MAUSAM, **67**, 1 (January 2016), 289-296

633 : 551.583 (540)

Establishing an operational system for assessment and forecasting the impact of extreme weather events on crop production

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सार – विभिन्न आर्थिक नीति और निर्णय लेने के लिए फसल उत्पादन का पूर्वानुमान आवश्यक है। देश में एफ ए एस ए एल (FASAL) नाम से एक अत्यंत प्रचालनात्मक कार्यक्रम है जो फसल पैदावार के पूर्व पूर्वानुमान के लिए बहुल दृष्टिकोणों का उपयोग करता है। मौसम की चरम घटनाओं में लगातार वृद्धि होने और खेती बाड़ी पर उनके बड़े पैमाने पर प्रभाव पड़ने के कारण उस प्रभाव का आकलन करने के लिए सुदूर संवेदी तकनीक के उपयोग की अत्यधिक आवश्यकता है। इस दिशा में कई कार्य किए गए है। इस शोध पत्र में तीन ऐसे मामलों के अध्ययन प्रस्तुत किए गए हैं जिसमें पेलिन चक्रवात के बाद धान की फसल के बाढ़ में डूबने, अवधि प्रचालनात्मक जिला / उप-जिला स्तर पर सूखे का निर्धारण करने तथा गेहूँ की फसल पर हाल ही के ओलावृष्टि / बेमौसम वर्षा के प्रभाव को समझने के लिए अन्य ऑकड़ो के साथ सुदूर संवेदी का उपयोग किया गया है। इस मामले के अध्ययन में फसल पैदावार पर मौसम की चरम घटनाओं के प्रभाव का निर्धारण करने के लिए सुदूर संवेदी के विस्तार पर प्रकाश डाला गया है।

ABSTRACT. Crop production forecasting is essential for various economic policy and decision making. There is a very successful operational programme in the country, called FASAL, which uses multiple approaches for pre-harvest production forecasting. With the increase in the frequency of extreme events and their large-scale impact on agriculture, there is a strong need to use remote sensing technology for assessing the impact. Various works have been done in this direction. This article provides three such case studies, where remote sensing along with other data have been used for assessment of flood inundation of rice crop post Phailin cyclone, period operational district/sub-district level drought assessment and understanding the impact of recent hailstorm/unseasonal rainfall on wheat crop. The case studies highlight the great scope of remote sensing data for assessment of the impact of extreme weather events on crop production.

Key words – Remote sensing, FASAL, Flood, Hailstorm, Drought, NADAMS, Extreme weather.

1. Introduction

Crop production forecasting is essential for various agricultural planning purposes, including pricing, export/import, contingency measures, etc. (Ray *et al*., 2015a,b). The Directorate of Economics & Statistics of Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India provides advance estimates of crop production through various sampling techniques and crop cutting experiments (DES, 2015). Final estimates of production based on complete enumeration of area and yield through crop cutting experiments (CCE) become available much after the crops are actually harvested. In order to supplement and complement these estimates at an early stage of crop growth, a programme called FASAL (Forecasting Agricultural output using Space, Agro-meteorology and Land based observations) was launched by Ministry of Agriculture in 2006, for which the technology was developed by Indian Space Research Organization (ISRO), in collaboration with various national and state level organizations. The scope of work of the FASAL scheme involved developing (*i*) econometric (Ghosh *et al*., 2008), (*ii*) Agromet (Ghosh *et al*., 2014) and (*iii*) Remote Sensing (RS) (Parihar & Dadhwal, 2002) based approaches to generate crop forecasts (*i*) in the beginning of the season, (*ii*) during mid-season crop growth and (*iii*) in the mid-and pre-harvest stage ofcrop growth respectively, at national, state and district level (DES, 2015; Parihar & Oza, 2006; Ray *et al*., 2015). With the maturity of the technology, the crop forecasting activity was operationalized in the Ministry of Agriculture by establishing a new centre, Mahalanobis National Crop Forecast Centre (MNCFC) in April, 2012. MNCFC provides operational national/state/district level crop production forecasts for 8 major crops, in collaboration with State Agriculture Departments and State Remote Sensing Centres, using the technology developed by ISRO. The FASAL scheme also envisages assessing the impact of episodic events on crop production. This article summarizes various technical activities being carried out in this direction.

