Satellite Remote Sensing Applications for Agriculture: A Review in Indian Context

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ABSTRACT

Agriculture is a major component of the Indian economy. With around 43% of the geographical area coverage, agriculture contributes 17% to the Gross Domestic Product (GDP) of the country and employs more than half of the working population of the country. India has a vibrant end-to-end space programme for national development. Starting from the first operational remote sensing (RS) satellite IRS 1A launched in March 1988, the country has launched many earth-observation satellites which have been used for various natural resources management applications, with major emphasis on agriculture. Operational large agricultural applications include crop production forecasting, drought assessment, cropping system analysis, horticultural assessment and development, crop intensification, site suitability analysis, satellite agro-meteorology, precision farming, crop insurance, etc. This paper discusses these applications, along with possible gap areas in space observation and way forward.

Keywords: *Agriculture, Remote Sensing, Crop Forecasting, Drought Assessment, Cropping System Analysis and Agricultural Resources Management.*

1. Introduction to Indian Agriculture

Globally, agriculture is a major economic sector, with food and agritech being a 5 trillion Euro global Industry. In India, agriculture sector contributes about 17% to Gross Domestic Product and employs 55% of the working population of the country. With 139.51 million ha of Net Sown Area, 67.3 million ha of Net Irrigated Area, 296.6 million tonnes of food grain production and 319 million tonnes of horticultural production, Indian Agriculture secures an important position in world's agricultural arena (Table 1) (DES, 2020). In the last seventy years, crop production has increased manifold from a meagre 50 million tons when India became independent to about 296 million tons by 2019-20. However, the net agricultural area has remained the same. Limitations like, small field size, low cropping intensity (141%), low productivity of crops in major parts of the country, diversity in cultural practices, low irrigation percentage (47.2%), limited infrastructure (market and storage) and being prone to multiple disasters (floods, drought, hailstorm, cyclone, etc.), have made agriculture a risky business. Improvement in food security necessitates increasing food production sustainably, through an increase in the cropping intensity, enhancing productivity per unit area, identifying and reclaiming culturable wastelands (salt-affected soils) and to bring post-Kharif fallows under cultivation during rabi season. Although the irrigation potential has increased considerably, the performance of the command areas has not been uniform. Additionally, there has been excessive exploitation of groundwater, showing alarming trends of decline in groundwater tables in some areas. All these efforts require comprehensive, timely and reliable information on land use/cover, soils, the extent of wastelands, crops, water resources, and the impact of hazards/natural calamities on agriculture. India has a conventional system of collecting information on agricultural statistics. It has limitations in terms of timeliness, manpower requirement and reliability. Season-wise information on crops, their acreages, vigour and production is necessary to adopt suitable measures to meet shortages, if any, and implement proper support and procurement policies. Hence, to make agriculture move from a subsistence economy to a profit-making enterprise, there is an urgent need to take advantage of advanced technologies for better monitoring and management. The Committee on Doubling Farmers' Income (DFI) in its report appreciated the role of digital technology, which can play a transformational role in modernizing and organizing how rural India performs its agricultural activities (DAC&FW, 2019). The possible components for modern management of agriculture, as per the DFI Report, are i) Remote Sensing; ii) Geographical Information System; iii) Data Analytics; iv) Artificial Intelligence & Machine Learning and v) Internet of Things.

Table 1. Some basic statistics of Indian Agriculture (Source: DES, 2020).

S.N.	Parameters	Year	Value
1	Net Sown Area (Million Ha)	2015-16	139.51
2	Net Irrigated Area (Million Ha)	2015-16	67.30
3	Total Foodgrain Production (Million Tonnes) (4th Advance Estimate)	2019-20	296.65
4	Total Horticultural Production (Million Tonnes) (3rd Advance Estimate)	2019-20	319.57
5	Cropping Intensity (%)	2015-16	141.25
6	GVA - Agriculture and Allied Sector at constant (2011-12) prices (Rs. Crore)	2018-19	18723 39
7	Average Landholding Size (Ha)	2015-16	1.15
8	Number of Operational Holdings (Millions)	2015-16	146.45
9	Total Number of Cultivators as per Census 2011 (Million)	2011	118.8
10	Total Number of Agricultural Laborers as per Census 2011 (Million)	2011	144.3

