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Agricultural Drought Monitoring and Assessment

13.1. Introduction

Drought is a climatic anomaly, characterized by deficient supply of moisture resulting either from sub-normal rainfall, erratic rainfall distribution, higher water need or a combination of all the three factors. Several definitions of drought are available in literature. In India, National Commission on Agriculture (1976) has categorized drought into three types, viz., meteorological drought, hydrological drought and agricultural drought based on the concept of its utilization.

In meteorological terms, a drought is "a sustained, regionally extensive, deficiency in precipitation". All other definitions are related to the effect or impact of below normal precipitation on water resources, agriculture and social and economic activities; hence the terms hydrological drought and agricultural drought. In quantitative terms, the definitions could vary among countries and regions. In India, the definition for "meteorological drought" adopted by the Indian Meteorological Department (IMD) is a situation when the deficiency of rainfall at a meteorological sub-division level is 25 per cent or more of the long-term average (LTA) of that sub-division for a given period. The drought is considered "moderate", if the deficiency is between 26 and 50 per cent, and "severe" if it is more than 50 per cent. Based on this definition, the National Commission on Agriculture has given the following broad classifications:

Hydrological drought is a prolonged meteorological drought situation resulting in depletion of surface water from reservoirs, lakes, streams, rivers, cessation of spring flow and fall in groundwater levels causing severe shortage of water for livestock and human needs.

Agricultural drought is a situation when rainfall and soil moisture are inadequate during the crop growing season to support healthy crop growth to maturity, causing crop stress and wilting. It is defined as a period of four consecutive weeks (of severe meteorological drought) with a rainfall deficiency of more than 50 per cent of the LTA or with a weekly rainfall of 5 cm or less during the period from mid-May to mid- October (the Kharif season) when 80 per cent of the country's total crop is planted, or six such consecutive weeks during the rest of the year. The National Oceanic and Atmospheric Administration (NOAA) defines agricultural drought as a combination of temperature and precipitation over a period of several months leading to substantial reduction (less than 90%) in yield.

Drought differs from other natural hazards in many respects -most complex and least understood of all disasters. While it is difficult to demarcate the onset and end of drought but the effects of drought accumulate for a considerable period of time. Prolonged droughts or abnormal weather conditions such as extended winters, cold summers, floods, biological factors like plague of locusts or rodents result in famines.

13.1.1. Drought impacts – the vicious circle

Practically all the developing countries, being primarily agrarian, are very much dependent on the vagaries of seasonal rainfall and climatic conditions. On an average, severe drought occurs once every five years in most of the tropical countries, though often they occur on successive years causing misery to human life and live stock. The crisis brought out by this hazard directly hit poorest and most deprived sections of our society thus destroy the life, economy, infrastructure, environment and society because all are inter linked.

Drought results from adverse (figure 13.1) climatic conditions leading to deleterious impacts on various sectors of the economy. The immediate impact is on crop area, crop production and farm employment. Reduction in income and purchasing power of farmers forces the small and marginal farmers to join the band of agricultural labourers leading to increase in unemployment. Speculation of poor farm harvest drives the food prices upwards. Market failure and advantage-seeking group work in perfect nexus to intensify the impact of drought. The effect of this nexus are catastrophic particularly to small and marginal farmers who constitute the large chunk of farming community, who tend to migrate obviously to urban areas in search of employment opportunities. Shortage of drinking water and starvation for food are the other consequences that emerge. Fodder problem drives away the animals to distress sales. Thus climate is the initial causative factor for drought, the implications and intensity of drought are manifested by human interactions with the situation leading to famines.

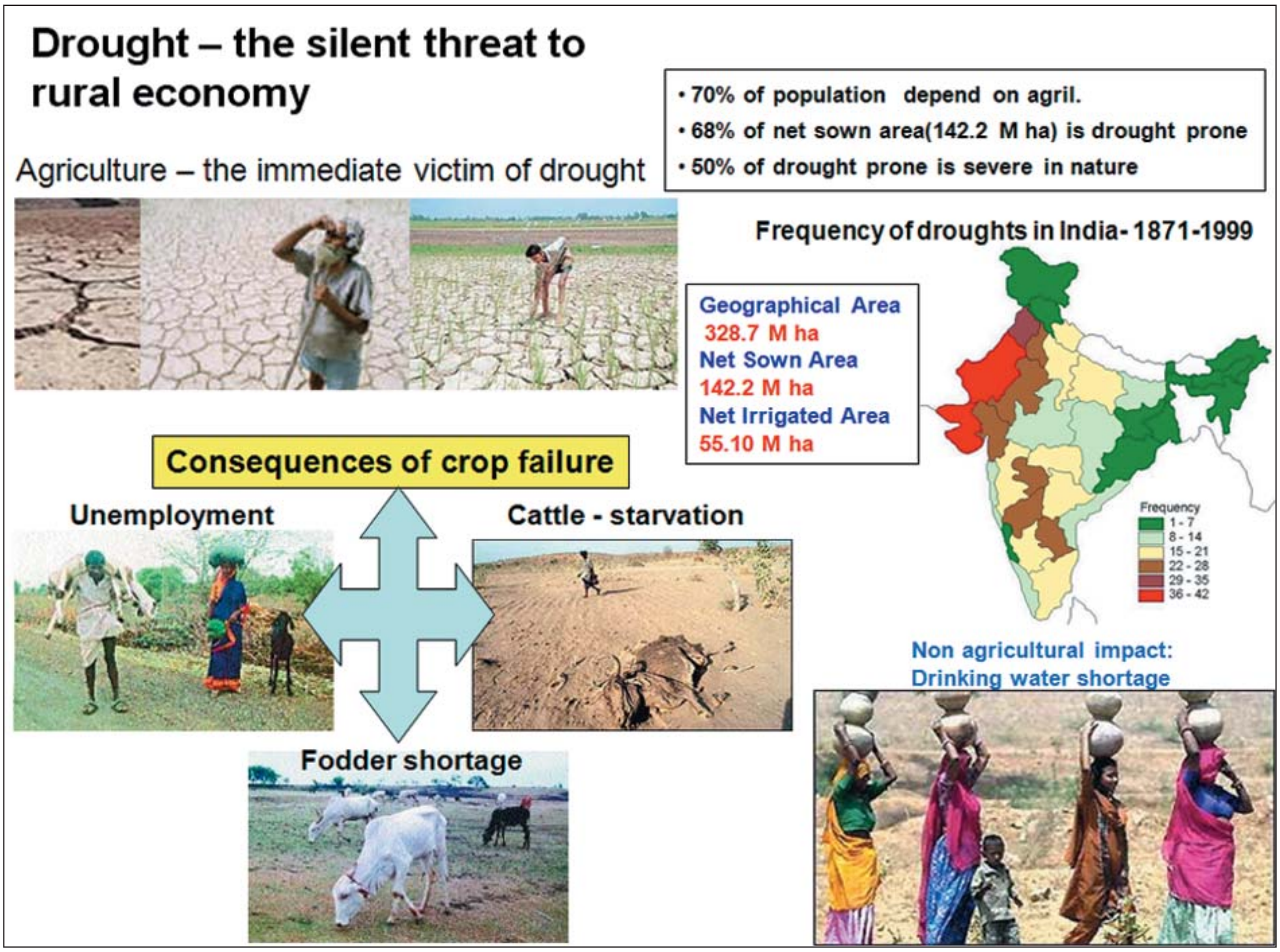


Figure 13.1: Multidimensional impacts of drought

13.1.2. Drought scenario in India

Indian economy is largely dependent on agriculture with more than 70% of the population depending either directly or indirectly on agriculture for their livelihood. Owing to abnormalities in the monsoon precipitation, in terms of spatial and temporal variation, especially, late onset of monsoon, prolonged break and early withdrawal of monsoon; drought is a frequent phenomenon over many parts of India. About two thirds of the geographic area of India receives low rainfall (<1000 mm), which is also characterized by uneven and erratic distributions. Out of net sown area of 140 million hectares about 68% is reported to be vulnerable to drought conditions and about 50% of such vulnerable area is classified as 'severe', where frequency of drought is almost regular. India experiences localized drought almost every year in some region or other. In the post independence era, major droughts that affected more than 1/3rd of the country were reported during 1951, 1966-67, 1972, 1979, 1987-88 and 2002-03 (Subbaih, 2004). Thus, despite significant technological advances since independence, Indian agriculture continues to be periodically affected by droughts (Table 13.1).

Table 13.1: Drought history of India

Period	Drought years	No. of years
1801-25	1801,04,06,12,19,25	6
1826-50	1832,33,37	3
1851-75	1853,60,62,66,68,73	6
1876-1900	1877,91,99	3
1901-25	1901,04,05,07,11,13,15,18,20,25	10
1926-50	1939,41	2
1951-75	1951,65,66,68,72,74	6
1976-02	1979,82,85,87,2002	5

(Source: Kulshreshta and Sikka, 1989)

Abnormally low rainfall in 1979, reduced the overall food grain by as much as 20%. The 1987 drought damaged 58.6 million hectares of cropped area affecting over 285 million people. The 2002 drought had reduced the sown area to 112 million hectares from 124 million hectares and the food grain production to 174 million tons from 212 million tons, thus leading to 3.2% decline in agricultural GDP. The total food grain production in India has to be stepped up from 212 million metric tons to 300 million metric tons by 2020 to meet the food demands of growing population.

13.1.3. Droughts – the global scenario

All the developing countries, being primarily agrarian, are very much dependent on the vagaries of seasonal rainfall and climatic conditions and hence more vulnerable to droughts. On an average, severe drought occurs once in every five years in most of the tropical countries, though often they occur on successive years causing severe losses to agriculture and allied sectors. More than 500 million people live in the drought prone areas of the world and 30% of the entire continental surface is affected by droughts or desertification process. In 2004, wide spread drought in much of Asia resulted in loss of agricultural production of hundreds of million dollars. In Thailand, drought hit 70 of 76 provinces and affected more than 8 million people. Southern Chines island of Hainan suffered its worst drought in 50 years during 2004. Vietnam's eight central highland provinces suffered severe drought in 2004. The direct impacts of droughts are wide ranging; physical, social, economical and environmental (Rathore, 2004). Drought prone areas of the world are depicted as (1) frequent and intensive (2) less intensive drought prone areas in Figure 13.2. Nearly 50 per cent of the world's most populated areas are highly vulnerable to drought. More importantly, almost all of the major agricultural lands area located there (USDA 1994). In the world's two largest agricultural producers, the United States and the former Soviet Union (FSU), drought occur almost every year.

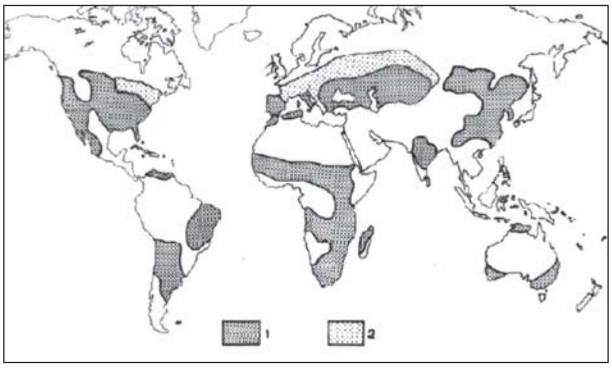


Figure 13.2: Drought prone areas of the World (source: Goldsberg,1972)

USA is the world's second largest grain producer accounting for 70% of corns and 60% of coarse grains and 30% of wheat (FAO 2000). Drought is typical for north American climate and occurs almost every year. USA had experienced many droughts and dry spells in the last century which had significant impact on economic, social and environmental sectors. Recent drought with devastating effect is that of 1988 drought which cost around $40 billions. The 1988 drought ranks as one of the nation's greatest disasters of 20th century. Yields of agricultural crops dropped so sharply that grain production fell below domestic consumption probably for the first time in the last half century (Kogan 1995). Other major droughts of the last 15 years included 1989 and 1996 which were quite similar.

In Europe, drought is a problem in the southern countries along the rim of the Mediterranean (Croatia, France, Greece, Italy, Slovenia and Spain). Over the past 1000 years of Russian history, catastrophic droughts occurred eight to twelve times in every century (Kogan 2000).

