productivity :

Animal husbandry is the main source of livelihood in arid zone. About 10 m ha land in arid region, including pasture, cultivable waste land, un-cultivable wastes and barren land are available for grazing to about 11.28 million ACUs. The dry fodder requirement is about 28 million tonnes to feed the livestock. Under normal situation, about 11 million tonnes of fodder is available, meaning a deficit of 28% during the normal years. Under drought condition this deficit is likely to be about 80-95% (Table 18). Therefore, to sustain the livestock, an additional 17 million tonnes of dry fodder will be required.

Table 17. Impact of agricultural drought on moth bean crop productivity in Bikaner district (1968-97)

Drought intensity	Frequency Area (ha)	Average	% reduction	Average production (tonnes)	% reduction	Average yield (kg/ha)	% reduction
No Drought	7	285148	-	79307	-	274.3	-
Mild Drought	6	294267	-	47660	40	159.0	42
Moderate Drought	7	262449	8	33145	58	124.6	55
Severe Drought	10	250035	12	11616	85	42.6	85

Prolonged drought can induce severe decrease in vegetation cover and causes changes in composition of the herbage layer. In a good rainfall year, a marginal surplus of 10 percent fodder is estimated after meeting the requirement, whereas, the grassland productivity during normal years meet about 44 percent of the total demand. In drought year, the deficiency was as high as 83 per cent (Shankarnarayan and Rao, 1985 and Rao *et al.*, 1997).

Human and animal migration for food and fodder during drought period in Rajasthan

Table 18. Average forage yield (kg DM ha^{-1}) in western Rajasthan during drought

Rainfall Zone	Drought intensity			
(200 mm)	No Drought	Mild	Moderate	Severe
< 200	1594	939	583	290
200-300	1372	714	528	357
300-500	1571	894	775	524

(Source: Shankanarayana *et al.*, 1985)

13 DROUGHT PROOFING AND MANAGEMENT IN CHRONICALLY DROUGHT PRONE REGIONS

Traditional drought prone areas in the country continue to be a challenge for development of a viable strategy in relation to providing optimal and satisfactory solutions to the numerous socio-economic problems encountered in the region. Low rainfall, unpredictability of monsoon rains, increased agricultural, industrial and human activities in recent decades, unpredictable severity of drought are serious issues in drought management. Both short and long term strategies developed from time to time in the past need to be refined and updated with the current needs and projections. In India, droughts occur more frequently in arid and semi-arid regions and therefore, the drought management strategies have to be identified separately both for arid and semi arid areas.

13.1 Drought management in arid areas

In arid areas, the length of the growing season varies between 30 to 100 days. The rainfall is greater than the evaporative demand up to a maximum period of about four weeks. Pearl millet, greengram, cowpea, moth bean, guar etc are grown commonly under rainfed conditions. The soils are prone to wind erosion due to lack of vegetative cover during most part of the year. Grazing is a serious problem in grasslands. The farmers do not invest on inputs like quality seed and fertilizer. Acute shortage of fodder and drinking water prevail even during normal years, there are very limited opportunities for drought management on short-term basis. The strategies have to be built up keeping this scenario in view.

13.2 Short term measures for drought management :

Depending upon the time of onset of monsoon, short term measures for drought management for early, mid and late season drought should be adopted. Whenever crops are grown under conserved moisture during post-rainy season, terminal drought is likely therefore the crops and varieties have to be chosen depending upon the stored soil moisture at the time of sowing.

Choice of crop : Considering probability of drought more area should be brought under short duration legumes like moth, kuthi, guar, cowpea crops which have low water requirement.

Minimizing adverse effect of drought through crop management Moisture conservation by adjusting plant population, fertilization and some mid-season corrections are important, every strategy is location, crop, time, and socio-economic *condition* specific.

Plant population management : If water stress conditions occur at the time of or immediately after germination, it would be best to re-sow the crop, preferably with some early-maturing variety. On the other hand, if water stress occurs around 40 to 50 days after crop emergence, thinning and ratooning should be considered.

Rainfall distribution model and contingency planning : The above corrective measures and contingency plans can be adopted successfully if rainfall distribution models are prepared for different situations. For example, at Jodhpur, the probability of early, normal, and late onset of southwest

Pearl millet crop affected by mid-season drought in arid Rajasthan

Fodder distribution is an immediate relief measure by Government agencies in arid Rajasthan

monsoon is 22, 58, and 20 per cent, respectively. The conditional probability of drought in different week/month and corresponding rainfall distribution under each situation has to be utilized for planning and management.