2. Extreme weather events and agriculture

Extreme weather events include extremes in temperature and rainfall, causing floods, droughts, heavy rainfalls, heat waves, hailstorms, thunderstorms, etc. Some extreme weather and climate events have increased in recent decades, and new and stronger evidence confirms that some of these increases are related to human activities (http://nca2014.globalchange.gov). It was found that the socio-economic impacts of the extreme weather events had been increasing. Extremes in temperature and rainfall can affect crop yields, crop pests and pasture productivity (Rosenzweig *et al*., 2001).The recent unseasonal rainfall and hail storm during February/March, 2015 causing large scale damage to *Rabi* season crops of Northern India has highlighted the need for using remote sensing technology for real time assessment of impact of extreme events on agriculture.

3. Remote sensing for studying the impact of extreme weather events in agriculture

Satellite based remote sensing data, because of its synoptic and temporal coverage at multiple spatial resolutions, are being used for impact assessment of extreme events on agriculture. Various remote sensing derived indices have been used to assess the crop condition. Some of these indices are mentioned below :

- The indices using VNIR (Visible Near Infrared) bands Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Enhanced Vegetation Index (EVI), etc.
- The indices using SWIR (shortwave infrared) bands: Normalized Difference Water Index (NDWI), Shortwave Angle Slope Index (SASI), etc.
- The indices using Thermal bands: Crop Water Stress Index (CWSI), Vegetation Index/Temperature Trapezoid, etc.

There is another set of indices, which uses long-term data set and is very much used for drought assessment, vegetation condition monitoring, index based insurance, etc. These indices include Vegetation Condition Index (VCI), Temperature Condition Index (TCI) and Vegetation Health Index (VHI). These indices can be computed as (Kogan, 1990; 1997):

$$\mathrm{VCI} = \frac{100 * \left(\mathrm{NDVI_i} - \mathrm{NDVI_{min}}\right)}{\left(\mathrm{NDVI_{max}} - \mathrm{NDVI_{min}}\right)}$$

$$\mathrm{TCI} = \frac{100 * \left(\mathrm{BT_{max}} - \mathrm{BT}\right)}{\left(\mathrm{BT_{max}} - \mathrm{BT_{min}}\right)}$$

$$\mathrm{VHI} = a * \mathrm{VCI} + b * \mathrm{TCI}$$

where NDVI, $\mathrm{NDVI_{max}}$, and $\mathrm{NDVI_{min}}$ are the smoothed weekly NDVI, its multi-year absolute maximum and minimum, respectively; BT, $\mathrm{BT_{max}}$, and $\mathrm{BT_{min}}$ are similar values for Brightness Temperature (BT); a and b are coefficients quantifying a share of VCI and TCI contribution in the total vegetation health. The VCI, TCI and VHI are indices estimating cumulative moisture, temperature and total vegetation health conditions, respectively on a scale from zero (extreme stress) to 100 (favorable condition) with 50 corresponding to average condition.

Most of the extreme events affecting agriculture are hydro-meteorological disasters. These are always associated with widespread cloud cover, which makes it difficult to obtain optical remote sensing data. Microwave remote sensing based SAR (Synthetic Aperture Radar) data has been found to be useful in such cases. SAR data has been extensively used for flood monitoring and flood impact assessment (Abhyankar *et al*., 2012).

4. Case studies

In the following sections three examples have been shown, which are typical cases of extreme weather events affecting agriculture in India, *i.e*., flood, drought and hail storm/unseasonal rainfall. Out of these, drought assessment is an operational programme, whereas in case of flood and hail storm impact assessment, the technologies are being developed to be operationalized.

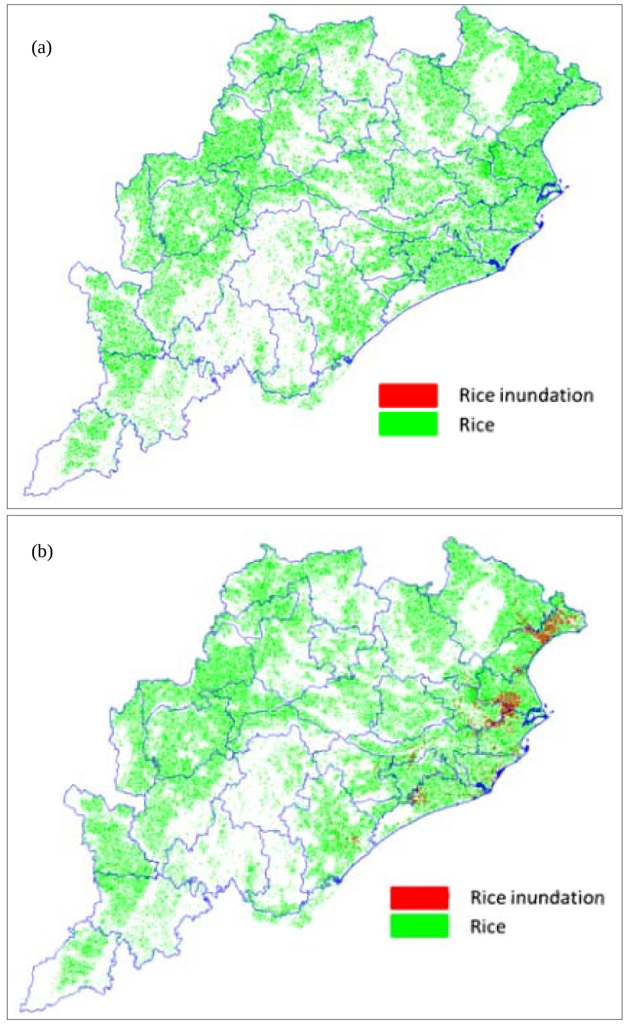
4.1. *Flood inundation in rice crop post-phailin cyclone*

