

## Agricultural drought : Assessment & monitoring

M. V. R. SETHA SAI, C. S. MURTHY, K. CHANDRASEKAR, A. T. JEYASEELAN,  
P. G. DIWAKAR and V. K. DADHWAL

*National Remote Sensing Centre (ISRO), ISRO, Department of Space, Hyderabad – 500 037, India*

**e mail : seshasai\_mvr@nrsc.gov.in**

सार – सूखा धीमी गति से प्रभावित करने वाली ऐसी प्राकृतिक आपदा है जिसका परिस्थितिकी और अर्थव्यवस्था पर दीर्घकालीन प्रभाव पड़ता है। इसके प्रतिकूल दुष्प्रभावों को कम करने के लिए सूखा प्रबंधन योजना के लिए सूखा का मॉनीटरिंग और मूल्यांकन करना एक बहुत ही संकटपूर्ण घटक है। कृषि के क्षेत्र में सबसे उत्तम विवेकपूर्ण निर्णय लेने के लिए स्थानिक विस्तार, तीव्रता और सूखे की अवधि की सूचना का होना आवश्यक है। उपग्रह दूरसंवेदी में लगे संवेदकों से सूखे की व्यापकता भीषणता, स्थायित्व और सूखा प्रभावित क्षेत्रों की जानकारी प्राप्त होती है। सूचना प्राप्त करने की नवीनतम तकनीकों से युक्त नव उपग्रह मिशनों ने सूखे के मानीटरिंग और मूल्यांकन की दिशा में नए आयाम खोल दिए हैं। इस शोध पत्र में कृषि संबंधी सूखे के पहलुओं पर चर्चा की गई है।

**ABSTRACT.** Drought is a creeping natural disaster with long lasting effects on ecology as well as economy. Monitoring and assessment of drought is a very critical component of the drought management strategy aimed at mitigation of its adverse impacts. Spatial extent, intensity and duration of drought related information is essentially needed for taking the choicest rational decision making in the field of agriculture. Satellite remote sensing enables deriving indicators that explain the prevalence, severity, persistence and spatial extent of the area affected by drought. New satellite missions coupled with novel information extraction techniques are opening new vistas towards monitoring and assessment of drought. Aspects related to agricultural drought are discussed in this paper.

**Key words** – Agricultural drought, Monitoring, Assessment, Mitigation, Vulnerability, Challenges, Extreme weather.

### 1. Introduction

Drought is a slow-onset natural hazard, often referred to as a ‘creeping disaster’ with effects that accumulate over a considerable period of time, *e.g.*, weeks to months. Both the ecological and economic systems are adversely affected by the drought. From the 1970s to the early 2000s, the percentage of the Earth’s land area affected by drought has more than doubled. A strong nexus of drought, desertification and degradation exists. There is no single universally accepted definition for drought. Drought originates from a deficiency of precipitation that results in a water shortage situation for a certain activity. Impacts of drought are cumulative and the effects magnify when occur in consecutive years.

Drought is a normal, recurring feature of climate with characteristics and impacts that can vary from region to region. Drought is also referred to as 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. Agricultural drought is a situation when rainfall and soil moisture are inadequate during the crop

season to support the timely cultural practices and healthy crop growth.

Drought results from adverse climatic conditions leading to deleterious impacts on various sectors of the economy. The immediate impact of drought is on crop area, crop production and farm employment. Less than normal crop sown area, delayed time of crop sowing, poor crop growth caused by inadequate soil moisture availability ultimately lead to decrease in crop yield or crop production with strong impacts on livelihood opportunities. Droughts have a multiplier effect on agricultural production during the subsequent year also due to non-availability of quality seeds for sowing of crops, reduced use of precious inputs like fertilizers as the investment capacity of the farmers’ decline, non-availability of raw material in agro-based industries etc.

Precipitation pattern has changed over many regions in recent decades. There are evidences of increased heavy precipitation and decreased light precipitation in widespread parts of the globe due to global warming. Studies using Modified Palmer Index suggest that there is

an increased risk of drought due to increased prolonged dry spells, total dry days, and decreased light precipitation days over India as a result of global warming (Mishra and Liu, 2014).

This article describes the significance of drought in India, indices used in assessment and monitoring, as operationalized in the National Agricultural Drought Monitoring & Assessment System (NADAMS), developed by ISRO (Indian Space Research Organisation). Further, the article also covers briefly the international endeavours and the challenges and opportunities to develop an effective drought monitoring system.

## 2. Drought occurrence in India

On an average, severe drought occurs once in five years in most of the tropical countries, though often they occur on successive years causing misery to human life and livestock. Almost every year one or the other region of the country is affected by drought in varying intensities. 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 about 142 million hectares, two-thirds is reported to be vulnerable to drought conditions. In the post-independence era, major droughts that affected more than 1/3<sup>rd</sup> of the country were reported during 1951, 1966-67, 1972, 1979, 1987-88 and 2002-03 (Subbaiah, 2004). In the last one decade, 2009-10 and 2013-14 have been drought affected years with huge impacts on agricultural production and livelihoods.