Weed management: As weeds also compete for little soil moisture with crops in stress. Therefore, weed control through inter-culture operation is essential.

Life saving irrigation: Wherever possible efforts should be made to harvest, conserve, and recycle excess rainwater for use during water stress. Semi-arid areas have great potential to adopt this strategy through runoff harvesting some farm ponds for supplementary irrigation at critical stages.

Water harvesting potentials: Studies have revealed that eastern parts of arid Rajasthan and southwestern region of arid Kachchh district comprising the coastal areas (> 250 mm) have better potentials for practicing water harvesting and its recycling for arid horticulture or for life saving irrigation.

Rainfall cistern system: A series of alternating raised and sunken beds laid across a slope in such a way that the raised beds act like donor catchments for the sunken beds, where high-duty crops like sorghum are grown, while on raised bed areas, lower or moderate water requirement crop-like arid legumes are grown. The sunken beds, in the case of maize crop a gentle gradient is also provided.

Following short-term strategies have been framed as contingency planning in drought affected region (Narain *et al.*, 2002).

- If drought affects *kharif* crop, prospects of improving production of *rabi* crop may be explored.
- Crop residues of wheat straw, stover from maize, pearl millet, sorghum and fodder collected from perennial grasses need to be properly utilized. Dry stover enriched with urea treatment can also be used for mushroom cultivation to increase the farm income.
- Mid-season corrections in the standing *kharif* crops, e.g., *in-situ* moisture conservation, weed management, alteration of crop density to match available soil moisture, irrigation wherever available, should be applied to save the crop.
- Alternative sources of livelihood for people in the drought-affected areas need to be created so as to cushion the adverse effects of drought.

Survey on animal health during drought in arid Rajasthan

- Ground water use should be rationalized and efforts should be made to depend more upon on the dynamic resource than on the static one.
- Fodder and seed banks should be established at Panchayat Samiti level to ensure their timely availability.
- The wastelands should be utilized for plantation of fodder trees and development of natural pastures, and more area be brought under silvopasture and hortipasture.
- Adequate vaccination and drenching schedule may be adopted to prevent this and other infectious diseases.
- To economize on water resources, watering of livestock may be done on alternate days and immediately after grazing. Likewise, long distance grazing may be restricted to avoid fatigue and conserve animal energy.
- Agro-industrial by-products and un-conventional feed, such as rice straw, mustard straw, sugarcane bagasse, *P. juliflora* leaves and pods should be included in animal feed with proper supplementation.
- Under drought condition the fodder is not only scarce, but the quality is also poor. Therefore, fodder has to be imported from neighbouring states in the form of fodder bales/compact blocks. The fodder should be fortified with urea and vitamin-A to prevent malnutrition.
- The small ruminants having medium body weight should only be bred during drought period so as to conserve the fodder.

Survey on socio-economic problems during drought in arid Rajasthan

- Elite drought hardy livestock germplasm of good animals should be conserved for replenishment of the stock after termination of the drought.
- Unproductive animals may be culled so as to save fodder for productive animals.
- Area-specific native breeds should be encouraged. For example, Tharparkar, Kankrej, Nagauri cows, Surti buffaloes, Marwari, Magra, Chokla, Nali, Malpura, Sonadi sheep, and Marwari, Jhakrana and Sirohi goats.
- Value-added products may be encouraged for marketing. For example, wool may be converted to products like blankets, shawls, namdas, carpets etc., skins may be processed as leather goods, bone, etc., may be used as manures, and value addition may be attempted in milk and milk products too.
- The recent droughts resulted in massive animal migration. Therefore, measures may be taken to provide water, fodder, health care and shelters during migration of animals.
- Food for work programme need to be focused for development works that could lead for drought proofing during subsequent droughts. These may include development of water harvesting structures and improvement of rangelands.
- Wider row spacing with low to moderate seed rate should be adopted so as to reduce competition for soil moisture. Attempts be made to optimize the crop production rather than to maximize it.
- Rational use of ground water is necessary and attempts may be intensified to recharge the existing ground water pockets.
- Wherever water is available, including IG canal command area, efforts may be made for cultivation of fodder crops rather than arable crops.
- Possibility may be explored for utilization of existing non-edible green biomass for fodder. If needed, this may be fortified with conventional forage.
- Package for *rabi* crops may be kept ready to take advantage of the late rains.