Flood is one of the most severe nature disasters and India is one of the most disaster-prone countries of the world especially for flood in coastal states of India. Identification of flood affected areas is an important input for planning the strategy for efficient management of floods. The methods to extract flood extent from optical remotely sensed data are hardly carried out because flooded area is usually covered by cloud. Today, Microwave remote sensing has become a very powerful tool for monitoring flood because it can obtain a good image especially in cloudy weather (Bhatt *et al*., 2010). During October 12, 2013 Tropical Cyclone Phailin hit Odisha coast. It was the most intense cyclone after the super cyclone of October, 1999. It caused very heavy to extremely heavy rainfall over Odisha leading to floods.

TABLE 1

District wise rice inundation area of Odisha post-Phailin cyclone

District	Rice Inundation Area (Thous. ha)
Baleshwar	35.79
Bhadrak	20.50
Jajpur	16.13
Kendrapara	15.79
Puri	11.32
Cuttack	7.18
Jagatsinghpur	7.15
Mayurbhanj	6.84
Ganjam	4.63
Khordha	4.12
Nayagarh	1.25
Keonjhar	1.00
Dhenkanal	0.68
Others	0.02
Total	132.40



Figs. 1(a&b). Maps showing (a) rice area and (b) rice inundation area in Odisha, post Phailin cyclone of 2013

Rice was the major crop during this period. An attempt was made to assess the rice flooded area due to this cyclone. Multi-date RISAT-1 SAR (MRS mode) was used along with ground truth site for rice area classification. Hierarchical classification method was used to extract rice area. Flooded area map generated by National Remote sensing Centre, Hyderabad using Radarsat and RISAT SAR data was overlaid on the rice map of Odisha. The derived map and the estimated area showed the district wise rice inundated area (Table 1 and Fig. 1). The results showed that Baleshwar, Bhadrak, Jajpur, Kendrapara and Puri were most affected districts. This was the first quantitative information, which was provided to the Central and State government for planning necessary contingency measures. A post-analysis ground truth was conducted which showed the accuracy of the rice flooded area mapping was 89 percent. Out of 18 sites visited, 16 were found to be correctly mapped using remote sensing data. The details of this work, along with analysis of rainfall pattern, are presented in Ray *et al*. (2005a).

4.2. *Drought assessment*

Drought is a perennial feature in India. Sixteen (16) percent of India's total area is drought prone and approximately, 50 million people are annually affected by droughts. Over 68-70% of total sown area in India is vulnerable to drought. A major initiative towards the operational assessment of drought is the 'National Agricultural Drought Assessment and Monitoring System (NADAMS)' project, conceptualized and developed by National Remote Sensing Centre (NRSC), ISRO, Department of Space (Murthy & SeshaSai, 2011; Ray *et al*., 2014). This provides near real-time information on prevalence, severity level and persistence of agricultural drought at state/district/sub-district level. Currently, NADAMS covers 14 states of India, which are predominantly agriculture based and prone to drought situation. These states are Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Haryana, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Tamil Nadu, Telangana and Uttar Pradesh, Out of these for 5 states (Andhra Pradesh, Haryana, Karnataka, Maharashtra and Telangana) the drought assessment is carried at sub-district level. A variety of satellite remote sensing based