The variability of summer monsoon rainfall in the country has been found to be closely linked to the variations in sea surface temperature over the equatorial Pacific and Indian Oceans (Gadgil *et al.*, 2003). Rajeevan and Pai (2006) indicated that most of the severe droughts over India are associated with El-Nino events. But all the El-Nino years have not resulted in drought occurrence. In addition to El Nino, Southern Oscillation (ENSO), Equatorial Indian Ocean Oscillation (EQUINO) also influences the summer monsoon rainfall in India. Severe droughts during 1958-2003 were associated with unfavourable phases of either ENSO or EQUINO phenomenon.

## 3. Types of drought

The main types of drought are : (a) Meteorological drought, (b) Hydrological drought and (c) Agricultural drought. This paper mainly emphasizes the agricultural drought assessment. India being a monsoon dependent nation for agriculture and most of the precipitation occurs

through south-west monsoon, monitoring of agricultural drought assessment is carried out during June to October months and is discussed in this paper.

### 3.1. Meteorological drought

Normal rainfall during south west monsoon season is 890 mm for the country as a whole and 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](http://www.imd.gov.in)). 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. The normal duration is roughly 100 days and its withdrawal starts from Punjab and Rajasthan by mid of September.

The onset of north east monsoon, though not well defined, starts from October to December. Tamil Nadu state receives significant rainfall from north east monsoon, and it is about 463 mm representing about half of its of annual rainfall.

Rainfall, in terms of amount and distribution, 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 parameters. Many studies have analysed the nature and frequency of droughts based on simple relation between actual and average rainfall. Rainfall, being a supply parameter of soil moisture, simple indicators like number of rainy days, length of the dry spells would also be of immense value in the assessment of drought situation. The main challenge in this case is to get quality data in a timely manner. Based on rainfall, temperature, soil moisture and evaporation, various indicators of meteorological drought like Standardized Precipitation Index, Palmer's index and Crop Moisture Index etc. have been developed.

During monsoon season, these maps are indicative of development of drought. 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. In addition, IMD also provides the information on weekly rainfall and its deviation from normal at district level for the entire country. This data is useful to identify the districts with deficit/scanty rainfall and the prevailing meteorological drought. Early season drought assessment using space derived indices is often a limitation in drought assessment and meteorological drought indicators will supplement the

information towards synergising the efforts. District level maps depicting different attributes of rainfall in terms of actuals, deviations and spatial analysis are generated by IMD.

IMD also monitors drought using climatic water balance technique. The aridity index is calculated as a fraction of water deficit/water need. The departure of aridity index from normal percentage terms is used to define the 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 which show the departures of actual aridity from normal aridity giving indication of the severity of water deficit to water demand relationship on weekly basis.

Standardized Precipitation Index (SPI) is an important and well accepted index for drought monitoring and is based only on precipitation. This index is negative for drought, and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive. The SPI is generated at the end of every month to identify the regions with prevailing or beginning/ending of the extremely/severely/moderately dry/wet conditions. IMD generates this information also.

### 3.2. Hydrological drought

Hydrological drought is defined as significant reduction in the availability of water in all its forms appearing in the land phase of hydrological cycle. The forms of water could be surface water, stream flow, lake and reservoir level, ground water level, etc. Hydrological drought may be the result of long term meteorological droughts that results in the drying up of reservoirs, lakes, streams, rivers and a decline in groundwater levels. Hydrological drought is characterized by its time of onset and its duration, areal extent and frequency of occurrence. Indices like Standardized Precipitation Index (SPI), Effective Drought Index (EDI), Stream flow Drought Index (SDI), Surface Water Supply Index (SWSI), Ground Water Resource Index (GRI) and Palmers Drought Severity Index (PDSI), etc. are used in the analysis or hydrological drought.

### 3.3. Agricultural drought

Agricultural drought results from the complex and nonlinear interactions between weather, soil, crop and human actions and hence, the assessment of the intensity of agricultural drought continues to be a challenging task

for researchers, drought managers and policy makers. Unlike meteorological drought measured by rainfall data recorded by weather stations and the hydrological drought assessed by inflows into the surface water bodies measured through gauging points, assessment of agricultural drought is not accomplished by direct and quantitative measurements (Sastry *et al.*, 1981). It requires the quantitative information related to rainfall, soil moisture, cropping pattern and crop condition along with their interactive effects in both spatio-temporal dimensions.

## 4. Agricultural drought assessment – Geospatial approach

No single index can fully describe the multi-scale, multi-impact nature of drought in all its complexity. Hence, all research efforts on drought monitoring and assessment are directed towards developing a composite index through appropriate blending techniques. In order to make it acceptable by a wider section of drought management, the information of drought also needs to be put in simpler terms.

Dynamic nature of droughts with complex phenomenon having multiple effects is 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 are needed to capture the spatial and temporal dimensions of drought intensity.