In Latin America and the Caribbean, the drought associated with the El Nino has severe impact. For example, after the El Nino of 1983, Peru's GDP fell by 12 percent, mostly because of a reduction in agricultural output and fishery. The national economy took a decade to recover. Damage in the Andean community countries (Bolivia, Colombia, Ecuador, Peru and Venezuela) due to the 1997-98 El Nino was estimated at more than US$7500 million (www.octi.gov.ve). The Caribbean countries that are highly vulnerable for drought are Antigua, Cuba, Guyana, Haiti and Jamaica.

West Asia is arid and vulnerable to drought with rainfall scanty and variable (ACSAD 1997). Nearly 80% of the region is classified as semi-desert or desert (AOAD 1995). Drought is the most important natural disaster in the region. The rainfall appears to be declining in some countries bordering the Mediterranean Sea. Over the past 100 years, precipitation has decreased by more than 5 per cent over much of the land bordering. Mediterranean with few exceptions such as Libya and Tunisia (IPPC 1996). The region suffered from drought during 1930s, 1960s and the 1990s. Cycles of drought have become intense and more frequent. The 1998-99 drought affected many countries and Syria was the worst hit, suffering its worst drought in 25 years (FAO 1999).

13.2. Monsoon pattern in India

About 70% of the annual rainfall over India is contributed by south west monsoon which commences in the month of May from the southern tip. Normally, the monsoon arrives in Sri Lanka and over the islands of the Bay of Bengal in the last week of May and reaches the extreme south of the Indian peninsula a week later. Then the monsoon advances in two directions as the Arabian sea branch (covering towards Mumbai) and Bay of Bengal branch (covering towards Assam). On reaching the southern periphery of the Himalayans, the Bay of Bengal branch deflects towards west covering gangetic plains. The Arabian seas branch covers central India and merge with Bay of Bengal branch to form a single current. Western UP, Haryana and Rajashtan states experience the first showers by first of July. By mid July, the monsoon extends to Kashmir area. The normal duration is roughly 100 days and its withdrawal starts from Punjab and Rajasthan by mid of September.

The normal rainfall during south west monsoon rainfall is 890 mm for the country as a whole, and it is 611 mm in north-west India, 994 mm in central India, 723 mm in southern India and 1427 mm in north east India. Out of 890 mm of normal rainfall in the country, June month accounts for 162 mm followed by 293 mm in July, 262 mm in August and 175 mm in September (www.imd.gov.in).

The onset of north east monsoon is not well defined and on many occasions there is no clear indication on the withdrawal of south west monsoon and onset of north east monsoon. Therefore, it is a general understanding that the rainfall in the winter months from October to December represents the northeast monsoon. Tamil Nadu state receives significant rainfall from north east monsoon, and it is about 463 mm representing 48 % of annual rainfall of the state (Das, 1968).

13.3. Agricultural Drought Monitoring & Assessment

The immediate and more devastating impact of drought is on agricultural crops leading to loss of production, unemployment, fodder shortage etc. The water needs in agricultural sector are going to be very high, as several thousand tons of water is required to produce each metric ton of food grains. Therefore, there is a need for effective monitoring of agricultural drought, its onset, progression and impact on crops to minimize the damages.

Monitoring and assessment of drought conditions at different scales and timely dissemination of information constitute the most vital part of drought management system. Inadequate system for monitoring the drought, unreliable data points, lack of standard procedures to calculate indices of drought prevalence and intensity could lead to inefficient management strategies. Therefore, the need is to have a sound, operationally feasible, objective and economically viable system for drought monitoring and analysis. Conventionally agricultural drought conditions are characterized by ground observations on meteorological parameters such as rainfall, aridity and agricultural parameters such as sown crop area, crop condition and crop yield.

13.3.1. Meteorological indicators

Rainfall is the most important single factor influencing the incidence of drought and practically all definitions use this variable either singly or in combination with other meteorological elements. Many studies have studied the nature and frequency of droughts based on simple relation between actual and average rainfall.

Based on rainfall, temperature, soil moisture and evaporation, various indicators of meteorological drought have been developed by researchers as shown in Table 13.2. Some of these indices like Palmer's index, Standardized Precipitation Index, Crop Moisture Index are being used operationally in some of the countries. Gibbs and Meher (1967) made a study of drought in Australia by using annual rainfall deciles as drought indicator. Using a network of 100 stations, maps have been prepared showing the decile ranges in which rainfall for each year has occurred. Van Rooy (1965) developed a drought anomaly index based on the ratios of rainfall departure from normal to the departure of threshold value from normal. The threshold value was taken as the average of the lowest ten values in series. Bhalme and Mooley (1980) developed a numerical index which is comparable in space and time, based on monthly rainfall and duration. They devised a scale, which ranged from -4 to +4 on the basis of which droughts were classified.

Table 13.2: Meteorological indicators of drought

Year	Index
1916	Munger's Index
1919	Kincer Index
1930	Morkowitch Index
1942	Blumenstock Index
1954	Antecedent precipitation index
1957	Moisture adequacy index
1965	Palmer's index (PDSI, PHDI)
1968	Crop Moisture Index
1968	Keetch Byram Drought Index
1981	Surface water supply index
1993	Standardized precipitaion index

Standardised precipitation index was developed by Colorado state university (Mc Kee *et al.*, 1993, 1995) to improve drought detection and monitoring capabilities. It is based on precipitation alone. Its fundamental strength is that it can be calculated for a variety of time scales. This versatility allows the SPI to monitor short term water supplies, such as soil moisture, important for agricultural production and long term water resources such as ground water supplies, stream flow and lake and reservoir levels. The ability to examine different time scales also allows droughts to be readily identified and monitored for the duration of the drought. Calculation of SPI for a specific time period at any location requires a longterm precipitation database with 30 years or more of data. The probability distribution functions are determined from the long term record by fitting a function to the data. The cumulative distribution is then transformed using equal probability to a normal distribution with a mean zero and standard deviation one, so the values of SPI are really in standard deviations. SPI values generally ranges from +2 to -2, from extremely wet to extremely dry conditions respectively (Mc Kee *et al.*, 1993, Wu *et al.*, 2006).

In 1965, WC Palmer developed an index to measure the departure of the moisture supply (Palmer, 1965). Palmer based his index on the supply-and-demand concept of the water balance equation, taking into account more than just the precipitation deficit at specific locations. The objective of the Palmer Drought Severity Index (PDSI), as this index is now called, was to provide measurements of moisture conditions that were standardized so that comparisons using the index could be made between locations and between months (Palmer 1965). The PDSI is a two layer moisture model. Palmer introduced the concept of CAFEC (Climatically approximate for the existing conditions) rainfall, which was normal for a given place. The anomaly between the CAFEC and actual precipitation is used as a drought indicator. To make this anomaly comparable in space and time, it is multiplied by a weighting factor K which depends on average moisture demand and supply and mean of the absolute values of anomaly of the place. The classification of drought intensity based on Palmer drought index is +4 representing extremely wet and -4 representing extremely dry conditions.

There are considerable limitations when using the Palmer Index, and these are described in detail by Alley (1984) and Karl and Knight (1985). Apart from the climatological parameters, physical parameters like canopy-air temperature differences have also been used for assessing the stress degree days (SDD) to indicate the impact of drought. The SDD have been found to correlate well with the yield fluctuations as a result of moisture stress. Also spectral ratios of infrared to red reflectance obtained from radiometers (Satellite or ground based) can be used to monitor the agricultural effects of drought based on the observed rate of change of absorbed radiation expressed as a fraction of the maximum rate.

The India Meteorological Department (IMD) prepares rainfall maps on sub-divisional basis every week throughout the year. These maps show the rainfall received during a week and corresponding departures from normal. During monsoon season, these maps are indicative of development of drought. In addition, IMD also provides the information on weekly rainfall and its deviation from normal at district level for the entire country. This information is useful to identify the districts with deficit/scanty rainfall and the prevailing meteorological drought.

IMD also monitors drought using water balance technique which addresses agricultural drought. The aridity index is calculated using the formula;

Aridity Index = (Actual Evapotranspiration – Potential Evapotranspiration) / Potential Evapotranspiration

The departure of aridity index from normal percentage terms is used to define the various categories of drought severity. Anomaly upto 25 % is attributed to mild drought, 26-50% to moderate drought and >50% to severe drought. IMD has been bringing out weekly aridity anomaly charts from 1979 onwards, based on data from different observatories, covering south west monsoon period. These charts show the departures of actual aridity from normal aridity giving indication of the severity of water deficit to water demand relationship on weekly basis. IMD is also preparing detailed maps of rainfall, temperature (maximum and minimum), cloud cover, relative humidity and analyze this information with prevailing crop conditions and an Agromet Advisory Bulletin is prepared and disseminated to users.

13.3.1.1. Limitations of using rainfall as agricultural drought indicator

Many studies have proved that spatial and temporal distribution of rainfall is more important than the total rainfall in a month or season. A review of past agricultural droughts in the country reveal the lack of unique relationship between incident ground measured rainfall (only a part of which replenishes soil moisture and thus available to vegetation) and the resulting vegetation development within and between seasons as well as across space. The “rainfall use – efficiency” varying over both time and space and the vegetation species dependence limits the use of rainfall as a sole or major agricultural drought indicator. Rainfall as an agricultural drought indicator is limited by the sparse ground observations (especially in view of high spatial variability of tropical rainfall) as well as the lack of spatially and temporally unique relationship between incident rainfall and vegetation development. Though the daily reporting network of IMD is supplemented by the State Government rain-gauge network in each state, real-time information from the latter is normally limited to rain-gauges located at Tahsil Headquarters. The possibility of observational errors also makes it necessary to process this data prior to its use leading to time delays. Aridity anomaly data currently available is only representative of large areas such as meteorological sub-divisions. The aridity anomaly also suffers from the same limitations as that of rainfall.

13.3.2. Water Balance Approach

Using the soil characteristics and initial soil moisture values, weekly/monthly water balance computations can be carried out. If monthly water balances are to be calculated input data required by the model consists of monthly values of precipitation, P_m , and potential evapo-transpiration, PET_m (calculated by any method appropriate to the region and available data). These values can be climatic-average values of a time period or actual monthly averages of a series of annual registers.

Also the model requires the soil-water storage maximum capacity, S_{max}

and the initial soil moisture content, S_0. The water balance model will then calculate soil moisture content, actual evapotranspiration and runoff (here water surplus).

Soil moisture content

If for a given month $P_m > PET_m$, the soil moisture at the end of that month is then obtained as:

$S_m = \min \{(P_m - PET_m) + S_{m-1}, S_{max} \}$.

Otherwise, if $P_m < PET_m$, the soil moisture is given as:

$S_m = S_{m-1} * \exp (P_m - PET_m / S_{max})$

ii. Actual evapotranspiration (ET_m)

For the first of the cases, $P_m > PET_m$,

$ET_m = PET_m$, otherwise

$ET_m = P_m + S_{m-1} - S_m$

Water surplus

It is assumed that soils will only produce water surplus whenever the soil moisture content at the end of a month will equal its maximum water storage capacity. In that case water surplus, T_m, will be calculated as

$T_m = P_m - PET_m + S_{m-1} - S_m$

Rainfall departures and Soil Moisture Index (SMI) values are useful for contingency crop planning based on the climatic conditions. Spatial distribution of weekly SMI (actual / available moisture) maps reveals moisture status spatially and temporally in a given area. Time to time contingencies can be suggested to the farmers, by closely monitoring the weather conditions during the season. The crop production strategies situation-wise alternate crops / cropping systems could be suggested.

13.3.3. Agricultural observations

Agriculture departments of different states collects information on crop sown areas, crop development, pests and diseases, etc., to assess the drought situation. A special task force known as Crop Weather Watch Group is constituted in India by Ministry of Agriculture. This group reviews the progress of monsoons, crop situations, water levels in reservoirs/dams, availability of fertilizers etc. Though the ground observations of agricultural conditions by the State Departments of Agriculture and Revenue are exhaustive such a system involves a significant amount of subjective judgment at various stages. The periodicity and extent of ground observations also vary significantly between different states. The nature of sparse ground observations also make it difficult to assess, in near real-time, average drought conditions over the district. Thus ground monitoring of both causative factors as well as impact of drought assessment suffer from various limitations such as sparse observations, subjective data etc.