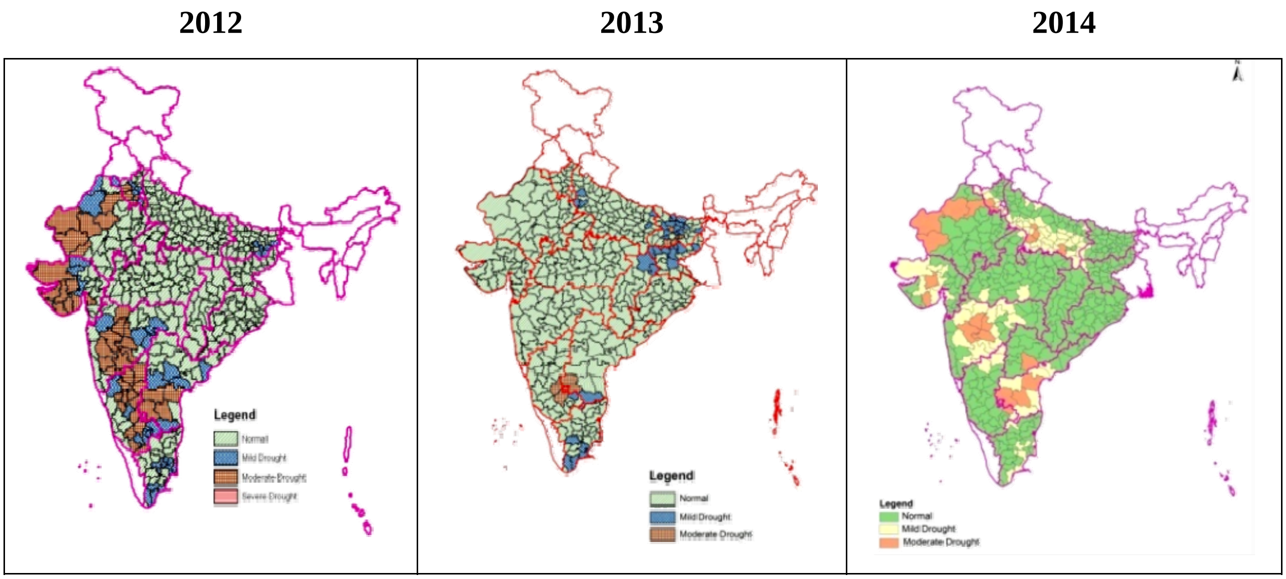


Fig. 2. District level drought assessment in 14 states during the Kharif season of last 3 years, under NADAMS project

TABLE 2

Districts with different drought conditions in 14 states

Category	2012	2013	2014
Normal	316	369	323
Mild	43	34	85
Moderate	51	8	22

indices (such as Normalized Difference Vegetation Index, Normalized Difference Water Index, Shortwave Angle Slope Index, Vegetation Condition Index) derived from NOAA-AVHRR, MODIS, Resourcesat-2 AWiFS data along with, estimated soil moisture, rainfall, crop sowing progression, irrigated area information are used through logical modeling approach for drought warning and assessment. Monthly report of drought condition is provided to the all concerned agencies in Centre and State under NADAMS. From the year 2012, the NADAMS project is being implemented by the Mahalanobis National Crop Forecast Centre (MNCFC), Ministry of Agriculture, after the technology was transferred to MNCFC by NRSC. A comparison of last 3 years drought assessment shows that, there was maximum number of districts with drought condition during 2012 followed by 2014 and then 2013 (Table 2 and Fig. 2).

A comparison of agricultural drought assessed by the NADAMS programme and declared by the states is given in Table 3. In 28 out of 39 cases the difference between number of districts assessed as drought affected by NADAMS and declared by the state is less than or equal to 5. On average the districts assessed as drought affected by NADAMS programme is lower than those declared by the states.

4.3. *Impact of hailstorm and heavy rainfall*

Hailstorms cause extensive damage to properties and growing crops. The extent of crop-hail damages depend upon size and intensity of hails, wind force during the event, intensity and amount of the associated rainfall and stage of the crop (Bal *et al*., 2014). Thunderstorms with associated rain and hail are commonly observed weather phenomenon in India, generally during the pre- and post-monsoon months.

During February and March, 2015 unseasonal heavy rainfall and hailstorms caused large scale damage to standing crops in Northern India, The initial unpublished reports mentioned that Rabi crops of nearly 100 lakh hectares might have been damaged. In this context, it was attempted to use multi-date (pre- and post- event) and multi-year (2014 and 2015) remote sensing data (Resourcesat-2 AWiFS) along with gridded rainfall data of IMD and selected ground truth to assess the possible impacts of heavy rainfall and hailstorm on wheat crop.