Unlike point observations of ground data, satellite sensors provide direct spatial information on vegetation stress caused by drought conditions. Satellite remote sensing technology is widely used for monitoring crops and agricultural drought assessment. Over the last 30 years, coarse resolution satellite sensors are being used routinely to monitor vegetation and detect the impact of moisture stress on vegetation. The NOAA AVHRR NDVI has been extensively used for drought/vegetation monitoring, detection of drought and crop yield estimation (Batista *et al.*, 1997; Moulin *et al.*, 1998 and Tucker *et al.*, 1985).

The United States Drought Monitor (USDM) is considered as the best example amongst the drought monitoring tools. USDM is a combination of several indices and ultimately synthesizes the information into D0 to D4 drought severity classification categories. USDM has adopted a percentile approach that enables the user to compare across the regions and time periods.

United States Agency for International Development has evolved a Famine Early Warning System Network (FEWSNET) by integrating the composite information on

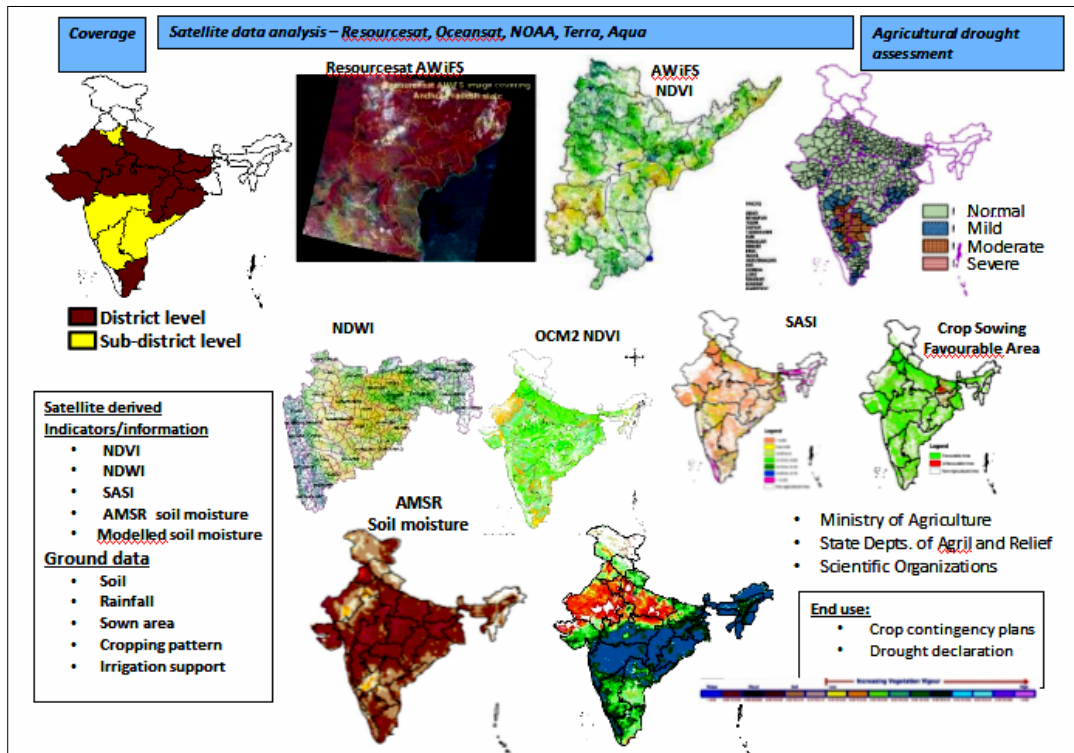


Fig. 1. Overview of National Agricultural Drought Assessment and Monitoring System (NADAMS)

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://ftpwww.gsfc.nasa.gov/bsb/hqvisit/16MAR2004/tucker.GIMMS\\_FEWS.pdf](http://ftpwww.gsfc.nasa.gov/bsb/hqvisit/16MAR2004/tucker.GIMMS_FEWS.pdf)).

The Drought Monitor of USA using NOAA-AVHRR data ([www.cpc.ncep.noaa.gov](http://www.cpc.ncep.noaa.gov)), Global Information and Early Warning System (GIEWS) and Advanced Real Time Environmental Monitoring Information System (ARTEMIS) of FAO using Meteosat-derived cold cloud duration and SPOT-VGT derived decadal NDVI composites (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.

Central Research Institute for Dry Land Agriculture (CRIDA), Hyderabad, provides information on drought conditions and their mitigations measures during the season. The weekly contingent crop plans for rain-fed

regions over the country during the crop growing seasons and at fortnightly interval in the rest of the period are prepared from the inputs provided by the centers of both the coordinating projects and the general weather situations prevailed over the period. In addition, India Meteorological Department (IMD) issues Integrated Agromet Advisories called the Gramin Krishi Mausam Sewa (GKMS). GKMS provides district level weather forecast and crop and location specific advisories to the farmers in the country. GKMS is enhancing its scope by using high resolution satellite data and value added products to provide weather forecast, near real time satellite meteorological and agro-meteorological products and value added products. The weather based agro-advisories prepared from the forecast of National Centre for Medium Range Weather Forecasting (NCMRWF) and crop condition are also updated regularly in the above mentioned website to meet any aberrant weather conditions.