13.3 Long-term approach for drought management :

Economy of water use in irrigated areas Economic use of water with drip or sprinklers should be the high priority. The major emphasis should be to ensure more economic production per drop of water rather than more productivity per unit area. There is a need to totally avoid use of ground water for cultivation of high water requirement arable crops particularly during summer season.

(i) growing low water requirement crops

ii) Emphasis on low water requirement perennial vegetation like tree, shrubs and grasses which can provide top-feed, fruits, fire wood.

iii) protective irrigation to arid horticulture crops

Efficient utilization of rain water : Even if the irrigated water is economically used, nearly 80 to 90 per cent of the arid areas may not have access to water supply through irrigation. Energy will be a serious constraint even to tap ground water for irrigation in the arid areas. Therefore, natural precipitation remains the only source of water and availability of water. It calls for in-situ moisture conservation, cultivation of crops in micro-catchments with the donor area either under grasses or permanent vegetation, modification of micro sites to ensure the establishment of tree species/ fruit crops and rain water harvesting and recycling for protective irrigation to the perennial vegetation and fruit crops.

Establishment of perennial vegetative cover: It is necessary to maintain vegetative cover on the soil to prevent wind erosion. Thus, silvopasture and horti-pasture systems are ideally suitable for reducing the soil erosion. However, farmers continue to grow annual crops for their subsistence, there is a need to adopt agro-horticulture, silvopasture and agro-pasture models developed by CAZRI for these areas in order to provide adequate vegetative cover during most part of the year.

Increasing biomass production Agricultural production systems designed for the arid region should be capable of utilizing even the off-season rainfall effectively so that the overall biomass production can be improved to meet the eventual shortages of fodder and fuel. Therefore, the perennial vegetation has to become as an integral part of the farming system.

Crop adjustment for alleviation of drought Moisture stress leads to drought, which, in turn, affects crop production adversely. Efforts were made to stabilise dryland agriculture by evolving contingent crop production strategies in rainfed areas. One of the best methods that were evolved is the adjustment of a suitable crop to the quantum of rainfall and distribution. Selection of suitable crop varieties, drought-resistance cultivars need to be grown. Three types of drought resistance crops are identified viz.,

1. drought 'escapability' - the ability of a plant to complete its life cycle before being subjected to serious water stress;
2. drought endurance with high internal water content, enabling a plant to survive drought by virtue of a deep root system or reduced transpiration; and
3. drought endurance with low internal water content during the period of drought but the ability to recover and grow when soil water is replenished.

Drought Management - Contingency Planning: The following long-term strategies have been framed (Narain *et al.*, 2002).

- There is a need to initiate collaborative researches at national and international levels to understand monsoon behavior and to develop effective and dependable strategies for short term and long term forecasting.
- Linkages may be developed and strengthened across the disciplines and institutions involved in drought prediction and drought management for efficient short-term, medium-term and long-term planning.

- Relationship between aerosol dust and other pollutants and anomalous rainfall/temperature need in depth investigation on behaviour of rainfall.
- There is a need to develop rainfed farming packages of cropping system for (a) delayed onset of monsoon, (b) timely onset of monsoon but intermittent droughts due to erratic distribution of rains, (c) terminal drought due to early withdrawal of monsoon, and (d) extended monsoon period due to late withdrawal of monsoon.
- There is a need to develop a national water transfer on grid to fill up major water reservoirs already created in the drought-prone areas and make the efficient use of this water to mitigate the adverse impact of drought.
- Efficient cropping zones should be identified as per agro-ecological sub-zonation. Over-exploitation/mis-use of ground water and surface water resources should be restricted.
- Policy frameworks on water, land use and drought at national level need immediate attention, with legal restrictions on over-exploitation of natural resource base.
- The carrying capacity of the region, for both human and livestock population may be worked out.
- *P. juliflora* trees are abundantly present in the region. Attempts may be made to improve the quality and palatability of *P. juliflora* leaves.
- Edible cactus, *Ailanthus excelsa* and thornless *Prosopis* may be propagated as feed for livestock in drought-prone areas.
- Promoting agroforestry and alternate land use systems, involving perennial plants and livestock may be encouraged and other income and employment generating activities be explored.
- Studies on socio-economic impact of drought need to be intensified.
- To minimize wastage, water should be charged on volume basis.
- Linkages between research and development may be strengthened.
- A compressive national policy on "Drought Management" may be prepared including both short term and long-term measures for drought mitigation should be in place specific to arid and semi-arid areas.