Wheat classified area mask derived from FASAL project was used for carrying out the study in wheat area. NDVI deviation image were generated from the NDVI

TABLE 3

Comparison of districts declared by the states as drought affected and those assessed by NADAMS programme

State	2012 State	2012 NADAMS	2013 State	2013 NADAMS	2014 State	2014 NADAMS
Andhra Pradesh (including Telangana)	6	9	3	2	6	9
Bihar	0	6	33	17	0	0
Chhattisgarh	0	0	0	2	0	0
Gujarat	16	12	0	0	0	9
Haryana	0	14	0	0	21	11
Jharkhand	0	0	0	8	0	1
Karnataka	26	22	22	3	9	5
Madhya Pradesh	0	0	0	0	0	3
Maharashtra	17	15	0	0	26	17
Odisha	0	0	0	0	0	0
Rajasthan	12	8	29	0	0	4
Tamil Nadu	31	10	0	5	0	7
Uttar Pradesh	0	0	0	5	43	39

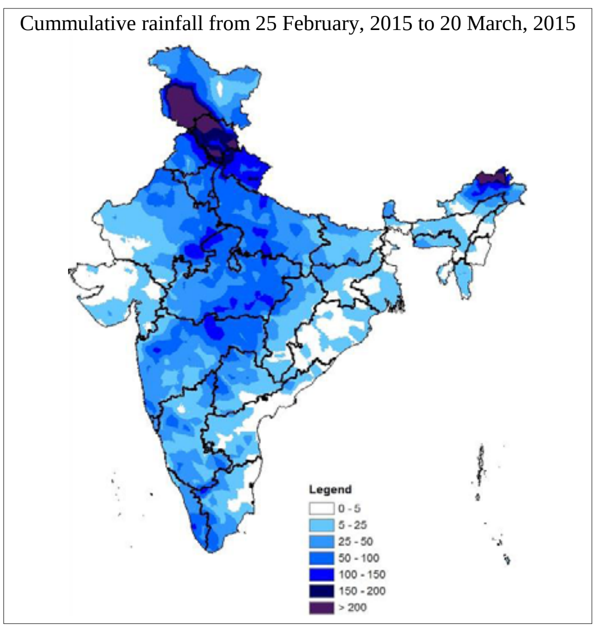


Fig. 3. Rainfall amount (mm) during 25th February to 20th March, 2015 (*Source* : IMD gridded data)

images of 2014 and 2015. Logical modeling approach was used to categorize the damages based on the extent of NDVI deviation and rainfall amount (Fig. 3). The ground truth carried out in 4 states showed the damaged (lodging) wheat crops (Fig. 4). The overall analysis showed that most severely affected districts were found in Haryana, Rajasthan and Madhya Pradesh (Fig. 5).

TABLE 4

Comparison of yield values of hailstorm affected wheat crop with unaffected crop

Crop type	No. of sites	Avg. yield (kg/ha)	Range (kg/ha)
Affected	16	2381	272-4614
Unaffected	33	2568	1054-4420

Crop cutting experiments for wheat were carried at 49 sites in 2 districts of Madhya Pradesh, *i.e.*, Betul and Hoshangabad. These sites had been selected based on stratified random sampling, where stratification had been done using NDVI images of pre-event period. Out of the 49 sites 16 were found to be affected (at least to some extent) by hailstorm and heavy rainfall. The average yield of affected sites was at least 7% lower than unaffected sites (Table 4).

5. Future plans

The above studies have shown the tremendous potential of remote sensing data for assessment of impacts

Fig. 4. Field photographs showing crop damages in different parts of Northern India