## 5. 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 moderate 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. Recently, most of the analysis of the satellite data, of a part of the field data has been automated. From kharif 2012, NADAMS project is being carried out by Mahalanobis National Crop Forecast Centre (MNCFC), Department of Agriculture and Cooperation & Farmers' Welfare, Ministry of Agriculture & Farmers' Welfare, with the technical support of NRSC.

Monitoring of agricultural drought is limited to kharif season (June-Oct/November), since this season is agriculturally more important and rainfall dependent. Resourcesat 1/Resourcesat 2 AWiFS are useful to make sub-district level agricultural drought assessment in 5 states namely Andhra Pradesh, Karnataka, Maharashtra, Haryana and Telangana. AVHRR/MODIS are useful for district level assessment in 9 states namely Bihar, Chhattisgarh, Gujarat, Madhya Pradesh, Orissa, Rajasthan, Uttar Pradesh, Jharkhand and Tamil Nadu. Oceansat-2 OCM data was brought into operational use in kharif 2011 by generating fortnightly and monthly Rayleigh corrected TOA NDVI composites for all the 14 states. MODIS 250m derived NDVI and NDWI are also used for assessment. Coarse resolution products of soil moisture from passive microwave data, rainfall estimates and rainfall forecasts are also used in the assessment. The Area Favourable for Crop Sowing/crop sown area (AFCS), derived from Shortwave Angle Slope Index (SASI) and ancillary data is a recently added product in NADAMS project. This product is useful to monitor the sowing period drought conditions. Overview of NADAMS project is shown in Fig. 1. The satellite derived crop indices that are widely used in NADAMS project viz., NDVI, NDWI and SASI are described in subsequent sections.

### 5.1. Normalized Difference Vegetation Index (NDVI)

Among the various vegetation indices, 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; Johnson *et al.*, 1993; Kogan, 2001). NDVI is a transformation of reflected radiation in the visible and near infrared bands of a sensor system and is a function of green leaf area and biomass. Computation of NDVI is given by :

$$NDVI = \frac{(NIR \text{ reflectance} - Red \text{ reflectance})}{(NIR \text{ reflectance} + Red \text{ reflectance})}$$

The severity of drought situation is assessed by the extent of NDVI deviation from its long term mean. Maps produced using relative greenness are quite useful to assess drought situation and hence this indicator is being used widely (Johnson *et al.*, 1993).

NDVI shows a lag correlation with rainfall and aridity anomaly. The lag time is about 2-4 weeks. 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. However, conjunctive use of rainfall/aridity anomaly and VI provides greater reliability in the assessment of agricultural drought situation.

The general crop growing period with regard to beginning, peak growth stage 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 occurs at about 4-6 weeks after sowings/transplantation. Availability of long term NDVI data enables computation of Vegetation Condition Index (VCI), which is a more robust parameter than the instant NDVI. NDVI is also constrained when its response saturates at high canopy density. Saturation of NDVI also depends upon the sensor characteristics such as the wavelength range, FWHM, and saturation radiance as well.

### 5.2. Normalized Difference Water Index (NDWI)

Normalised Difference Water Index (NDWI) is derived from two bands including a moisture sensitive SWIR band and moisture insensitive NIR band (Gao, 1996). In the beginning of the cropping season, when soil back ground is dominant, SWIR is sensitive to surface wetness of top soil. As the crop progresses, SWIR becomes sensitive to leaf moisture content. When the crop is grown up, the response in SWIR band is mostly from canopy and not from the underlying soil. Indices based on the reflectance of Shortwave Infrared (SWIR) bands have been found to be sensitive to moisture available in

soil as well as in crop canopy (Tucker and Choudhary, 1987; Wang *et al.*, 2008). NDWI using SWIR can complement NDVI for drought assessment particularly in the beginning of the season. Computation of NDWI is given by,

$$\text{NDWI} = \frac{(\text{NIR reflectance} - \text{SWIR reflectance})}{(\text{NIR reflectance} + \text{SWIR reflectance})}$$

NDWI has been a popular index for crop stress detection and for monitoring moisture condition of crop/vegetation canopies over larger areas (Fensholt and Sandholt, 2003; Jackson *et al.*, 2004; Maki *et al.*, 2004; Chen *et al.*, 2005; Gu *et al.*, 2007). The response of NDWI to moisture is instantaneous without any time lag. NDWI is more sensitive to both desiccation and wilting. NDVI is more sensitive to canopy chlorophyll changes and tend to saturate at high biomass levels. In view of the limitations associated with individual indicators either NDVI or NDWI, combination of both the indicators may provide a robust approach for drought monitoring. Combination approach would amplify the anomalies and become more responsive to the ground agricultural situation. Gu *et al.* (2007) combined NDVI and NDWI to form Normalised Difference Drought Index (NDDI) which was found to be more sensitive to drought conditions over grass lands. Combined use of NDVI and NDWI temporal anomalies has better delineated the rice transplanting areas in China (Xiao *et al.*, 2002).