14. MEDIUM RANGE WEATHER FORECAST AND AGROMETEOROLOGICAL ADVISORY SERVICES

Medium range weather forecast (3-4 days) plays vital role to formulate agricultural advisory. As this technique has not fully been developed in tropics and may take some years for perfection, incorporation of knowledge of the probabilities of continuous dry or wet spells will be useful in operational decisions. Hence, agrometeorological bulletins based on the forecast can be made more useful if these also include probability of occurrence of meteorological events.

CAZRI is preparing the Agrometeorological Advisory Bulletins (AAB) since 1998 for Jodhpur region on the basis of medium range weather forecast received from NCMRWF, preceding week's weather and current crop situation in consultation with agricultural scientists. These bulletins are disseminated to the farming community through electronic, TV, Radio, and print media like local daily newspapers and to selected progressive farmers through personal contact. CAZRI also gives feedback on the daily weather data to NCMRWF and forecast verifications using actual weather data of the local meteorological station (Agromet. Observatory under respective AMFU centers)

14.1 Verification and performance of medium range weather forecast:

1. During 2000 to 2005 for Jodhpur region, the success percentage of medium range weather forecast on an annual basis varied between 87 and 93 with respect to occurrence of rain and no rain and between 62 and 78 with respect to cloud cover (Table 19). Similarly, the success of forecast for monsoon rainfall ranged from 68 to 83 percent and for cloud cover 72 to 88 percent, respectively. However, the rainfall forecast for rest of the season including winter was highly reliable (93 to 96 percent). But the failure of 4 to 7 percent is more important as a small drizzle at the time of crop harvest can become highly detrimental to crop like cumin grown in the region.
2. During winter season, low temperatures cause frost injury to crops. Temperature forecast for maximum and minimum temperature was successful in 36 and 39% cases during 2004, whereas for 36 and 40% during 2005.
3. Correlation coefficient between predicted and actual minimum temperature during winter season was 0.82 against 0.93 for the year. Similarly, correlation coefficient between predicted and observed maximum temperature was 0.94 for winter season and 0.92 on annual basis. Hence, performance of the global circulation model for prediction of minimum temperature is poor against the prediction of maximum temperature.
4. Wind speed forecast was usable in all the seasons during the year. The success of forecast for dominating wind direction was 35 percent during winter and 62 percent during summers

Table 19. Success percentage of rainfall and cloud cover forecast for Jodhpur region

Year	No. of observations	Rainfall		Cloud cover	
		Annual	Monsoon	Annual	Monsoon
2000	295	92	79	78	83
2001	291	88	76	76	85
2002	349	93	83	62	72
2003	351	87	68	67	88
2004	356	87	73	64	76
2005	357	91	80	71	75

14.2 Agrometeorological advisories and their impact on crops

The objective of agrometeorological advisory bulletins is to provide information to the users on a real time basis so that they can avail advantage of climatic information to better their production or minimize the damage, which may be caused directly or indirectly by unfavourable weather. This can be possible if information is provided to the farmers, in advance, on the type of weather situations likely to be encountered and the method to be adopted for efficient management inputs for minimizing risks.

Product of the forecast tells about six weather parameters viz., rainfall, cloud cover, maximum and minimum temperatures, winds and relative humidity. Medium term forecast for cloud cover and rainfall received for February 15 to 20, 2003 and its comparison with observed weather indicated that though there was variation between observed and forecasted values, but forecast has given at least relative indications regarding different meteorological variables over the region (Table 20). These changes in weather conditions coincided with the critical flowering and seed filling stage of cumin, and are considered to be favourable for the development of *Alternaria blight* (Gemawat and Prasad, 1972) and adoptions of prophylactic measures.