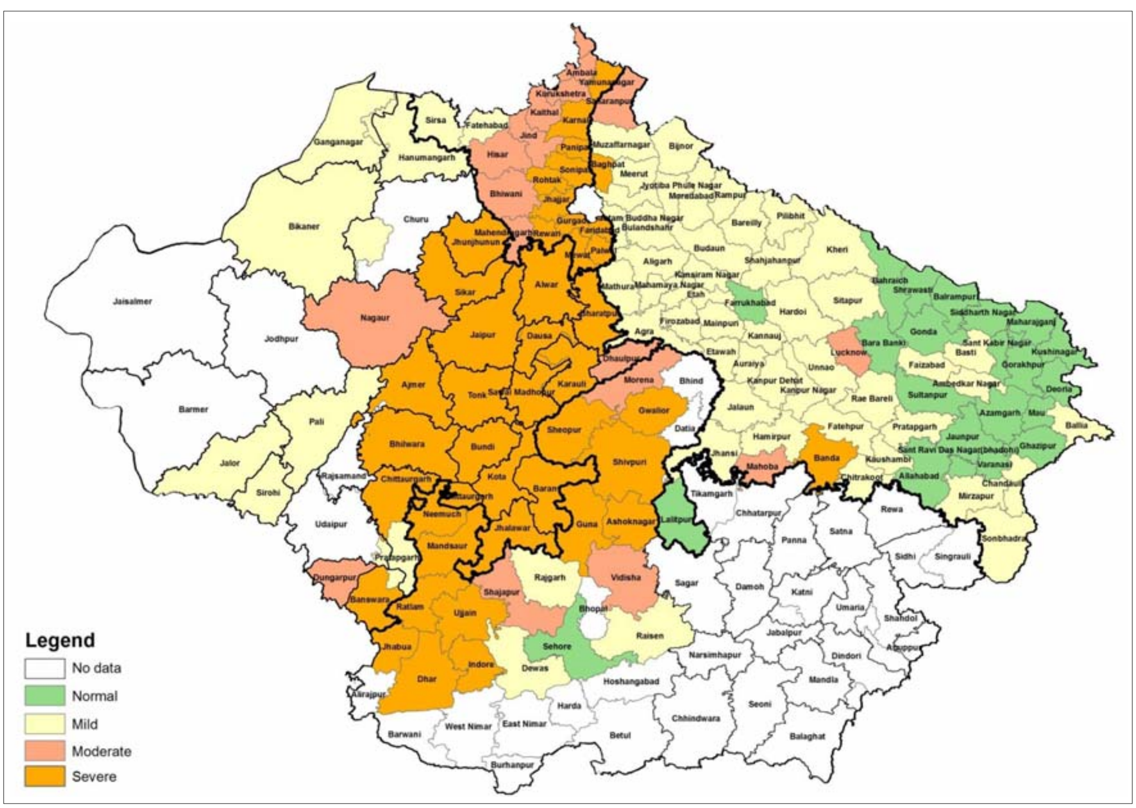


Fig. 5. Wheat crop situation assessment post unseasonal rainfall and hail storm during February/March, 2015

of various extreme weather events on agriculture. However, there is strong need for improvement in each assessment. For example, Cyclone damage comprises wind damage as well as inundation damage. The study discussed in this paper maps inundated area. Inundation depth and duration of inundation are critical parameters for studying crop damage. This is because some rice varieties are tolerant to certain number of days of inundation. High temporal resolution SAR data will be required to monitor the inundation period. To utilize SAR data for flood depth estimation, methods have been developed that derive flood heights from flood extent data. The methods used combine SAR data with elevation data sources like DEMs altimetry and triangular irregular networks (TINs) (Musa *et al*., 2015). Similarly, for drought assessment large number of new indices/approaches has been developed. Some of these indices include Vegetation Drought Response Index, Normalized Difference Drought Index, which are being experimented at National Drought Mitigation Center, USA. There is need to evaluate these indices and develop an integrated approach. In case of Hailstorm impact, further studies need to be carried out to explore the scope of remote sensing for assessing the structural damages of the crop. It is also essential to quantify the impacts of extreme events on crop yield.

Additionally, for taking up necessary government intervention measures, *e.g*., crop insurance, disasters relief, etc., there is a need to estimate production loss at disaggregated level, *i.e*., gram panchayat or block level, even if not in parcel level. This will necessitate improving not only the earth observation capacity but also the modeling technology for translating the remote sensing derived parameters into crop yield. A study by Navalgund *et al*. (2010) showed that a possible constellation of 5 (satellites), including 3 optical and 2 microwave, would be needed for providing the required coverage for disaster monitoring. In order to understand the role of remote sensing technology for real-time disaggregated level crop yield and damage assessment, Ministry of Agriculture has launched a pilot study to evaluate the use of advanced technology, such as remote sensing, mobile phones, GPS, geoportals and modeling tools. This study will bring out the opportunities and limitations of the space technology in crop damage assessment.

Acknowledgement

The Authors are grateful to the Directors of Space Applications Centre, Ahmedabad & National Remote Sensing Centre, Hyderabad and Joint Secretary (IT) of Department of Agriculture, Cooperation & Farmers Welfare, New Delhi for their strong support for these studies. Authors wish to acknowledge the Scientists and Analysts at SAC, NRSC & MNCFC for their contribution to these studies.

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