13.4. Drought information needs

Objective information on the prevalence of drought and its intensity along with its spatial and temporal dimensions is very critical for evolving drought combating strategies either of short term or long term. The information requirements of scientific/research organizations for effective drought assessment and the requirements of government functionaries and farming community for drought management at community level or farm level differ in various issues are shown in Table 13.3. For example, the needs of federal government are mostly at district level while district administration requires detailed drought information at sub district level such mandals/ taluks for generating and implementing technically feasible and economically viable drought management strategies.

Table 13.3: Requirements of drought information (Source: Roy et al., 2006)

	A. Information requirements for drought assessment
	Spatial rainfall on weekly basis
	Spatial aridity
	Spatial soil moisture (real time)
	Spatial crop condition
	B. Information requirements for drought management
1	**Beginning of the season** (a) Extent of delay in sowings (no. of days/weeks) (b) Extent of reduction in sown area (c) Expected sown area
2	**Middle/end of the season** (a) Impact of drought on standing crops. (b) Expected reduction in crop yield
3	**Scale of information** At different spatial units (mandals/taluks) within district Weekly/fortnightly information
4	**Quantitative assessment of drought impact** (a) Area affected by drought - list of drought affected mandals/taluks along with severity level.
5	Early warning on drought occurrence/severity
6	**Drought relief management** Prioritization of the areas in terms of drought severity level.

13.4.1. Gap Areas

The gap areas for technology development to meet the information needs for drought assessment and drought management are mentioned below:

- Geospatial data bases
- Use of new indices for drought assessment
- Data bases of drought related information
- Advanced tools for geospatial data analysis
- Spatial Decision Support System
- Climatic models for simulation of drought events
- Drought assessment at local scales
- Drought early warning
- Quantitative assessment of drought impact
- Institutional framework
- Drought information delivery mechanism

High quality data on drought related parameters and powerful geospatial tools for analyzing such data are required to address these gap areas.

13.5. Application of Geospatial Information Technology

Dynamic nature of droughts with complex phenomenon having multiple effects form a major challenge in planning, monitoring, predicting, assessing impact and offering solutions to drought hit areas. Because of these complexities, high quality data and improved tools to capture the spatial and temporal dimensions of drought is required.

Geoinformatics constitute the geospatial data i.e., mostly available from various satellite platforms and the technology available for analysis of such data such as Geographic Information System (GIS), and other integrative tools like Global Positioning System (GPS). The ever increasing pressure on natural resources to meet the requirements of growing population calls for the development of plans that maintains equilibrium environment, ecology and human needs. The use of contemporary technology tools like Geoinformatics to find solutions for sustainable use of land and water resources has been found to be an indispensable management and decision making tool. Geoinformatics facilitate the cost effective, timely, customized and simplified solutions for resource use. Geoinformatics has become a new tool in the hands of modern cartographers and the technology has been proved beyond doubt for its efficiency to generate maps with accuracy and time effectively particularly to depict the physically devastated areas by disasters, impact assessment and quick dissemination of disaster information to people (Dutta, 2002). The application of Geoinformatics for resource management at micro level was successfully demonstrated by integrating both satellite imagery and ground data to generate action plans for land development (www.gisdevelopment.net/application/ nrm/overview/ma03226pf.htm).

The Risk Management Agency (RMA) of US Department of Agriculture in collaboration with the University of Nebraska, the National Drought Mitigation Center, and the High Plains Regional Climate Center started the development of geospatial decision support tools to address agricultural drought hazards and identify regions of vulnerability in the management of drought risk. The objective of this joint research project National Agricultural Decision Support System (NADSS) is to develop a support system of geospatial analyses that will enhance drought risk assessment and exposure analysis. The NADSS is a collection of decision support tools designed to help agricultural producers assess a variety of risks. The architecture is separated into four layers: knowledge, information, data, and presentation ({kozaldg, culvermg, harmssk}@unk.edu).

University of Nebraska developed hydrological drought index map for the great plains region of the USA using an approach called Intelligent Joint Evaluation of Data and Information (IJEDI) using geospatial data. The data base from a variety of parameters related to hydrological drought such as surface water, ground water, above ground climate and geomorphology was integrated and analysed using GIS based tools. The data analysis module of IJEDI consists of four modules namely knowledge acquisition, knowledge discovery and data mining, data and information fusion and Multi agent Intelligence. The output products for IJEDI include hydro climatic products such as state of water resources report, seasonal water supply outlooks, stressed streams and lakes and stressed community and public lands (Zhang *et al.*, 2004).

Today's powerful geospatial tools, especially remote sensing, positioning, navigation and timing (PNT), and geographic information systems (GIS), can assist the characterization of a disaster situation. Remote sensing technologies, together with other geospatial technologies such as GIS and PNT systems, have a significant role to play in the improvement of disaster management and critical infrastructure condition assessment. Remote sensing from space combines a broad synoptic view with the ability to detect changes in surface features quickly and routinely.

Geospatial data from satellites provide a complete inventory of natural and biological resources at different spatial and temporal scales which is the fundamental requirement for the assessment and management of droughts. It is important to determine the vulnerability of these resources to periods of water shortage that result from drought. The most obvious natural resource of importance is water – its location, quality, quantity, accessibility and optimal use. Biological resources refer to the quantity and quality of grasslands/rangelands, forests, wildlife, and so forth.

The capabilities of remote sensing technology to provide the information on land and water management issues that is critical to drought/famine management process have been proved through various studies. Today, remote sensing has been operationalised to cover diverse themes such as agricultural crop acreage and yield estimates, forestry, drought monitoring, flood monitoring, land use/land cover studies, waste land delineation and reclamation, water resources development and management, ground water prospecting, marine resources survey, urban planning, mineral targeting, environmental impact assessment and so on, thus encompassing every facet of sustainable development and management. The synoptic and repetitive information provided by satellite data is useful to map surface water bodies, monitor their spread and estimate volume of water. This information is useful to measure the loss of storage capacity of reservoirs. Water bodies of the order of 0.5 ha size and above can be mapped using IRS-LISS III data. Satellite data analysis enables estimation of pre-harvest acreage and production besides assessment of crop condition. High-resolution data are useful for estimating minor crops. IRS LISS-III data merged with PAN data provides information on the extent of horticultural crops such as mango, coconut etc.

The spatial and temporal information on cropping pattern, crop intensity and crop condition form basic inputs for assessing the performance of irrigated command areas. Satellite data derived geological, geomorphological and hydrogeomorphological maps on 1:50,000 scales are useful to generate ground water prospecting maps. Generation of forest cover maps and monitoring changes in forest areas can be achieved through the analysis of satellite data. Information on all natural resources of the watershed namely soils, geology, geo-morphology, ground water, land use/cover, slope generated from satellite data are very useful inputs for watershed development plans.

13.6. Space Technology for Agricultural Drought Monitoring

Unlike point observations of ground data, satellite sensors provide direct spatial information on vegetation stress caused by drought conditions and the information is useful to assess the spatial extent of drought situation. Satellite remote sensing technology is widely used for monitoring crops and agricultural drought assessment. Over the last 20 years, coarse resolution satellite sensors are being used routinely to monitor vegetation and detect the impact of moisture stress on vegetation. AVHRR on NOAA's polar orbiting satellites has been collecting coarse resolution imagery world wide with twice daily coverage and synoptic view. The NOAA AVHRR NDVI has been extensively used for drought/vegetation monitoring, detection of drought and crop yield estimation (Batista *et al.,* 1997, Benedıtte and Rossini, 1993, Moulin *et al.*, 1998, Goward *et al.*, 1985, Justice at al., 1985 and Tucker *et al.*, 1985). The 10 bit resolution digital data from the AVHRR is processed in the Spacecraft's Manipulated Information Rate Processor (MIRP) to produce four products namely (1) direct readout to ground stations of High Resolution Picture Transmission, HRPT world wide, (2) direct readout to ground stations of Automatic Picture Transmission (APT) worldwide, (3) Global Area Coverage, GAC at relatively low resolution (4 km) for central processing and (4) Local Area Coverage, LAC, from selected portions of each orbit at high resolution 1 km (Cracknell, 1997). Space technology has become a global potential tool for detection and mitigation of natural disasters like drought and the availability of long term satellite data enhance the accuracy of hazard detection, monitoring and impact assessment (Kogan, 2001). Integration of remote sensing derived inputs on land cover and bio physical parameters with crop simulation models under GIS environment would enhance the accuracy of crop monitoring and crop yield estimation methods in agriculture. The Drought Monitor of USA using NOAA-AVHRR data **(**www.cpc.ncep.noaa.gov**)**, Golbal Information and Early Warning System (GIEWS) and Advanced Real Time Environmental Monitoring Information System (ARTEMIS) of FAO using Meteosat and SPOT – VGT data (Minamiguchi, 2005), International Water Management Institute (IWMI)'s drought assessment in South west Asia using Modis data (Thenkabail, 2004) and NADAMS drought monitoring in India with IRS–WiFS/AWiFS and NOAAAVHRR (Murthy *et al.*, 2007) data are the proven examples for successful application of satellite remote sensing for operational drought assessment.

Spatial information technology like remote sensing from a wide range of satellite sensor systems currently available, offer a different dimension to agricultural drought assessment compared to conventional subjective, non spatial and non consistent mechanisms being practiced.

13.6.1. Drought Indices from satellite data

The crop/vegetation reflects high in the near infrared due to its canopy geometry, the health of the standing crops / vegetation and absorbs high in the red reflected radiance due to its biomass and accumulated photosynthesis (Figure 13.3). Using these contrast characteristics of near infrared, red and middle infra red bands which indicate both the health and condition of the crops/ vegetation, different types of vegetation indices have been developed. Parry and Lautenschlager (1984) provide an extensive review of vegetation indices based on LANDSAT and NOAA satellite data as shown below:

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

- Normalized Difference Wetness Index
- Enhanced Vegetation Index

13.6.1.1. Normalised Difference Vegetation Index (NDVI)

Among the various vegetation indices that are now available, Normalized Difference Vegetation Index (NDVI) is widely used for operational drought assessment because of its simplicity in calculation, easy to interpret and its ability to partially compensate for the effects of atmosphere, illumination geometry etc., (Malingreau 1986, Tucker and Chowdhary 1987, Jhonson, *et al.*, 1993, Kogan 1995). NDVI is a transformation of reflected radiation in the visible and near infrared bands of NOAA AVHRR and is a function of green leaf area and biomass.

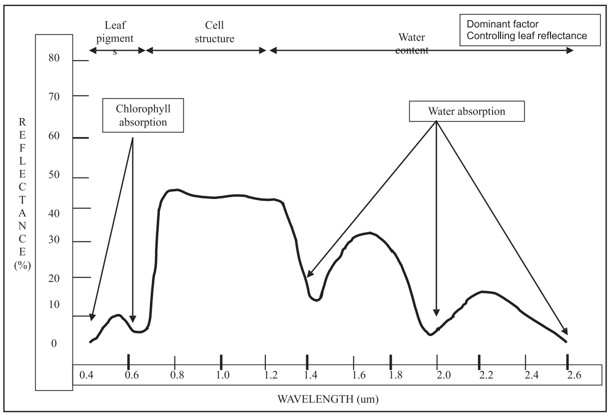


Figure 13.3: Spectral response of vegetation (source: Swain and Davis, 1978)

NDVI is derived as under:

NDVI = (NIR-Red) / (NIR+Red)

where, Near Infra Red and Red are the reflected radiations in these two spectral bands.

Water, clouds and snow have higher value in the visible region and consequently NDVI assumes negative values for these features. Bare soil and rocks exhibit similar value in both visible and near IR regions and the index values are near zero. The NDVI values for vegetation generally range from 0.1 to 0.6, the higher index values being associated with greater green leaf area and biomass (Tucker, 1979). Currently, NDVI products can be generated from the data of most of the satellite sensor systems. The MODIS NDVI of 250 m and 1000 m, SPOT VGT NDVI of 1000 m, NOAA AVHRR NDVI of 1000 m, IRS WiFS NDVI of 188 m and IRS AWiFS NDVI of 56 m are widely used for drought monitoring purpose because of the advantages of spatial and temporal coverage of these products.