### 5.3. Short-wave Angle Slope Index (SASI)

A relatively new index - Shortwave Angle Slope Index (SASI), adopted from Khanna *et al.* (2007), is being used in NADAMS project from kharif 2010 for generating a geo-spatial product called Area Favourable for Crop Sowing (AFCS), as an indicator of the crop sown area. This product provides the estimates of the potential kharif area that is either favourable for sowing or already sown, progressively from June to August, at state level. Such crop sowing related information is a direct indicator of the impact of early-season agricultural drought.

MODIS 500m 8-day composite images of NIR (858 nm), SWIR 1 (1240nm) and SWIR 2 (1640 nm) spectral bands are being used for computing the index. SASI is very sensitive to surface wetness. SASI is calculated as product of the angle at SWIR1 ( $\beta_{\text{SWIR1}}$ ) and the inclination of the line that passes through the NIR and SWIR2 of a triangle with vertices at R(NIR), R(SWIR1) and R(SWIR2), where R is the reflectance at broad bands. The slope of line,  $(R_{\text{SWIR2}} - R_{\text{NIR}}) / (\lambda_{\text{SWIR2}} - \lambda_{\text{NIR}})$  can be approximated by the difference of the reflectance at NIR and SWIR2 since the wavelength difference between the two vertices is constant. An advantage of angle indexes is

that they are relatively insensitive to albedo differences for comparison between spectra. Das *et al.* (2011) demonstrated that weekly SASI profiles at district level revealed seasonality and strong association with rainfall and sown area pattern.

In the absence of operational procedures for near real-time soil moisture estimation, SASI can act as surrogate parameter to draw inferences on the commencement and progression of crop sowings and to characterize the agricultural situation in the early part of the season.

Using multiple criteria – SASI, soil texture, rice/non-rice areas, Soil Moisture Index derived from spatial soil water balance, a procedure has been evolved to generate spatial product on crop sowing favourable area or already cropped area in the season. This product called Area Favourable for Crop Sowing (AFCS) has been generated on fortnightly or monthly scale from June-September. After validation with state level crop sown area statistics reported by respective agriculture departments, the product is generated and used operationally from kharif 2010. The cloud covered pixels in SASI images are resolved with the support of rainfall and water balance derived soil moisture index. Extending SASI for rabi season monitoring, Murthy *et al.* (2012), mapped spatial patterns of surface wetness in the transplantation period of rabi season of recent 10 years (2002-03 to 2011-12) in a rice dominant irrigated command area.

### 5.4. Soil moisture index from soil water balance model

A simple book keeping – bucket type – water tight model was developed to derive the top 30 cm profile soil moisture. This model considers the initial root depth of 30 cm throughout the season to capture the soil water scenario for crops sown and germinating during any part of the cropping season. The soil water balance in the upper layer is governed by daily values of rainfall, runoff, evapo-transpiration (ET) and drainage to the second layer. When the upper layer saturates in excess of Field Capacity (FC) due to rainfall, the excess water percolates to the lower passive root zone and are instantaneously redistributed in that zone. The excess soil water in the passive zone, moves out as deep percolation. Since the upper 30 cm is considered for the soil water assessment the lower limit of soil water is the residual water content of the soil as the upper layer is exposed to the atmosphere and subjected to upward flux due to the direct solar radiation. The climatic, soil and crop parameter are the main inputs for the SWB. The daily near real time TRMM 3B42RT spatial rainfall product and the daily global potential evapo-transpiration data are used as the rainfall

and climatic input, respectively. The soil information was derived from the 1 : 0.5 million scale NBSS&LUP soil map. Since this model does not take into account the irrigation applied from various sources, the results of the model should be considered over rainfed areas alone. The Soil Moisture Index (SMI) derived is defined as the proportion of the difference between the current soil moisture (SM) and the permanent wilting point (PW) to the field capacity (FC) and the permanent wilting point. The index values range from 0 to 100 with 0 as extreme dry condition and 100 as extreme wet condition.

$$SMI = (SM - PW / FC - PW) \times 100$$

5.5. Grid-based Vegetation Index (VI) Products

Historically, coarser resolution VI products have been evolved for quick assessment of vegetation changes and drought detection over larger areas – countries and continents. The LAC data of AVHRR has given rise to GAC data of 4 km resolution for global change detection studies. The GIMMS data of 8 km resolution has been widely used across the globe for various applications related agriculture, hydrology and climate change. In NADAMS project, monthly composite 1 km NDVI images derived from NOAA AVHRR, 1 km NDWI images derived from Terra MODIS data and OCM2 NDVI were transformed to generate 5km Grid images. Grid VI images were generated for each month from June to November for historic years (2009, 2010, 2011 and 2012). Monthly NDVI/NDWI anomalies for different months of kharif 2012 were also computed, jointly with MNCFC. These Grid images are useful for rapid assessment of agricultural situation during each month. These NDVI/NDWI deviation images were integrated with rainfall, soils, cropping pattern for effective interpretation of the agricultural situation. The grid images were useful as inputs in the modeling tasks such hydrological, land surface and energy balance models. All the grid VI products, their anomalies and interpretation were disseminated to user community through Bhuvan portal.