Table 20. Predicted weather based advisory for plant protection and its comparison with observed conditions in cumin during 2003

Date	Cloud cover (Octa)	Mean RH (%)	Rain (mm)	Wind speed (km h^{-1})	Wind direction*	Temperature (^{0}C)	
						Max.	Min.
Predicted Feb 15	2	28	0.0	4.2	NE	28.7	17.1
Observed	4	22	0.0	1.7	NE	33.5	12.6
Predicted Feb 16	3	41	0.0	3.0	E	31.1	18.4
Observed	8	26	0.0	1.9	WSW	28.5	17.3
Predicted Feb 17	7	49	5.0	6.0	WSW	29.9	21.1
Observed	6	50	20.0	6.7	WSW	24.0	17.2
Predicted Feb 18	5	42	5.0	5.0	WSW	28.3	15.8
Observed	6	80	2.7	11.9	WSW	24.6	16.0
Predicted Feb 19	2	56	0.0	5.0	W	22.5	9.2
Observed	0	49	0.0	7.8	WSW	21.2	12.2
Predicted Feb 20	2	59	0.0	3.0	N	25.2	12.5
Observed	2	38	0.0	5.4	NNE	24.2	11.0
Predicted Feb 21	0	41	0.0	4.0	NE	27.9	15.6
Observed	0	40	0.0	4.0	NNE	25.6	13.2

* NE Northeast, E East, W West, WSW West southwest, NNE North of northeast

Table 21. Yield and yield attributes of cumin cultivars at harvest stage

Winter 2001-02

Cultivars	Plant popula -tion (plant m^{-2})	Crop height (cm)	No. of umbels	No. of Umbe- llate per umbel	Dry matter above ground (g plant^{-1})	Seed weight (g plant^{-1})	Weight of 1000 grain (g)	H.I.	Seed yield (kg ha^{-1})
RZ19 +TC	46	36.0	27	5.0	3.55	1.43	3.8	0.40	660 (120)*
RZ19	44	32.0	24	4.5	2.45	1.09	3.7	0.44	480 (60) *
RZ209 +TC	52	36.5	24	4.5	2.58	1.15	3.8	0.45	600 (100) *
RZ209	40	32.5	19	4.5	2.35	1.10	3.7	0.45	420 (40) *
Local seed +TC	40	31.0	18	4.5	2.52	1.12	3.5	0.45	450 (50) *
Local seed	38	28.0	16	4.0	1.77	0.79	3.4	0.45	300
LSD (P=0.05)	5.3	NS	10.5	NS	1.7	NS	NS	NS	83

TC - Tumba cake

Winter 2002-03

RZ19 +TC	54	35	28	5.0	2.97	0.89	3.5	0.30	481 (190) *
RZ19	53	37	17	5.0	3.00	0.75	3.4	0.25	395 (138) *
RZ209 +TC	56	35	23	5.5	2.37	0.83	3.4	0.35	462 (180) *
RZ209	54	38	20	5.0	2.37	0.71	3.4	0.30	384 (131) *
Local seed +TC	40	32	18	4.5	1.87	0.56	3.1	0.30	223 (34) *
Local seed	34	32	15	4.5	1.63	0.49	3.0	0.30	166
LSD (P=0.05)	3.8	3.2	1.9	NS	0.38	0.05	NS	NS	31

* Percent increase in yield due to impact of weather-based advisory bulletins against traditional practices.

NS - Non-singhficant

(Source : Singh et al., 2005)

Study revealed that adoption of agrometeorological advisory services (AAS) has enhanced the seed yield of cumin from 120 to 360 kg ha^{-1} in 2001-02 and from 57 to 296 kg ha^{-1} in 2002-03 compared to traditional practices adopted by cumin growers. Timely prediction from AAS could save the crop due to adoption of corrective measures (light irrigation prior to frost, spray of 0.1% H_2SO_4). However, considerable loss (20 to 25%) was observed without frost preventive measures (Table 21). As a result, farmers are taking keen interest to respond positively to advisory bulletins.

The feedback information collected from farmers shows that advisory bulletins were found very useful to them. Advisory services can be made further useful for the cumin growers if information on duration of cold waves, core period of hail/dust storm followed by drizzling rain associated with western disturbances during critical growth stages of cumin are given in the bulletin

15. ECONOMIC IMPACT ASSESSMENT OF AGROMETEORO LOGICAL ADVISORY SERVICES (AAS)

Economic assessment of AAS was studied in Jodhpur region on field of 80 farmers, 40 each under AAS and non-AAS category during 2003 to 2005 in Manai, Narva and Palri Mangalia villages of Jodhpur district. Test crops were pearl millet and guar during *kharif* season and cumin and mustard during *rabi* under rainfed and irrigated conditions.