In general, growth and decay of crop canopy represents similarities in the temporal vegetation index profile during the crop growth. The peak of this profile corresponds to peak vegetation cover of the crop. Interpretation of vegetation index (VI) profile can be used to derive information on the crop stage. Further, VI at peak vegetative stage or the time integration of VI profile is related with accumulated biomass in the crop or crop condition or crop yields. Lowering of VI values reflects moisture stress in vegetation, resulting from prolonged rainfall deficiency. Such a decrease in VI could also be caused by other stresses such as pest/disease attack, nutrient deficiency or geochemical effects. The seasonal VI profile is thus reflective of vegetation dynamics and condition. Comparison of VI profile of the reporting year and a previous normal agricultural year provides assessment of drought impact in the scale of previous agricultural scenario.

NDVI shows a lag correlation of up to 4 weeks with rainfall and aridity anomaly. However, the correlation is not unique either through the season or between the areas. The rainfall use efficiency varies in time and space making direct satellite monitoring of vegetation development essential for reliable and objective monitoring of agricultural drought conditions. However, conjunctive use of rainfall/aridity anomaly and VI provides greater reliability.

NDVI values contaminated by high residual (after time compositing) cloud cover or by thin clouds unidentified by visible band cloud masking or due to off-nadir viewing or as a result of insufficient cloud free passes in compositing period require validation before use in drought assessment. Heavy rainfall at the time of heading/flowering can disturb grain development and lead to yield reduction which however may remain undetected by the satellite which will show healthy canopy conditions. Excessive wide spread rainfall or flooding can also decrease VI value.

The general growing period in regard to start, peak growth and senescence can be identified through the seasonal NDVI profile. However, NDVI can be an indicator of crop development/condition only after significant spectral emergence of crops, which has a lag of 2-3 weeks after the completion of significant sowings in the district.

13.6.1.2. Normalised Difference Water Index (NDWI)

Shortwave Infrared (SWIR) band is sensitive to moisture available in soil as well as in crop canopy. In the beginning of the season, soil back ground is dominant hence SWIR is sensitive to soil moisture of top 1-2 cm. As the crop progresses, SWIR becomes sensitive to leaf moisture content. SWIR band has got no penetrating capability. It provides only surface information. When the crop is grown-up, SWIR response is only from canopy and not from the underlying soil. NDWI using SWIR can complement NDVI for drought assessment particularly in the beginning of the season.

NDWI is derived as under;

NDWI = (NIR-SWIR) / (NIR+SWIR)

where Near Infra Red and SWIR are the reflected radiations in these two spectral bands. Higher values of NDWI signify more surface wetness.

13.6.1.3. Drought indices derived from NDVI and Temperature

Kogan (1990, 1995) developed Vegetation Condition Index (VCI) using the range of NDVI and Temperature Condition Index (TCI) with brightness temperature data as under;

$VCI = (NDVI-NDVI_{min}) / (NDVI_{max}-NDVI_{min})*100$

$TCI = (BT_{max}-BT) / (BT_{max}-BT_{min})*100$

VTI = a*VCI + b*TCI

Where,

NDVI, $NDVI_{max}$ and $NDVI_{min}$ are smoothed weekly NDVI absolute maximum and its minimum

BT, BT_{max} and BT_{min} are smoothed weekly brightness temperature absolute maximum and its minimum

VCI is Vegetation Condition Index

TCI is Temperature Condition Index

VTI is Vegetation Health Index

The severity of drought situation is assessed by the extent of NDVI deviation from its long term mean. The concept of relative greenness i.e., the ratio of current NDVI to the historic mean NDVI for the same period was introduced by Burgan and Hartford (1993) and is given by

$NDVI_{dev} = NDVI_i – NDVI_m$

$NDVI_i$ is the NDVI in the i th month

$MDVI_m$ = long term average for the same month

Maps produced using relative greenness are quite useful to assess drought situation and hence this indicator is being used widely (Johnson *et al.*, 1993).

Peters *et al.*, (2002) developed Standardised Vegetation Index based on NDVI which indicates the probability of vegetation condition’s deviation from normal using z scores of NDVI distribution derived from long term historic NDVI data sets.

13.6.1.4. Process based indicators

By modeling the energy and matter transfer between atmosphere and surface, a process based indicator known as Evaporative Fraction (EF) is derived. EF is defined as the fraction of available energy used for evapotranspiration. EF is derived as under;

$R_n = G + H + lE$

Where,

R_n = Net Radiation

G = Soil heat flux *lE*

H = Sensible heat flux

lE **=** Latent heat flux

$lE = (R_n\text{-}G) – c_p * \gamma_{air} * 1 / r_a * (T_s\text{-}T_x)$

c_p= Sp. Heat of air

γ_{air}= Air density

r_a= Surface roughness

T_s= Surface temperature

T_x= Maximum temperature

$EF = lE / (R_n – G)$

EF is Evaporative fraction

As long as adequate soil moisture is available, energy will be used for its evapotranspiration and EF will be close to one (no water stress). In the absence of soil moisture, all available energy will be directed into warming up surface and the ambient air and EF will approach zero indicating serious water stress (Bastiaanssen, 1998). Although there are many vegetation indices and derived indices, VCI and NDVI deviation from historic NDVI are being widely used on operational basis to assess drought situation (Kogan 1995, Burgan *et al.*, 1996, Hayes and Decker, 1998).

13.7. Rainfall and Soil Moisture Estimation from Satellites

Observations from Meteorological Geostationary satellites may be more useful in indicating or forecasting an eminent drought rather than its monitoring. However, the prediction of such situations is still a major challenge for atmospheric scientists. In a recent significant study, Goswami and Xavier (2003) have shown that by analysis of past observations of rainfall and circulation, it is possible to predict the monsoon breaks with a lead time of ~ 20 days. Fortunately with the advent of high resolution microwave sensors onboard new generation satellites, it is now possible to make quantitative estimates of precipitation on global scales. Adler *et al.*, (1998) suggested a method to merge the information from microwave sensors onboard polar orbiting satellites and that from the geostationary satellite to produce more frequent and regionally continuous maps of quantitative precipitation.

The availability of real-time rainfall observations may be useful for defining the indicators of drought. Other important meteorological observations are the global patterns of sea surface temperature (SST) and Outgoing long-wave radiation (OLR). Recent studies have indicated that there is a relationship between equatorial convection patterns and the variations of Indian summer monsoon rainfall. The authors of this study found that the link of the Indian monsoon to events over the equatorial Indian Ocean is as important as the well-known link to the dramatic events over the Pacific (El Niño Southern Oscillation; ENSO). Over the equatorial Indian Ocean, enhancement of deep convection in the atmosphere over the western part is found to be associated with suppression over the eastern part and vice versa. The reliable drought prediction technique based on the analysis of global patterns of convection and other satellite observations is not available today, but the availability of high quality satellite observations can definitely boost the efforts in this direction.

Drought is a consequence of the prolonged period of dry soil due to lack of rainfall and could be inferred from soil moisture conditions over a long period of time. This, in turn, could be monitored regularly using microwave remote sensing techniques. In recent years satellite-based microwave radiometers have been used widely to monitor soil moisture conditions (Schmugge *et al.,* 1986, Chaudhury and Golus 1988, Owe *et al.,* 1988, Jackson 1993, Njoku and Entekhabi 1996). Recently, Rao *et al*., (2001), Thapliyal (2003) and Thapliyal *et al.,* (2003, 2005) have demonstrated the potential of microwave radiometers for surface soil moisture estimation over India.

Lower microwave frequencies are preferred for soil moisture observation as they are least affected by vegetation, surface roughness and atmospheric cloud liquid water. Theoretically 1.4 GHz is considered best for soil moisture observations. However, due to power constraints, the lowest frequency used so far by satellite microwave radiometers is 6.6 GHz, e.g., Scanning Multi-frequency Microwave Radiometer (SMMR) onboard Nimbus (1978 to 1987) and Multi-frequency Scanning Microwave Radiometer (MSM R) onboard IRS-P4 (1999 to 2001). Currently, the TRMM Microwave Imager (TMI) launched in 1998 with lowest frequency at 10.7 GHz is providing observations at higher spatial resolution (~40 km as compared to ~100 km for a similar channel in SMMR and MSMR). Jackson and Hsu (2001) compared TMI 10.7 GHz brightness temperatures with observed soil moisture over the Southern Great Plains of USA and concluded that it has great potential for soil moisture estimation. Thapliyal (2003) showed that 10.7 GHz show high sensitivity to the surface soil moisture over India, which is comparable to that of 6.6 GHz of MSMR and SMMR.

The SSMI on board DMSP satellites is 7 channel, four frequency, linearly polarized passive microwave system, that measures micro wave brightness temperatures from atmosphere, ocean and terrain with different foot prints ranging from 13 X 15 km to 43 X 69 km. Soil moisture is one of the important derivatives from SSMI foot prints that has potential applications for regional level drought studies.

Advanced Microwave Scanning Radiometer AMSR-E onboard Aqua satellite provide the data that is useful to derive the soil moisture in the top few millimeters by averaging over the retrieval footprint. The soil moisture data can be generated at a spatial resolution of 25 Km.

European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) is the second Earth Explorer Opportunity mission scheduled for launch in 2009. SMOS is capable of providing observations on soil moisture and ocean salinity by capturing emitted microwave radiation around 1.4 GHz frequency. This information will be useful for forecasting extreme weather events and seasonal climate changes (www.esa.int).

13.8. National Agricultural Drought Assessment and Monitoring System (NADAMS)

In India, National Agricultural Drought Assessment and Monitoring System (NADAMS) was initiated towards the end of 1986, with the participation of National Remote Sensing Agency, Dept. of Space, Government of India, as nodal agency for execution, with the support of India Meteorological Department (IMD) and various state departments of agriculture. NADAMS was made operational in 1990 and has been providing agricultural drought information in terms of prevalence, severity and persistence at state, district and sub-district level. Over a period of time, NADAMS project has undergone many methodological improvements such as use of high resolution data for disaggregated level assessment, use of multiple indices for drought assessment, augmentation of ground data bases, achieving synergy between ground observations and satellite based interpretation, providing user friendly information, enhanced frequency of information etc.

The complete chain of activities of NADAMS project starting from procurement of satellite data till dissemination of information to user community are currently being undertaken by Decision Support Centre located at National Remote Sensing Centre, Hyderabad, India under the preview of Disaster Management Support Program (DMSP) of Department of Space, Government of India.

The coverage of the project includes 13 agriculturally important and drought vulnerable states of the country. Monitoring of agricultural drought is restricted to Kharif season (June-Oct/November), since this season is agriculturally more important and rainfall dependent. Since drought declaration by the State Government involves the use of a large number of drought indicators, many of which are not amenable to satellite sensing, the emphasis of NADAMS is on agricultural drought conditions. Agricultural conditions are monitored at state/district/sub-district level using daily observed coarse resolution (1.1 km) NOAA AVHRR data for 9 states. Moderate resolution data from Advanced Wide Field Sensor (AWiFS) onboard Resourcesat 1 (IRS P6) of 56 m and Wide Field Sensor (WiFS) of IRS 1C and 1D of 188 m are being used for detailed assessment of agricultural drought at district and sub district level in four states namely, Andhra Pradesh, Karnataka and Maharashtra. Details of satellites/sensors being used for drought assessment are shown in Table13.4.

Indian Remote sensing Satellite (IRS) series (IRS 1A, IRS 1B, IRS 1C, IRS 1D and IRS P3) have unique payloads to monitor and assess various natural resources available in the country and around globe at different spatial resolutions. Among the payloads available IRS 1C, IRS 1D and IRS P3 have WiFS (Wide Field Sensor) payload (Table 13.4). WiFS sensor collects data in two spectral bands 0.62-0.68 µm (red) and 0.77-0.86 µm (near infrared) with spatial resolution of 188 m and ground swath of 810 km with a revisit period of 5 days. The combined use of three satellites cover any part of the country once in 3-4 days. The Advanced WiFS (AWiFS) sensor onboard IRS P6 provides data in 56 metres resolution with a swath of about 700 km. Due to higher spatial resolution use of WiFS/AWiFS data enables detailed monitoring at district and sub-district level.