6. Agricultural drought assessment in NADAMS project

The assessment of agricultural drought situation in each district/block/taluk takes in to consideration the following factors; (i) seasonal NDVI/NDWI progression, *i.e.*, transformation of NDVI/NDWI from the beginning of the season, (ii) comparison of NDVI/NDWI profile with previous normal years – relative deviation and vegetation condition index, (iii) weekly rainfall status compared to normal and (iv) weekly progression of sown area. The relative deviation of NDVI/NDWI from that of normal

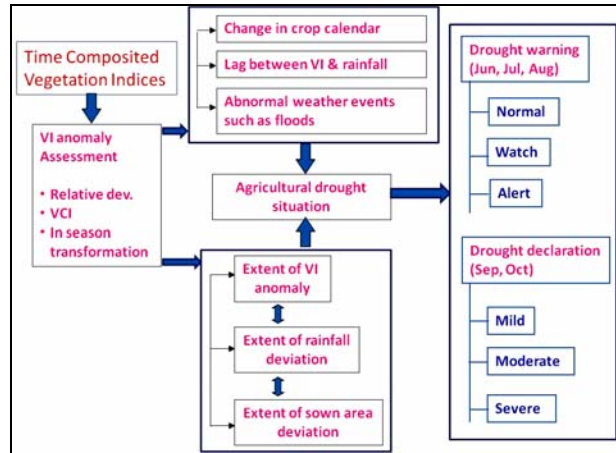


Fig. 2. Methodology for agricultural drought assessment

and the rate of progression of NDVI/NDWI from month to month gives the first level indication about the agricultural situation in the district. Ancillary data on rainfall, soil moisture index, crop sown area, cropping pattern, irrigation support is analysed to attribute the VI anomalies to agricultural drought situation. The ground data from different states are organized in to a data base along with satellite derived NDVI/NDWI data. The agricultural drought assessment methodology is depicted in Fig. 2.

During June to August, the extent of crop sowing favourable area/crop area against normal kharif area in each state is assessed using AFCS product derived from SASI, modeled soil moisture and other ancillary data. AFCS based crop sown area progression is useful to detect the intensity of crop-sowing period drought.

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.

The mandals/taluks of mild agricultural drought category are characterised by about 10-20% reduction in NDVI and NDWI persistently for more than a month. The agricultural situation of this class represents one or more of the attributes - slightly reduced crop sown area or slightly reduced vigour of crops leading to slight reduction (about 10%) in crop yield.