2. Remote Sensing for Agriculture: the Principles

Conventionally, remote sensing (RS) refers to imaging a target through the light reflected/emitted by the surface at different wavelengths (blue, green, red, infrared, microwave etc.) at frequent time intervals through sensors placed on board the satellites orbiting around the earth. Different earth surface features (e.g. crops) reflect/emit light differently at different wavelengths and/or at different times, hence facilitating their identification, discrimination and assessment. For example, crops have higher reflectance in the green region, low reflectance in red and blue regions (due to absorption by chlorophyll pigment) and very high reflectance in the near-infrared region (due to leaf internal structure) (Figure 1). This reflectance varies for different crops, crop types, crop conditions, associated features and crop phenology. Hence, it is not only feasible to identify a crop but also to assess the health of the crop. The sensors, operating in the thermal region, sense the temperature of the vegetation and hence can assess the crop stress due to lack of moisture availability. In microwave domain, especially for remote sensing through SAR (Synthetic Aperture Radar), the portion of the outgoing radar signal that the target (crop or soil) redirects directly back towards the radar antenna, is controlled by various target parameters, such as surface roughness and dielectric coefficient. In agriculture, microwave sensors have been highly useful for rice crop assessment, flood monitoring, soil moisture estimation and biomass assessment (Panigrahy & Ray, 2006).

Through the use of different information available from satellite remote sensing sensors, at various spatial, spectral and temporal domain, different parameters related to crops/agriculture can be obtained. These include,

(i) The existence of vegetation, as seen from the colour composite images,

(ii) Crop statistics and maps (for major crops),

(iii) Crop condition/stress, by deriving vegetation indices, which are mathematical combinations of reflectance at different wavelengths,

(iv) Crop growth profile using multi-date data (sowing/harvesting pattern), and

(v) Agro meteorological parameters, such as rainfall, land surface temperature, evapotranspiration, soil moisture, etc.

All these parameters are used for various agricultural applications, as can be seen in the later sections.

There are several advantages of using satellite remote sensing for agriculture. These include:

(i) Large area coverage provided by the satellite images.

(ii) Inaccessible area coverage.

(iii) Data is available in many scales (spatial resolutions) suitable for both regional and local level applications

(iv) Frequent observations during a crop growing period.

(v) There is a long time-series of satellite data, which helps not only in the year to year comparison but also long-term monitoring.

(vi) Many satellite data are free of cost with open access (e.g. Sentinel and Landsat).

(vii) There are diverse measurements (reflectance, temperature, backscatter, etc.) available from the satellite.

(viii) Because of the similar sensor characteristics, there is consistency in data and, data from different sensors can be made comparable through inter-sensor calibration.

3. Indian Satellite Remote Sensing Programme

India has an end-to-end space programme. The space agency of the country is the Indian Space Research Organization. Based on the observation need assessment of applications, it builds appropriate sensors, the satellites on which these are to be placed and also builds rockets/launch vehicles to put the satellites in suitable orbits. It receives data through its network of ground stations, processes and disseminates the data. It develops applications along with stakeholder

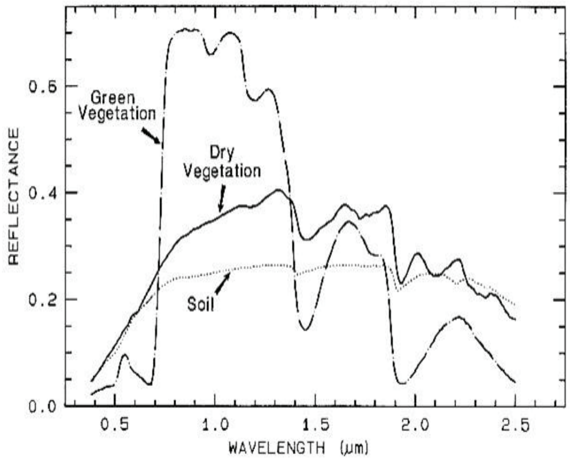

Figure 1: Spectral Signature of green vegetation compared to dry (image source: academic.emporia.edu).