Table 13.4: Satellites/sensors being used for drought monitoring in NADAMS project

S.No	Satellite/sensor	Spectral resolution (microns)	Spatial resolution (metres)	Radiometric resolution (bits)	Temporal resolution
1	NOAA-AVHRR (Swath= 2700 km)	0.58-0.68 0.725-1.10 3.55-3.93 10.3-11.3 11.5-12.5	1100	10	Twice a day
2	IRS 1C/1D-WiFS (Swath= 810 km)	0.62-0.68 0.77-0.86	188	7	5 days
3	IRS P3 WiFS (Swath = 810 km)	0.62-0.68 0.77-0.86 1.55-1.75	188	7	5 days
4	Resourcesat-1-AWiFS (Swath= 740 km)	0.53-0.59 0.62-.068 0.77-0.86 1.55-1.70	56	10	5 days

13.8.1. Integration of satellite derived indicators and ground data

In NADAMS, compositing of NDVI with maximum value approach for the period of 15 days and one month is being adopted. Drought assessment is carried out on fortnightly basis and reporting of information to the User departments is done on monthly basis. The assessment of agricultural drought situation in each district/block/taluk takes in to consideration the following factors; (1) seasonal NDVI/NDWI progression – i.e transformation of NDVI/NDWI from the beginning of the season, (2) comparison of NDVI/NDWI profile with previous normal years – relative deviation and vegetation condition index, (3) weekly rainfall status compared to normal and (4) weekly progression of sown. The relative deviation of NDVI/NDWI from that of normal and the rate of progression of NDVI/NDWI from month to month gives the indication about the agricultural situation in the district which is then complemented by ground situation as evident from rainfall and sown area. The ground data from different states has been organized in to a data base along with satellite derived NDVI/NDWI data. Concept and basic details of drought assessment in NADAMS is depicted in Figure 13.4. The seasonal AWiFS NDVI progression and drought assessment over Haryana state was shown in Figure 13.5. The Modis NDWI 250 metres images comparing a drought year (2008) and a normal year (2007) shown in Figure 13.6 indicate surface dryness caused by deficit rainfall in selected districts of Maharashtra state.

The methodology being adopted in NADAMS essentially reflects the integration of satellite derived crop condition with ground collected rainfall and crop area progression to evolve decision rules on the prevalence, intensity and persistence of agricultural drought situation. Some of the coarse resolution products being used for drought assessment are shown in Figure 13.7. The agricultural drought warning and declaration procedures being followed are shown in Table 13.5. During June to August, drought warning information is issued in terms of “watch, alert and normal” categories. In case of ‘watch’, external intervention is required if similar drought like conditions persist during the successive month while ‘alert’ calls for immediate external intervention, in terms of crop contingency plans. During September and October, based on NDVI anomalies corroborated by ground situation, drought declaration is done in terms of mild, moderate and severe drought.

13.8.2. Drought reports and user feedback

Since inception in 1989, NADAMS has transformed from biweekly bulletins to detailed monthly drought reports. The reports are sent to the Central relief department (nodal agency for relief for the country), Planning Commission, State Relief department (nodal agency for relief for the state) and agricultural department and host of other organizations, which are dealing with drought. Currently, monthly drought reports from June to November are being disseminated. Whenever need arises, drought information is also disseminated on fortnightly basis, subject to availability of cloud free satellite data. The NDVI images describing the spatial pattern of vegetation development

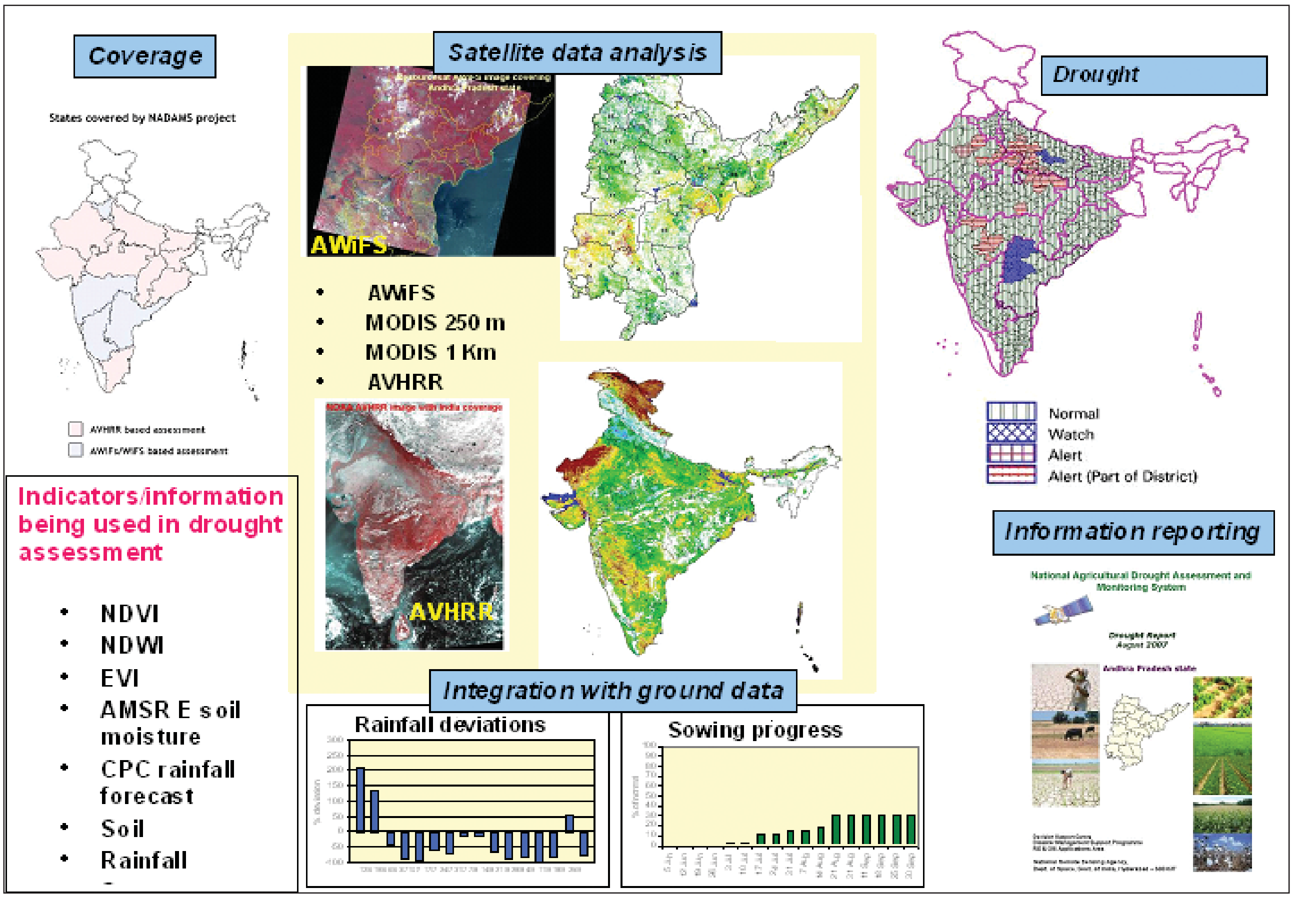


Figure 13.4: Details of NADAMS project

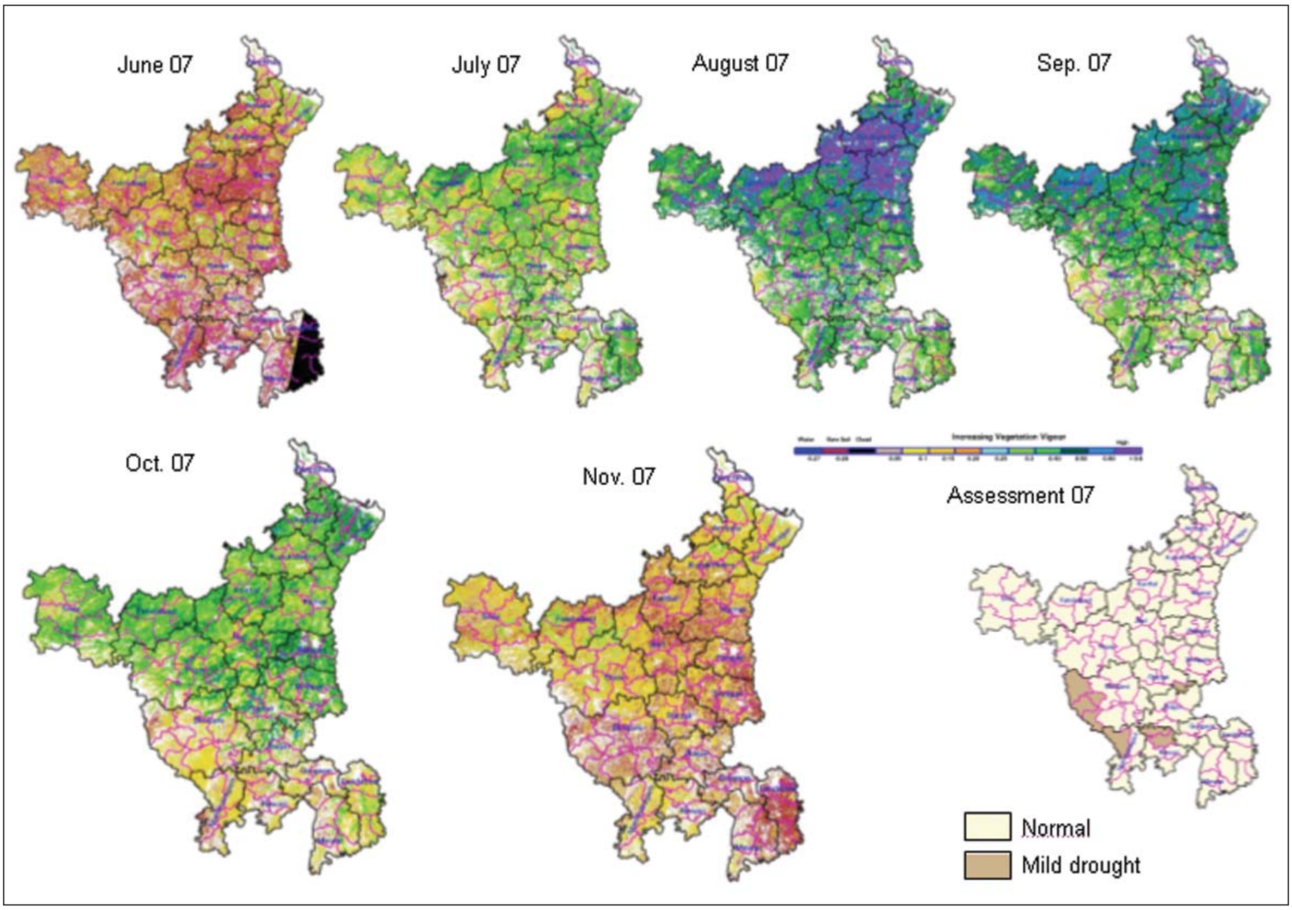
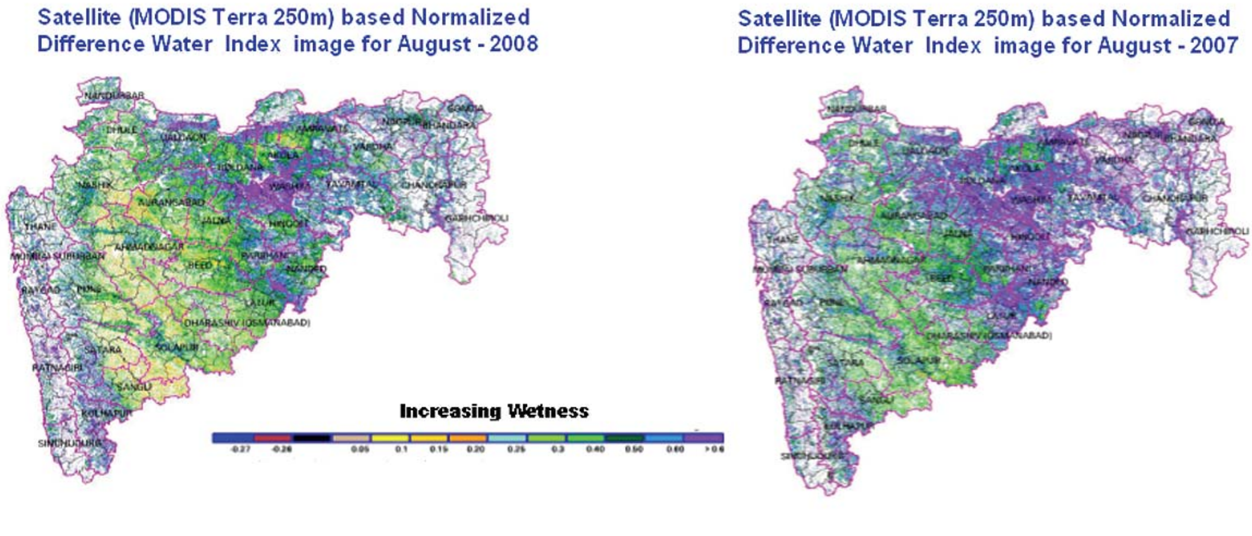


Figure 13.5: Seasonal NDVI progression and drought assessment over Haryana state – Kharif 2007



NDWI values are significantly less than normal, in 2008, in the districts of Madhya Maharashtra and Marthwada regions indicating surface dry ness caused by deficit rainfall, reduced crop sown area.