During *kharif* 2005, AAS farmers who have followed weather-based advisory could get more return Rs.5698 per ha in pearl millet compared to non-AAS farmers who got Rs.3592 per ha. In clusterbean also AAS farmers got higher return @ Rs. 3723 per ha compared to non-AAS farmers who got Rs.878 per ha. The cost-benefit ratio of AAS and non-AAS farmers was 1.93 in pearl millet compared to 1.24 in clusterbean (Table 22).

During *rabi* season, bi-weekly agrometeorological advisory bulletins were disseminated particularly to AAS farmers in the selected villages for their benefit in day to day operations in cumin

Table 22 Impact of agromet advisory services in pearl millet and clusterbean

Treatment	No. of farmers	Grain yield (kg ha^{-1})	Gross return (Rs ha^{-1})	Cost of cultivation (Rs ha^{-1})	Net return (Rs ha^{-1})	B:C Ratio
Pearl millet						
AAS	32	645	8648	2950	5698	1.93
Non-AAS	26	447	6480	2888	3592	1.24
t-test value		2.00**				
Clusterbean						
AAS	07	385	7483	3760	3723	0.99
Non-AAS	07	155	3200	2322	878	0.37
t-test value		2.22**				

**Significant at 5% probability level (at P=0.01) AAS: Group of farmers following agromet advisory services.
Non-AAS Group of farmers wh did not follow agromet advisory services.

and mustard. Farmers who followed the advisory reported higher yield and net returns in case of cumin as well as mustard.

During 2005 *rabi* season, farmers who followed weather-based advisory could get more return Rs.5281/ha in mustard and Rs.2594/ha in cumin through higher yield in comparison to those who had not followed advice (Table 23). Hence, agrometeorological advisory services is not only useful in increasing the productivity of cumin and mustard of AAS farmers but also helps to mitigate the adverse weather situation experienced by the farmers in the region.

Table 23 Impact of agromet advisory services in cumin and mustard

Treatment	No. of farmers	Grain yield (kg ha^{-1})	Gross return (Rs ha^{-1})	Cost of cultivation (Rs ha^{-1})	Net return (Rs ha^{-1})	B:C Ratio
Cumin						
AAS	24	193	15718	12052	3666	0.30
Non-AAS	14	168	13762	12690	1072	0.08
t-test value		2.07**				
Mustard						
AAS	34	1683	24395	12307	12088	0.98
Non-AAS	27	1472	21395	14588	6807	0.46
t-test value		2.00**				

**Significant at !% probability level (at P=0.01) AAS: Group of farmers following agromet advisory services.

Non-AAS Group of farmers who did not follow agromet advisory services.

(Source APR of NCMRWF, CAZRI)

Dr. L.S. Rathore, NCMRWF, New Delhi along with Scientists of CAZRI, Jodhpur interacting with farmers of Manai village (Rajasthan) on the use of weather based Agro-Advisory Services

CONCLUSIONS

Droughts in India occur more frequently in arid and semi-arid regions. The arid areas are almost subjected to permanent droughts and semi-arid areas are likely to be subjected to intermittent droughts. Therefore, the drought management strategies have to be identified separately both for arid and semi arid areas.

Arid region is the home of drought, it will occur in the region in one or another part, with varying severity. Drought preparedness is required at all levels including Government, Society and Individual. Long-term forecast of monsoon/drought has always an element of uncertainty. However, highly advanced forecasting system of IMD and term forecasts of NCMRWF and AAS drought mitigating technologies developed by the CAZRI and other research institutions with adequate infrastructure and funding information technology has equipped better now to face drought than before. Between 1901 and 2005 western Rajasthan experienced 58 moderate to severe droughts. There were five occasions when drought occurred in successive years: 1903-05, 1957-60, 1966-71, 1984-87 and 1998-2000. Droughts of 1918, 1987 and 2002 were most severe, when rainfall departure from the normal was -81, -65 and -70 per cent, respectively. The 2002 drought during July in India was unique with reference to its climate anomalies, their impacts as well as the institutional responses. However, the country was equipped with better coping mechanism. The month of July, normally expected to be wettest month turned out to be the driest in the recorded history since 1877 causing a loss of around 24 million tonnes of foodgrain reported across the country. The estimated crop loss works out to be Rs 240 thousand crores. The prediction provided by NCMRWF on week-by-week basis was of great value to monitor the drought situation.