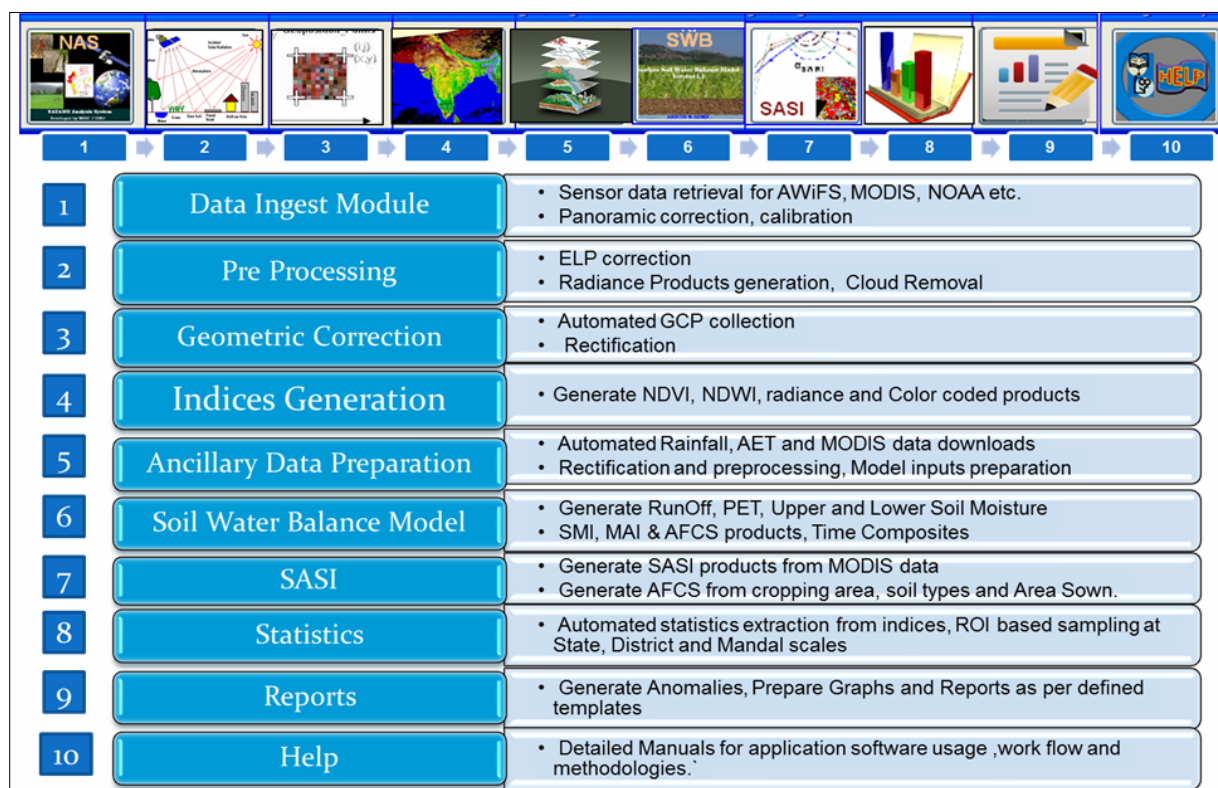


Fig. 3. Work flow of DMS software

Moderate agricultural drought category mandals/taluks are characterised by more than 20-30% reduction in NDVI and NDWI persistently for more than a month. The agricultural situation of this class represents one or more of the following attributes – more than a month delayed sowing time, more than 25-50% reduction in crop area, poor greenness/moisture levels of crop vegetation, significant reduction in crop yield.

In case of mandals/taluks under severe agricultural drought category there would be more than 30% reduction in NDVI and NDWI persistently for more than a month. The agricultural situation of this class represents one or more of the following attributes – more than a month delayed sowing time, more than 50% reduction in crop area, poor greenness/moisture levels of crop vegetation, significant reduction in crop yield.

Monthly drought reports from June to November are prepared and disseminated to the Departments of Agriculture and Relief of different states in addition to the Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India. Whenever need arises, drought information is also disseminated on fortnightly basis, subject to availability of cloud free satellite data. Feedback received from the states indicates that the

drought reports are used as inputs in their review meetings on agricultural situation. The agricultural drought information of NADAMS reports are 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 Meteorological Department.

## 7. Automation of the analysis

Providing timely deliverables of the information products is essential for early warning and preparing for the contingencies as a part of drought mitigation. These products are also being made available through web based dissemination / access.

In order to automate the processing of satellite data and derivation of various satellite and ground based indices, NRSC developed software called the Drought Monitoring System (DMS). DMS software is designed and developed for automating the process of preparing inputs on drought indicators from different sensors like AWiFS, MODIS, NOAA-AVHRR etc. This provides required band data for generating



various indices like Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) apart from Shortwave Angle Slope Index (SASI), particularly from MODIS sensor. The Interface for all the sensors is maintained in almost similar fashion for ease of use.

DMS is an integrated approach towards providing end-to-end software system for drought monitoring and analysis. It is thoroughly customized to suit NADAMS data and processing requirements. The work flow of DMS software is depicted in Fig. 3. Main emphasis of the automated process is :

- (i) Standardize data processing from different satellite platforms and sensors.
- (ii) Reduce the burden of intense learning curve for RS and GIS procedures towards routine processes.
- (iii) Capture the cognitive skills of domain expertise and represent in easy to use standard tools for production environments.
- (iv) Create scalable environment to add continuity to data sets as and when new sensors are available, *viz.*, AVHRR, AWiFS, MODIS, NPP-SUOMI, TM etc.
- (v) Establish single and well tested methodology in a unified platform for space based and ground based data analysis for Decision Support process.
- (vi) Reduce the dependency on Enterprise solutions (Commercial Packages) and provide free to use 'Open Source' Libraries based software solution.

Towards this, DMS software was developed using Geospatial Data Abstraction Library (GDAL) and C++/VC++ platforms providing all requisite functionality envisaged in project. Software architecture is based on the following guidelines.

- RAD (Rapid Application Development) with prototyping.
- Fishbone architecture for supporting RS & GIS requirements.
- Highly reusable with MFC based components.
- Performance maximized with multi-core processing utilities.
- Monolith Application with reduced user interaction (Minimal windows/screens / GUI).

- Capability to directly interact with different servers for data upload/download etc.

This software has been customized to Sri Lanka as DMS-SL under one UN ESCAP-ISRO initiative. Similarly, one mobile app was developed for Sri Lanka for field data collection, which could be instantly used in the analysis of satellite for drought assessment.

## 8. Agricultural drought vulnerability

Vulnerability to agricultural drought is referred as exposure, sensitivity and adaptive capacity of an agricultural area to reduced soil moisture availability during the crop season. Exposure component includes rainfall related parameters, that of sensitivity include cropping pattern, integrated NDVI and that of adaptive capacity include irrigation support, soil parameters. Vulnerability mapping and hazard zonation are indispensable requirements to evolve more effective long term disaster management strategies which include management and structural interventions for soil and water conservation. Thus, objective information on drought vulnerability plays a key role to prioritize the areas for development and implementation of long term drought management measures.