Figure 13.6: MODIS – 250 m – NDWI images of drought year (2008) and normal year (2007), Maharashtra state

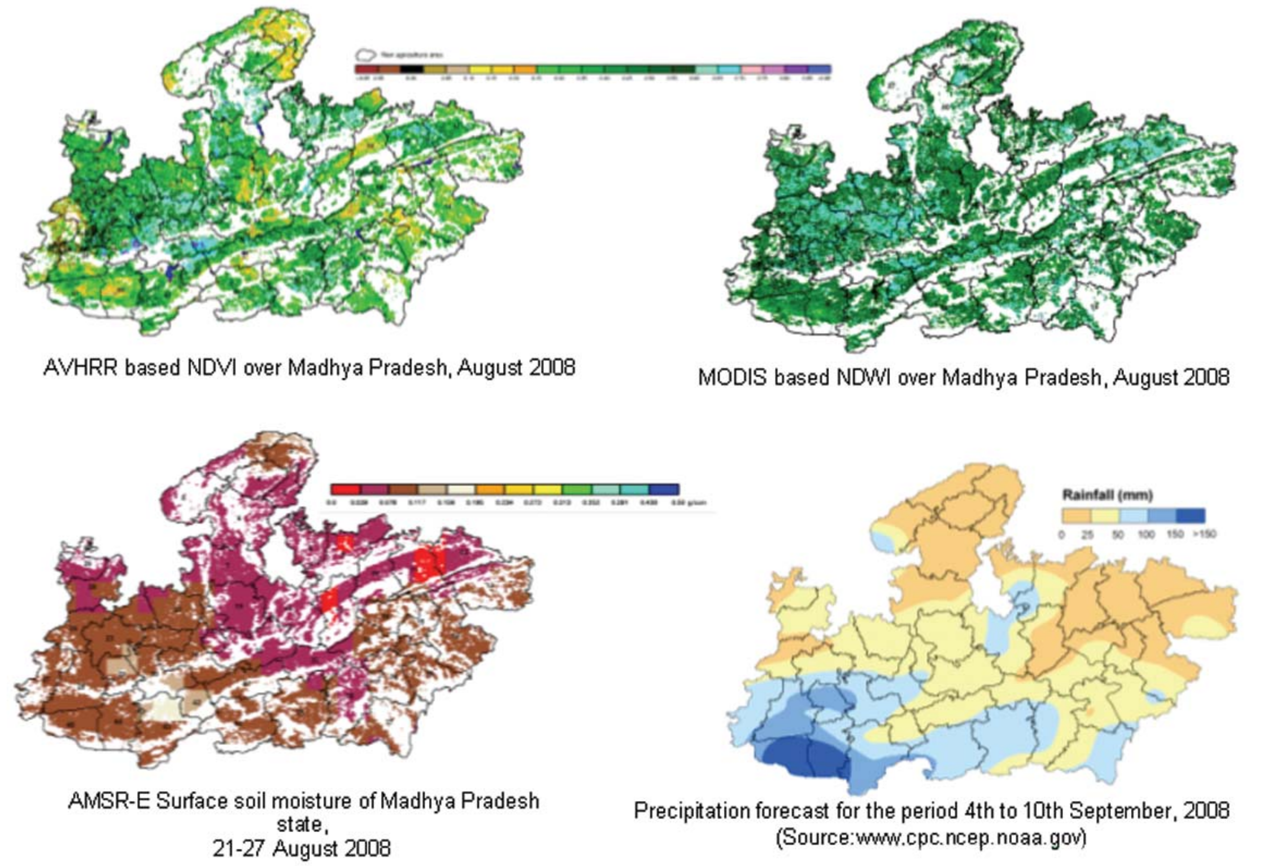


Figure 13.7: Coarse resolution products being used in NADAMS project for drought assessment

are being given to state agriculture departments on request for their crop and seasonal conditions review meetings.

The NADAMS report is useful for the decision makers for the management of agricultural drought at state/district/sub-district level. This report provides a comprehensive picture of the drought situation which acts as a complimentary information along with their ground based information.

Feedback received from some of the states indicates that the drought reports are being used as inputs in their review meetings on agricultural situation. The agricultural drought information of NADAMS reports are being used as inputs in the development of contingency plans and in relief management. It was also found that there is good correlation between NDVI images of NADAMS and aridity maps being provided by India Meteorology Department.

Today, the real strength of NADAMS project lies in the operational use of moderate resolution AWiFS/WiFS images for detailed assessment of agricultural situation within a district at regular intervals of one month to enable the User departments taking strategic decisions in drought management.

Table 13.5: Agricultural drought warning and declaration in NADAMS project

Month	Assessment	Implications
June	Normal	Agricultural situation is normal
July August	Watch	• Progress of Agricultural situation is slow • Ample scope for recovery • No external intervention needed
	Alert	• Very slow progress of agricultural situation • Need for intervention. • Develop and implement contingency plans to minimise loss
Sept. Oct.	Mild drought	Crops have suffered stress slightly
	Moderate drought	• Considerable loss in production. • Take measures to alleviate suffering
	Severe	• High risk Significant reduction in crop yield • Management measures to provide relief

13.9. Drought declaration by different states

Declaration of drought is the subject matter of State Governments. During the season, after examining the various aspects on rainfall, crops, irrigation, ground water etc., the state government identifies the number of administrative units - Taluks or blocks, affected by drought. The drought declaration helps assessment of relief requirements and guides relief management. Some states declare drought in middle of season and some states declare at the end of season.

Existence of considerable disagreement about the definition of drought itself makes it impossible to devise a universal drought index. Furthermore, drought characteristics and the wide range of economic sectors on which it has an impact make its effects difficult to quantify. Because of the complexities of drought, no single index has been able to adequately capture the intensity and severity of drought and its potential impacts on such a diverse group of users. Different states are adopting different methodologies for drought assessment, preparation of drought memorandums, drought declaration and relief assessment etc.

The criteria adopted in different states also vary depending on the rainfall and crops grown in the region. Tamil Nadu considers regions receiving less than 900 mm rainfall as drought affected, while Karnataka considers regions which received rainfall less than 400 mm during *kharif* and less than 30 per cent during the cropping season and 20 per cent deficiency of rainfall during critical stage of crop growth as drought affected areas. Rajasthan on the other hand considers an year as scarcity year when the productivity decreases by 50 per cent compared to a good crop year. Many of the states also follow the ‘Annawary’ system wherein the crop conditions are assessed through visual estimates. The criteria followed is production above 75% of normal – no drought, 50 to 75% normal – moderate drought, 25-50 % - severe drought, <25 per cent – disastrous drought. Karnataka state has recently revised its norms for drought declaration in the light of four consecutive years of chronic drought. It was felt that the current norms to define drought affected areas were inadequate and inappropriate. The taluks of the state are divided in to four categories based on annual rainfall. The threshold values for rainfall deviations and number of dry weeks for drought declaration vary across the four groups of taluks. The criteria also differ for year to year, for the taluks experiencing consecutive years of drought. Details are available in the annual report (2005-06) of Revenue Department of Government of Karnataka.

13.10. Drought Management

There is lot of confusion still existing between science and policy communities about the characteristics of drought as a result of which drought management practices all over the world is progressing slow. Governments respond to drought through adhoc or crisis management approach rather than through coordinated or strategies. The specific goals, the task of drought management is expected to deliver are:

Food production & security: for procurement, storage and distribution of food grains from food surplus to deficit areas, distribution of essential through public distribution system.

Employment generation: Employment generation schemes need to be prepared, technically evaluated and kept ready for implementation to provide jobs to the drought affected population.

Contingency crop plan: Alternate crop plan with sufficient infrastructure availability to stabilise farm level production.

Livestock management: Fodder supply, prevent distress sales, cattle camps

Drinking water: Augment the fleet of rigs available for drilling tube wells to provide drinking water.

Economic aspects: Waiving loan and providing monitory relief.

Social security schemes: Infrastructure facility can be expanded to cover the vulnerable section of the population.

There are two types of management measures namely (short term measures and long term measures). Short term measures include adoption of contingent crop plans, cultivation of drought tolerant crops, mulching, cultivation practices like optimal spacing, rationing, nutrient management and rainwater management. Long term management include land and water management practices to enhance the productivity in a sustainable manner.

Drought management in India was evolved as a national approach and has undergone changes in the light of status of resources and technological developments. The famine codes based on recommendations of Indian Famine commission (1880) constituted a mile stone in the history of drought management in India. This was the first time systematic approach was used. In the 1950s famine codes were replaced by scarcity relief with the objective of preventing starvation deaths. In mid 60’s drought response mechanisms were built up to ensure physical and economic access to food. Since 1970 drought management is being carried out by providing relief and by adopting drought impact minimization thought short and long term drought mitigation measures.

While India struggled to manage the 1965-66 drought by importing more than 10 millions of tons of food grains, in 1987-88 drought which is of greater severity in terms of rainfall deficiency and twice as that of population affected, was efficiently managed. The difference in impact can be explained by resilience in terms of distress indicators such as rise in food grain prices, increase in crimes, sale and mortgage of land etc., starvation level which were very low in 1987 and also due to improved level of drought preparedness and management which was considered as an integral part of country’s development programs.

The primary responsibility for management of drought in India vests with the State Governments. The Central Government supplements the efforts of the State Governments in dealing with disaster situations and also provides the major part of the financial resources for disaster response. There is an institutional arrangement at the national, state, district and sub-district levels to deal with emergency situations. A National Contingency Action Plan exists for ensuring emergency assistance in the wake of natural disasters at the national, state and district levels. The State Governments have their Relief Manuals/Codes which lay down the procedures and powers for emergency management and provision of relief.

A Calamity Relief Fund (CRF) is allocated to each state on an annual basis, 75% of which is contributed by the Central Government. The quantum of the CRF is determined by independent Finance Commissions once in five years. In the process, the drought relief management has become high sensitive to political and financial implications and hence a reliable drought assessment and monitoring mechanism has evolved using remote sensing in the country.