The districts of Jaisalmer, Barmer, Bikaner and Ganganagar have the maximum probability of drought recurrence in one place or the other even in good rainfall years. Production of pearl millet during *kharif* is reduced by 10-30% during mild drought, 35-60% during moderate drought and 75-90% during severe droughts. Surface water availability also declined during drought years with the drought severity creating drinking water problem. Fodder scarcity which is shorter by 20-30% of the demand during normal years, touches 80-100% during severe droughts. Consequently, large-scale animal and human population migration for food, fodder and water, as was the practice also reduced due to better management of drought and resistance from neighbouring states which were earlier more open to irrigation.

CAZRI has developed number of drought resistant, short-duration crop varieties, which yield better grain and stover and can avoid terminal drought. The Institute has also developed a number of alternate land use systems that help to minimize the impact of drought. Though, government drought relief is common in the region, gravity of drought warrants an exclusive policy for drought proofing.

Droughts are mainly due to scarcity of precipitation. However, human activities do contribute in escalating the impacts of droughts. Though traditional wisdom exists to reduce the impact, these are becoming victim of development and luxury. Therefore, policies need to be framed not only to mitigate drought impacts with temporary solutions but to eliminate its impacts on society permanently. With the improved technological innovations and awareness created by mass media and

Governmental efforts, the capabilities to meet the challenges have improved considerably over the past few years.

Sustainable strategies must be developed to alleviate the impact of drought on crop productivity. In areas of recurring drought, one of the best strategies for alleviating drought is choice of crop and varietal manipulation, through which drought can be avoided or its effects can be minimized by adopting varieties of short duration crops that are drought-resistant at different growth stages. If drought occurs during the middle of a growing season, corrective measures can be adopted; these vary from reducing plant population to fertilization or weed management. In better rainfall areas where there are a series of wet and dry spells, rainfall can be harvested either in farm ponds or in village tanks and can be recycled as life saving irrigation during a prolonged dry spell, no strategy can be adopted universally. In fact, all such strategies are location, time, crop, crop stage, and (to some extent) socioeconomic condition specific. Developing such strategies for each specific condition can help make agriculture sustainable.

The monitoring and analysis of drought have long suffered from the lack of an adequate understanding data collection and reasonable model for drought prediction. Accurate and timely monitoring of the dynamic drought conditions is important for reducing the impacts of drought, but this information must be communicated to decision makers. In India, the drought situation is usually monitored with the help of synoptic records, remote sensing techniques and other standard methods that include empirical technique. A comprehensive early warning system is considered to be a critical component of a state or regional drought plan. The remote sensing tool is especially beneficial if weather data is not available and/or non-representative due to sparse weather observing network. If real-time weather information is reliable, it should be combined with satellite derived characteristics and used as a comprehensive tool for monitoring vegetation stress, estimating drought, assessing drought impacts and crop yields.

The management of drought is initiated by careful monitoring of rainfall situation over different parts of the country or region on day-to-day, week-by-week and on month-to-month basis. Use of automatic weather recording stations linked with a national network for a real time monitoring of drought is suggested Prolonged and accumulated deficiency of rainfall over an area or region could evolve into a drought situation. Therefore, medium and extended range predictions assume considerable importance for initiating suitable mitigation measures.

The Agrometeorological Advisory Unit of Central Arid Zone Research Institute, Jodhpur has been preparing bi-weekly weather advisory bulletins based on the medium range weather forecasts obtained from National Centre for Medium Range Weather Forecasts (NCMRWF), New Delhi since 1998. The advisories includes weather dependent agricultural operations such as timely sowing, irrigation, harvesting dates, expected pests and diseases and their eradication, anticipated drought, heat and cold waves conditions and their remedial measures to minimize the risk from the vagaries of weather. From a study on the economic impact of weather advisories to farming community revealed that the advisories were useful for increasing the productivity of cumin, mustard, wheat and pearl millet. The efforts of CAZRI and NCMRWF in drought warning and mitigation will continue in future.