## 9. Challenges in agricultural drought assessment

Because of the complexities of drought, no single index has been adequate to capture the intensity and severity of drought and its potential impacts. Different states are adopting different methodologies for drought assessment, preparation of drought memorandum, drought declaration and relief assessment in India. The criteria adopted in different states also vary depending on the rainfall and crops grown in the region. Keeping in view the need for rationalization of drought criteria and adoption of uniform and integrated approach, the Ministry of Agriculture, Government of India, brought out a drought manual in 2010 after conducting wide range of discussions with different experts. The manual is available at [www.agricoop.gov.in](http://www.agricoop.gov.in). The main challenges in the operational drought assessment are discussed in subsequent sections.

### 9.1. Integrated approach

Development of a unified index for drought severity assessment by integrating the data from different sources is an important challenge. There is a need to arrive at a scientifically acceptable indicator of drought for the country. The index should give appropriate weightages to the rainfall, soil moisture and crop condition and to make the criteria uniform irrespective of region or state.

Standardized departures from normal of different indices need to be blended to characterize the drought intensity. Empirical models, process based models, satellite data and ground surveys with sampling techniques need to be explored in this context.

### 9.2. Early warning systems

An early warning system should provide the information about the onset, progress and end of drought conditions to the decision makers at all levels. 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. 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. Vulnerability profile of the area should also form an important component of early warning methodology.

Remote sensing data provides wide ranging inputs to drought early warning system. Time series data on different vegetation indices are extremely useful to detect the response patterns of agricultural crops to weather variations. Satellite meteorology provide inputs to all the three types rainfall prediction systems currently in operation in India (Roy *et al.*, 2006). In the long term rainfall prediction using global and regional atmosphere, land and ocean parameters, the remote sensing data from geo-stationary and polar orbiting weather satellites, such as, INSAT, NOAA etc 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 Radiosonde 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. Process based indicators such as evapo-transpiration deficits, root zone soil moisture profile at field scales fit for agricultural decision making, need to be developed.

### 9.3. Quantification of the drought impact

Assessment of the impact of drought in quantitative terms is highly essential to provide compensation / relief to the farmers. Response of crop plants to the growing environment is mostly non-linear in nature. The effects are further compounded when multiple factors are operating in the process of the progression of drought. Vegetation indices like NDVI and NDWI, etc. have certain inherent limitations such as low responses under sparse canopy

conditions and problems of saturation at higher canopy densities. During the monsoon season, computation of indices in the visible - near and mid infrared and thermal regions is not possible. Quantitative information on the impact of drought is required in all the stages of the crop growth like early-season, mid-season and terminal drought as the impacts vary with the crop phenology. Though conducting crop cutting experiments provide the cumulative effect, to cover larger areas, manually, would be tedious. Thus, quantification of drought impact remains a major challenge for remote sensing community and drought experts.

### 9.4. New satellite missions

Satellite remote sensing applications with the launch of several new instruments would open new vistas for Drought Monitoring. Soil Moisture Active/Passive (SMAP) mission is intended to provide the measurements of Soil Moisture and freeze/thaw state. SMAP with its L band radar and L band radiometer enables mapping of soil moisture with a 10 km resolution within a 2 to 3 day revisit period. GRACE mission has provided new insights into terrestrial water storage which acts as an important indicator for drought monitoring. Visible/Infra Red Imager Radar Suite (VIIRS) with legacy from AVHRR and MODIS has contributed significantly to develop several drought monitoring modules. The next generation Geo satellites like GEOS-R and GISAT are equipped to provide more frequent data for drought assessment. Thus, land data assimilation systems will be better enhanced with both sun-synchronous and Geo Stationary Satellites.

## 10. Conclusions

Agricultural Drought is a complex hydro-meteorological disaster. Occurrence of agricultural drought is determined by a number of parameters – rainfall, soil moisture, cropping pattern, crop stage etc. State departments of Agriculture and Relief are adopting a number of parameters and indices for monitoring and management of drought situation. Geospatial approach for drought assessment involving different satellite derived indices, ground measured data and derived indices and their integration brought rationality, objectivity, spatial and temporal perspective to agricultural drought assessment. NADAMS successfully incorporates different satellite derived indices, geospatial products to represent soil moisture and crop status during the season, showcased the operational robustness of geospatial approach and strengthened the drought assessment mechanism in the country. Drought impact assessment and early warning are some of the yet-to-be operationalised issues to take the drought monitoring endeavor to next level and to achieve weather resilient rain-fed agriculture in India. Integration

of remotely sensed indicators continues to gain acceptance with the decision makers' understanding on the inherent limitations and strengths to explain the prevailing drought situation. Active involvement of remote sensing community and drought experts is highly essential towards enhanced outreach and utilization of the drought information products through rigorous validation and field campaigns.

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