13.10.1. Drought Preparedness

Drought preparedness activities include identifying drought prone area which generally refers to the area frequently affected by drought and to carry out the long term drought mitigation activities that minimize the impact. Irrigation commission in 1972 suggested following criteria for determining drought proneness (i) low rainfall regions, (ii) areas that receive irrigation support less than 30 % of net sown area (iii) frequency of famine and scarcity. Later in 1976 National Commission on Agriculture suggested areas based on four rainfall categories (i) rainfall below 375 mm create conditions of extreme aridity, (ii) semi arid zones have rainfall between 375 mm and 750 mm (iii) the dry sub humid areas receive rainfall between 750 mm and 1125 mm and (iv) certain areas which receive above

1125 mm experience failure of crops. The task force on Drought prone area program and Desert Development Program evolved broad indicator comprising of rainfall and irrigation with relaxed irrigation yardstick to 40 per cent for areas having less than 750 mm rainfall and 30 per cent for areas having rainfall higher than 750 mm. However, the drought prone area identified based on limited data on rainfall and irrigation details of 1970's was not revised so far in spite of increase in the irrigated area and changes in the land use during recent years. The frequent change in the land use, irrigation development, cropping pattern and agricultural practices, it is necessary for frequent updating of drought prone area with enhanced understanding of drought impact using satellite data is essential.

13.10.2. Prediction of Drought

The prediction of drought is carried out mainly based on rainfall predictions. The rainfall predictions are of three kinds:

- Long range rainfall prediction: Since 1875 seasonal rainfall forecast for the entire country as a whole is being provided by India Meteorological Department. Over recent years, since 1989, forecasts are fairly accurate due to the use of parametric, dynamic, stochastic transfer and power regression models. These forecasts are issued in two stages, the first tentative forecast is issued in mid April and final forecast in last week of May. The seasonal total rainfall for the entire country is predicted in the forecast
- Medium range rainfall prediction: National Center for Medium Range Weather Forecasting (NCMRWF) provides in advance the weather forecast at every 2.5° x 2.5° grid. Operationally for 24 stations, 3 day forecasts are provided and Agriculture advisory committee members from various departments and universities meet and decide about necessary advice to farmers of these regions. This prediction is still in experimental mode and needs improvement in the accuracy
- Short range rainfall predictions: Based on INSAT data supported with weather observation, qualitative predictions of weather valid for 24 to 72 hours are being issued daily

NCMRWF is currently providing extended range forecasts through monthly predictions based on simulations from global T80/L18 atmospheric model. The extended range forecasts are useful for planning and management of water resources. Efforts are in progress at NCMRWF, to develop a more accurate 'Atmosphere- Ocean-Land' coupled system, to predict the monsoon environment a season in advance.

13.11. Drought proneness/drought vulnerability

Vulnerability mapping and hazard zonation are indispensable requirements to evolve more effective long term drought disaster management strategies. In India, the identification of drought prone districts and blocks was done by Hanumanth Rao Technical committee in 1994 using the criteria of percent irrigated area in different climatic zones and found that 1173 blocks representing 185 districts and 13 states, occupying 120 M ha of geographic area was drought prone area. However, the rapidly changing agricultural scenario with increasing irrigated area on one hand and significant climatic changes on the other hand, indicate the need for the development of new set of criteria for delineation of drought prone areas. Recently to be in tune with changing environmental concerns and agricultural scenario globally, the Parthasarathy Committee (2005) was asked to re-look into the criteria related to drought prone areas delineation in the country.

Drought proneness of a given area is largely determined by the response of agricultural situation and crop condition to the combined effects of causative factors - rainfall variability, irrigation support and soil type etc. Therefore, drought proneness- its characterization and delineation can be done using two approaches – one on the basis of causative factors and the other on the basis of response factor.

13.11.1. Drought vulnerability based on causative factors

Central Research Institute for Dryland Agriculture (CRIDA) carried out a pilot study to delineate drought prone blocks in Mahaboobnagar and Anantpur districts of Andhra Pradesh. Long term block wise rainfall data (for 30 years) and percent irrigated area was the data used in the analysis. A composite drought index with weighted drought index derived from rainfall data and weighted irrigation index derived from percent of source wise irrigated area was developed. Blocks of the two districts were delineated using this index in to more prone and less prone classes. The procedure is being fine tuned with different weighing factors to arrive at more objective criteria for application to rest of the districts in the country.

13.11.2. Drought vulnerability based on response factors

Vulnerability analysis and hazard zonation from the point of view of response of agricultural situation and crop condition to rainfall variability and irrigation support at sub district level would be possible using the indicators derived from agricultural area NDVI of the season. NDVI based assessment of drought proneness takes in to account the actual condition of standing crops during the season and its comparison among different years of normal and abnormal years. The fluctuations of crop condition as triggered by weather and water supply conditions determine the drought proneness of a given area. Long term NDVI data base consisting of extreme drought events and normal season facilitates quantification of NDVI variability which directly indicates drought vulnerability.

Pilot studies on drought proneness using agricultural area NDVI data sets from 1999-2005 for kharif seasons for two districts namely, Anantpur and Mahaboobnagar were undertaken by NRSC. Drought proneness at block level in Anantpur and Mahaboobnagar districts was identified using a set of NDVI based indicators namely, relative NDVI differences, inter annual NDVI variability, probability of occurrence of low NDVI etc. (Murthy *et al.*, 2008). Based on this study, blocks with more drought proneness and less drought proneness could be delineated (Figure 13.8). The NDVI based criteria are now being integrated with ground parameters such as rainfall, irrigation support to better represent the drought proneness at sub district level.

13.12. Challenges in drought assessment

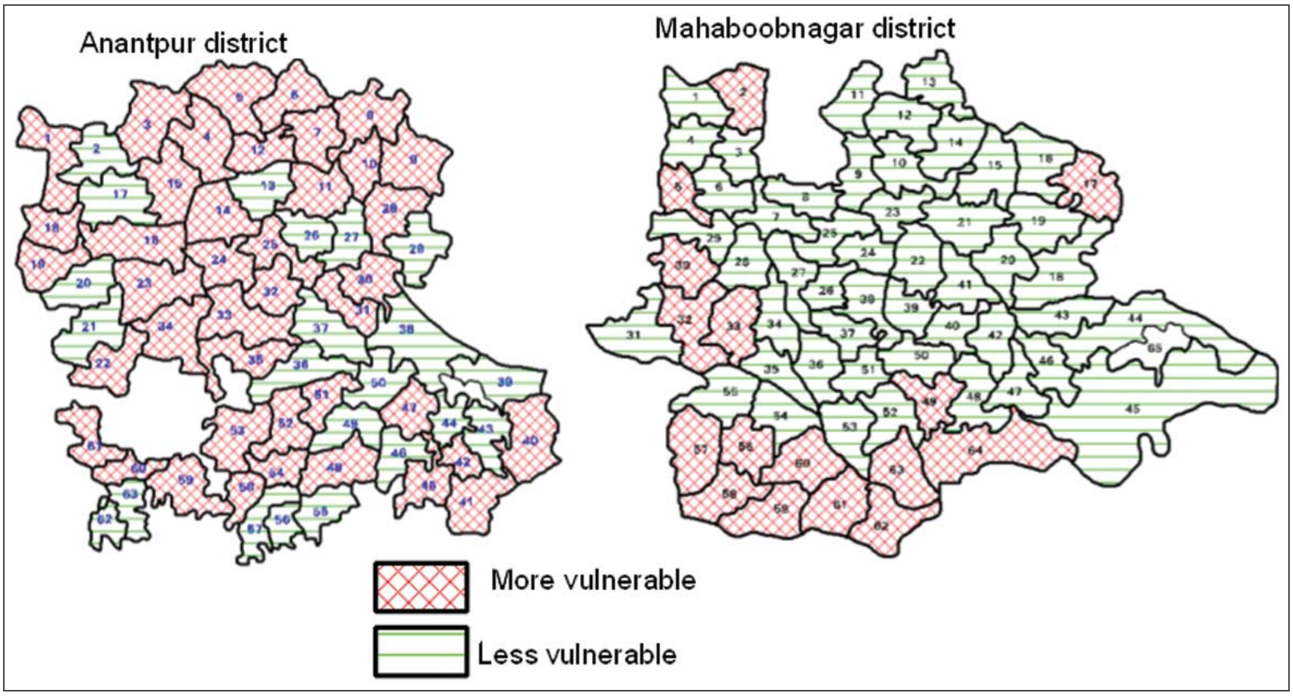


Figure 13.8: Drought proneness assessments on the basis of historic NDVI

13.12.1. Future Satellite Systems for Drought Analysis

Future missions are planned to meet the requirements of the meteorology community. The INSAT-3D to be launched in the year 2010 will carry improved VHRR and vertical sounders for temperature/humidity profiles. The imager will have six channels and the sounder will have nineteen channels. The Oceansat – 2, next in oceansat series of satellites, proposes to carry a scatterometer for surface wind retrieval. These surface winds are essential inputs for the weather prediction models.

The Megha-Tropiques mission will be a joint effort of ISRO and CNES, France towards study of the water cycle in the tropical region, which is very critical for forecast of monsoon. The unique payloads of the Megha-Tropiques are MADRAS (multi-frequency microwave radiometer – including 89 and 157 GHz), ScaRab (radiation budget – for both short and long wavelengths) and SAPHIR (atmospheric sounder – six channels). The mission will operate with an inclined equatorial orbit for repetitive coverage of tropical areas. The mission is expected to give insights into the convective processes in tropics and their characterization (Table 13.6).

Radar Imaging Satellite (RISAT), scheduled to be launched in 2009, is expected to boost the utilization of microwave images in the fields of agriculture and disaster management. One of the major constraints of using optical data is persistent cloudy conditions during monsoon season resulting in non-availability of sufficient cloud free data. In this context, microwave remote sensing offers great potential for monitoring crop and soils especially during the monsoon season due to capability of radar systems to acquire data under all weather conditions. The multi mode, multi polarization SAR images of RISAT will be useful to study the crop sown area progression, crop condition and soil moisture during the monsoon season to strengthen the existing drought assessment methodology.

Resourcesat-2 is planned to be launched in 2010 as a continuation to existing Resourcesat-1. With the availability

Table 13.6: Payload characteristics of and applications of future Indian satellites

Satellite	Payload	Bands/Resolution	Resolution(in Km.)	Applications
INSAT-3D	6 Channel IMAGER	Spectral bands (µm) Visible : 0.55-0.75 Short wave IR:1.55-1.70 Mid wave IR: 3.70-3.95 6.50-7.10 Thermal IR: 10.30-11.30 11.30-12.50	 1km 1km 4km 4km 4km 8km	Cloud characterization Mesoscale processes
	19 Channel Vertical SOUNDER	Spectral bands (µm) Short wave infra red : six bands Mid wave infra red: five bands Long wave infra red: seven bands Visible :one band	10×10 for all bands	Atmospheric water vapour/temperature
Megha Tropiques	SAPHIR	Six bands around 183 GHz	10 km Horizontal Resolution	Water vapour profile Six atmospheric layers upto 12 km height
	SCARAB	4 Channels: Sc-1 (Visible), Sc-2 (Solar), Sc-3 (Total) Sc-4 (IR window)	25 km at nadir	Radiation budget
	MADRAS	Radiation instrument in short& long wave 89&157GHz radiometer 10,18&37GHz radiometer	40km Horizontal Resolution 10 km Horizontal Resolution	Ice particles in cloud tops cloud liquid water and precipitation; sea surface wind speed 23 GHz : integrated water vapour
	GPSROS			Vertical profile of temperature and humidity

of AWiFS sensor on both Resourcesat 1 and 2 from 2010, the frequency of moderate resolution AWiFS images would significantly increase permitting improved drought assessment at subdistrict level by way of minimizing cloud cover in the images.

13.12.2. Unified index

Development of a unified index for drought severity assessment by integrating the data from different sources is an important activity recently undertaken to enhance the scope of drought assessment. There is a need to arrive at a scientifically true measure cutting across various rainfall zones and socio economically acceptable indicator of drought for the country. The index should be completely and comprehensively explain the phenomenon of drought. The index should give appropriate weightages to the rainfall, soil moisture and crop condition. To make the criteria uniform irrespective of region or state, Standardized Precipitation Index will be used to assess the deficiency of rainfall, since it has been standardized with mean zero and variance one. The impact of rainfall can be measured in terms of soil moisture availability through Soil Moisture Index (SMI), retrievable through water balance procedures. This index allows incorporating variability of soil parameters, crops and weather, which lead to better assessment of drought over the growing season. However, the spatial variability in the soil moisture index within a district depends largely on the spatial rainfall data and spatial Available Water Content (AWC) of soils that are representative of blocks/mandals. NDVI which indicates the agricultural vegetation condition is a response factor. Thus, a drought index which encompasses rainfall, soil moisture and crop condition would become complete and comprehensive. Combination of three parameters-rainfall, SMI and NDVI, if available at sub district level on weekly/fortnightly basis provide scope to evolve a unified index. A pilot study has been proposed for block level drought assessment by integrating rainfall, soil moisture and crop condition.