Strategy of drought proofing requires

- Collection of long-term oceanographic and meteorological data and their interpretation for development of forecasting model for monsoon/drought.
- Integration of remote sensing data with meteorological data for refinement of prediction /monitoring of drought models on regional as well as local scales.
- Development of a sound land and water use policy to pre-empt difficulties faced in the event of drought. Utilization of relief partly to arrange provisions and partly to evolve permanent land base assets like silvipastures, common grazing lands, water harvesting and re-use structures with participation of people.
- Adopting coping mechanism with traditional wisdom and innovations.

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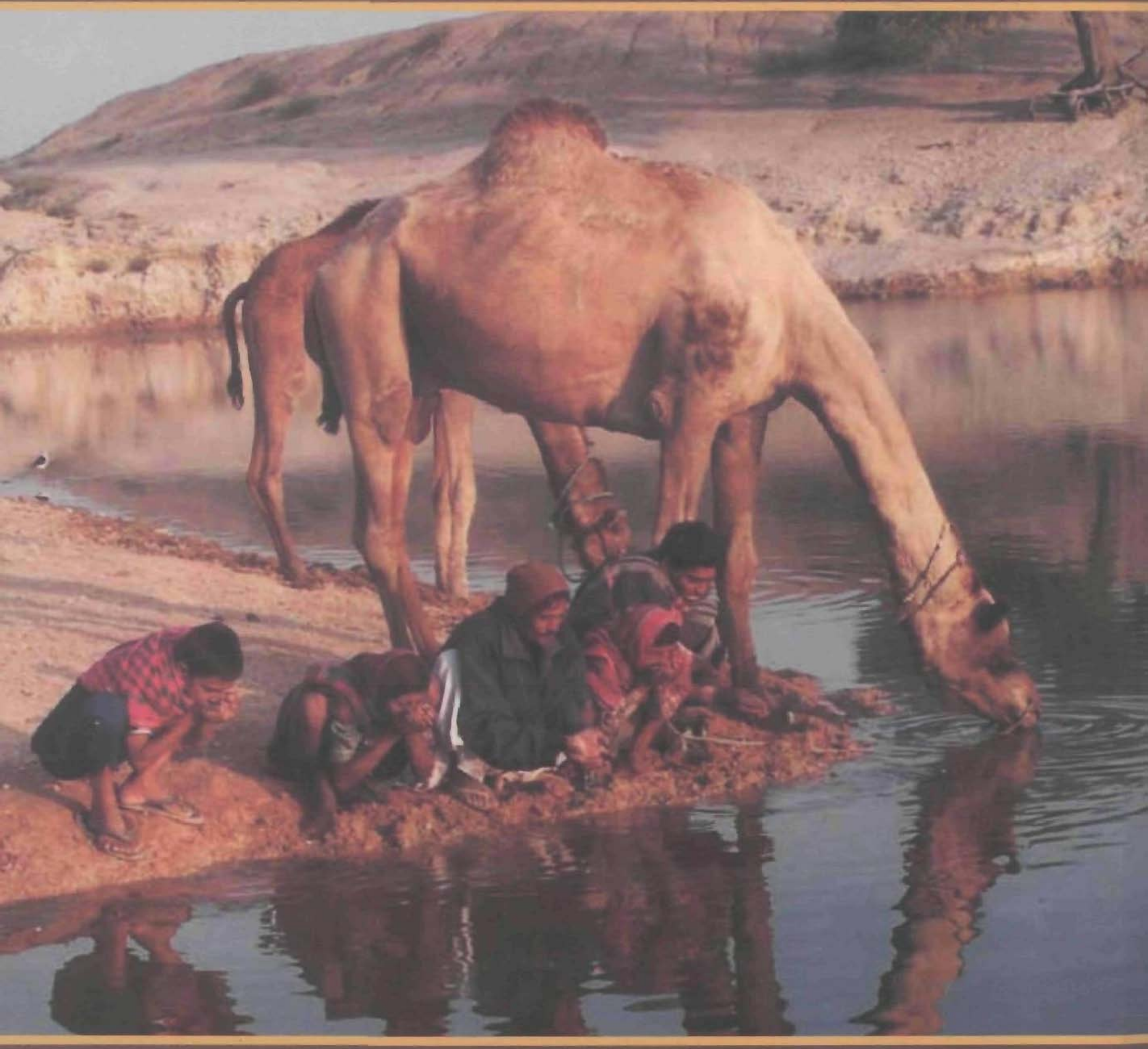

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