Procedures have to be developed for early drought detection and assessing the quantitative impact of drought on agricultural production through the use of satellite data and assimilation of data from ground segments, routinely collected by various agricultural related departments of the country. Empirical models, process based models and ground surveys with sampling techniques need to be explored in this context.

13.12.3. Enhanced exploitation of space technology

Activities planned towards retrieval of additional information from currently available satellite sensor systems, for improving the drought assessment, include;

- exploitation of SWIR region to detect crop water stress
- analysis of crop area progression using microwave data
- improved vegetation indices using BRDFs
- improved temperature retrievals for quantification of ET to develop process based indicators
- exploration of soil moisture retrievals operationally at different canopy closures
- extended data support from geo-stationary satellites
- estimation of spatial rainfall
- process based indicators

13.12.4. Data base

Collection of high quality information related to a variety of physical, meteorological, agricultural, environmental and socio-economic at different spatial and temporal scales in standard formats. Rainfall, temperature, evaporation, soil moisture, stream flow, vegetation health are some of the crucial parameters that are required to be measured continuously at different spatial and time scales during the season for drought assessment. These data bases enable adoption of an integrated approach for timely assessment and early warning.

13.12.5. Early warning systems

Green revolution has increased the yields of various crops but at the same time the amplitude of fluctuations in yields have also raised parallelly. In good years hybrids yield better, but generally in poor years the yield are worse, thus has led to increased sensitivity to rainfall variations. Since drought is a slow phenomenon, information on early warning is more relevant. However, the difficulty is to detect the start of the drought process even when variety of data is available. The monitoring/early warning system should provide decision makers at all levels with information about the onset, progress and termination of drought conditions and should become an integral part of drought management process.

Early warning systems help in formulating drought intervention strategies that respond to the needs of the people and enables individuals/community to face the risk with reduced damage. Objective and scientific information on the possibilities of the occurrence of drought situation in a given area enhance the credibility of early warning signals. An ideal early warning system should provide periodical information on meteorological, agriculture, hydrological conditions and their impact on the environment along with advisory services. Traditional early warning systems consist of physical indicators of the recent meteorological conditions. A good early warning system should have a composite database on meteorological conditions, agricultural situation, production estimates, availability of drinking water, fodder, price trends of food and feed etc. Early warning system should not end in the collection and processing of data but should be designed to mitigate/respond to the crisis (Buchanan-Smith, 1994). Vulnerability profile of the area should also form an important component of early warning methodology. Vulnerability information include trends in recent rainfall, production, prices, nutritional status, environmental status, soil fertility and house holed status. The physical aspects of an early warning system should be able to provide information on spatial extent of drought, duration of drought, time of occurrence of drought in relation to the crop calendar and severity of drought.

United States Agency for International Development has evolved a Famine Early Warning System NetWork (FEWSNET) by integrating the composite information on temperature, winds, humidity, soil and topography, observations on conflict, civil interest, health, market prices, field observations on agriculture, satellite derived rainfall and NDVI. FEWSNET is operationally issuing monthly food security reports for decision makers in Africa and USA (http://ltpwww.gsfc. nasa.gov/bsb/hqvisit/16MAR2004/tucker.GIMMS_FEWS.pdf).

Remote sensing data provides major input to all the three types rainfall prediction systems currently in operation in India. In the long term rainfall prediction by 16 parameters which include global and regional atmosphere, land and ocean parameters (Temperature, pressure, wind, snow, El-Nino, etc.) remote sensing data from geo-stationary and polar orbiting weather satellites such as INSAT, NOAA and other global data is used. In the medium range weather prediction, the NCMRWF uses satellite based SST, NDVI, snow cover area and depth, surface temperature, altitude, roughness, soil moisture at surface level and TOVS and Radio sonde data on water vapour, pressure and temperature at vertical profile data in the T86/NMC Model. However at present only global data with poor spatial resolution is being used. In the short range rainfall prediction also INSAT based visible and thermal data is being used.

13.12.6. Improved deliverables

The deliverables from drought monitoring projects should lead to enhance the capabilities of administration and farming community to evolve action plans to minimize the impact of drought. Therefore value addition to the drought assessment has to be done on the following aspects;

- Vulnerability mapping - drought prone area identification need to be updated at least once in five years due to change in the land use, irrigation development, cropping pattern and rainfall, etc.
- Rainfall predictions- quantitative predictions over smaller regions
- Crop monitoring – early season drought detection, stress detection at local level
- Crop specific crop condition assessment and early warning on expected yield at district and sub district level
- Quantitative assessment – drought impact on sown area, crop production
- Regular monitoring of water availability at minor, medium and major irrigation tanks and reservoirs with the help of remote sensing is required for better accuracy and timeliness
- Action plan for sustainable development in all drought prone area need to be taken up
- Decision support system drought assessment in all the drought prone districts for planning and operation of various drought relief management activities

13.12.7. Delivery mechanism

The information on drought assessment, predictions produced by different agencies is very often technical, complex and do not follow any standardized format. Many potential users do not even know the existence of such information. Therefore there is a need for evolving an effective mechanism to disseminate the information to the user agencies. The delivery mechanism should allow active interaction in the identification of problems and providing solutions with the use of scientific information. This can be achieved through internet portals in an interactive environment. Internet will also provide access to related research that is not always disseminated in a timely way or through easily accessible modes. User feedback on the functional aspects of the system and utility of the information will form essential part of management approach. Communication satellites have significant potential for real-time dissemination of information.

13.12.8. Integration between Science and Policy

An essential aspect of the planning process is integrating the science and policy of drought management. The policy maker's understanding of the scientific issues and technical constraints involved in addressing problems associated with drought is often limited. Likewise, scientists generally have a poor understanding of existing policy constraints for responding to the impacts of drought. In many cases, communication and understanding between the science and policy communities must be enhanced if the planning process is to be successful.

Integration of science and policy during the planning process will also be useful in setting research priorities and synthesizing current level of understanding and capabilities.

13.12.9. Institutional frame work

Drought management requires a joint efforts of individuals/institutions originating from multidisciplinary aspects and together should evolve a mechanism to understand the inter relations of various aspects and generate the action plan. For example meteorologists foresee the availability of water through rainfall; natural resource managers or environmental specialists focus on the analysis of the impact of different water availability situations on various interests like agriculture, live stock and people. The major challenge lies in bringing these groups together with inter connectivity and synergy to evolve group actions. The different institutions in the drought management plan should include water institution, meteorology, agriculture, ground water, environment and socio-economic. These groups collectively should address various issues such as identification of human, biological, financial and legal constraints, identification of research needs, integration of science and policy, formulation of drought plan, creation of public awareness, implementation of planned activities either short term or long term etc. A model for institutional participation is shown in Figure 13.9.

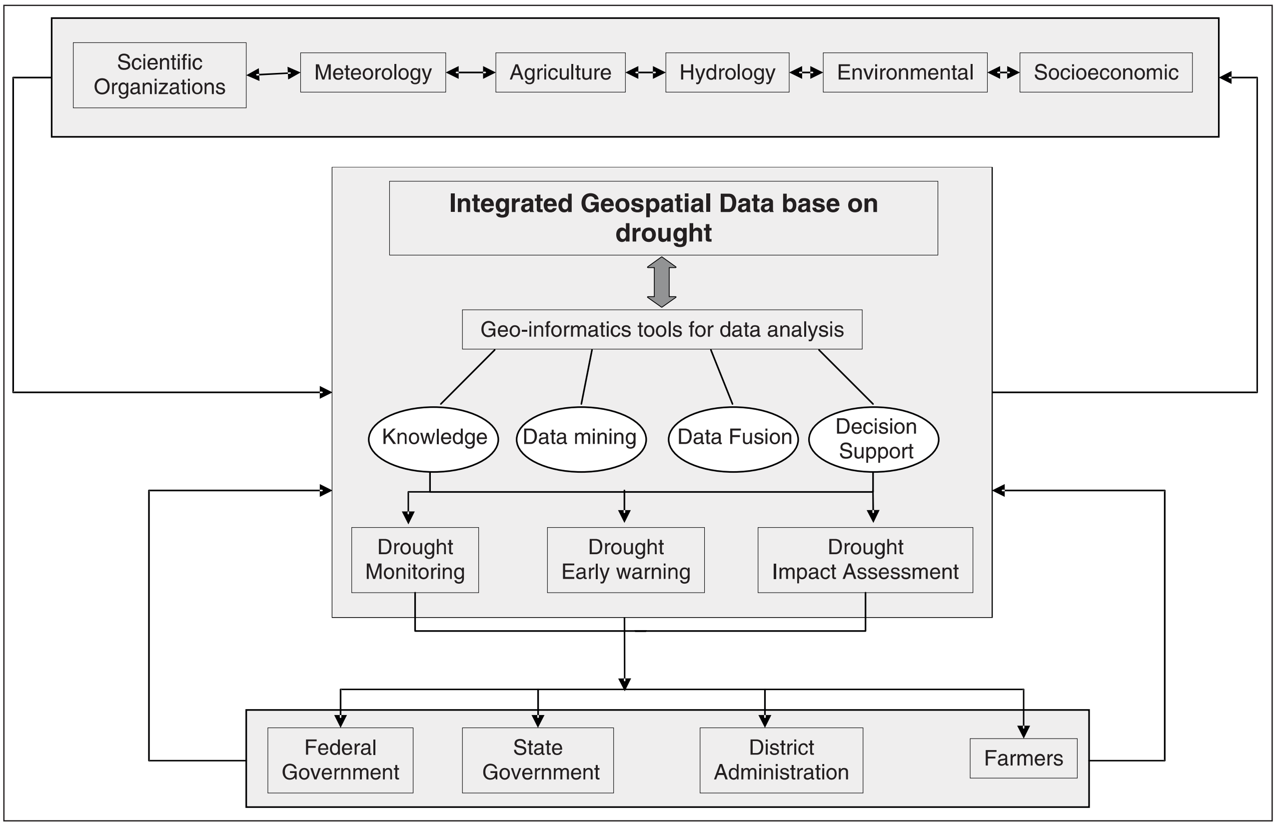


Figure 13.9: Frame work of Institutional linkages, data flow, application of Geoinformatics for drought assessment and use of information for drought management

13.13. Conclusions

Drought is a weather related disaster affecting a large portion of the most productive agricultural areas of the world. With spatial and temporal abnormalities in monsoon precipitation and 68% of agricultural area depending on rainfall, agriculture in India is increasingly affected by droughts of different intensities. A number of indicators related to weather, soils and crops are currently available for assessing the agricultural drought situation.

Dynamic nature of drought in terms of its onset, progression, intensity and impacts requires improved tools and high quality data to capture the spatial and temporal dimensions of drought by complementing and supplementing different indicators.

Geoinformatics with geo-spatial data from various satellites, Geographic Information System (GIS) and integrative tools provide immense opportunities to evolve a variety of drought indicators and integrate the same with ground based indicators for objective assessment of drought at different spatial scales.

The unique capabilities of remote sensing satellites to provide comprehensive synoptic and multi- temporal coverage of large areas at regular intervals help in the development of sound, operationally feasible, objective driven and economically viable system for near real time agricultural drought monitoring and assessment.

Geospatial technologies are also useful for hazard and vulnerability mapping to help development of long term strategies of drought management.

The proposed launch of state of the art indigenous microwave satellite RISAT, in the year 2009 gives scope for studying cropped area progression and soil moisture in the monsoon season, thereby enhancing the drought monitoring capabilities.

Institutionalization of contemporary technologies, development of spatial decision support systems, impact assessment and early warning are some of the issues that needs to be addressed to strengthen the agricultural drought management system of the country.

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