organisations and also does the capacity building, to enable efforts of technology absorption (Navlagund, 2006). During the last three decades, India has successfully built and launched several remote sensing satellites which provide data at different level of details (spatial resolutions) and at as frequently as once every five days. India has also developed a satellite with SAR, a microwave sensor which can look at the crops even during cloudy conditions. All these satellites/sensors have been tailored to meet the requirements of Indian agriculture. A list of Indian Remote Sensing satellites, which have been used for agriculture is presented in Table 2. The current major earth observation satellites, Resourcesat 2 and 2A, have multiple multispectral sensors (cameras), whose data are used regularly for agricultural monitoring. These cameras include AWiFS (Advanced Wide Field Sensors) with 56 m spatial resolution and 5-day revisit, LISS (Linear Imaging and Self Scanning) III with 23.5 m spatial resolution and 24-day repetition and LISS IV with 5.8 m spatial resolution. Now with two satellites available simultaneously, the temporal coverage has improved for AWiFS to 2-3 days, LISS III to 12 days and LISS IV to 24 days. Apart from the Indian satellites, many foreign satellites (Radarsat 2 of Canada, Landsat 8 of USA, Sentinel 1 and 2 of Europe) are available, whose data are regularly used for agricultural monitoring (Table 3).

Table 2. Indian Remote sensing satellites which have been operationally used for agricultural applications (Source: https://directory.eoportal.org/web/eoportal/satellite-missions/).

Name of the Satellite	Year of Launch	Sensor	Specifications (Bands, Resolution, Swath, Repetition cycle)
IRS 1A/1B	1988, 1991	LISS I LISS II	4 band (B,G,R, NIR), 72.5m, 148 km, 22day 4 band (B,G,R, NIR), 36.25m, 74x2 km, 22day
IRS P2	1994	LISS II M	4 band (B,G,R, NIR), 32x37m, 66x2 km, 24day
IRS 1C/1D	1995, 1997	LISS III Pan WiFS	4 band (G, R, NIR, SWIR), 23.5/70m, 142/148 km, 24day Panchromatic, 6m, 70km, 5 day (Revisit) 2 band (R, NIR), 188m, 804 km, 5 day (Revisit)
Resourcesat 1	2003	LISS III LISS IV AWiFS	4 band (G,R, NIR,SWIR), 23.5m, 140 km, 24day 3 band (G,R, NIR), 5.8m, 23.9/70km, 5 day(Revisit) 4 band (G,R, NIR,SWIR), 56m, 740 km, 5 day(Revisit)
Resourcesat 2/ 2A	2012, 2016	LISS III LISS IV AWiFS	4 band (G,R, NIR,SWIR), 23.5m, 141 km, 24day 3 band (G,R, NIR), 5.8m, 70km, 5 day(Revisit) 4 band (G,R, NIR,SWIR), 56m, 740 km, 5 day(Revisit)
RISAT 1	2012	SAR	5.350 GHz (C-band), < 2 m to 50 m, 100 – 600 km

IRS- Indian Remote Sensing Satellite, LISS – Linear Imaging and Self Scanning, WiFS – Wide Field Sensor, AWiFS – Advanced WiFS, SAR – Synthetic Aperture Radar.

Table 3. Examples of some currently available international satellites which are mostly used for agricultural applications (Source: https://directory.eoportal.org/web/eoportal/satellite-missions/).

Name of the Satellite	Agency	Year of Launch	Sensor	Specifications
Sentinel 1-A Sentinel 1-B	ESA	2014 2016	C Band SAR	Multiple Modes, Dual polarization, 12-day repeat cycle
Sentinel 2 Sentinel 2A	ESA	2015 2017	MSI	13 bands (443–2190 nm); Resolution 10m (VNIR), 20m (red edge, SWIR) & 60 m (atmospheric correction bands); Swath: 290 km; 5-day revisit with 2 satellites
Landsat 8	NASA	2013	OLI	9 bands (443 -2300 nm), Resolution 30m (VNIR/SWIR), 15m Pan; Swath: 185 km, 16-day revisit
Radarsat 2	CSA & MDA	2007	C band SAR	Fully polarimetric, 3-100 m resolution in different modes, 24-day repeat cycle

ESA – European Space Agency, NASA – National Aeronautics and Space Administration, CSA- Canadian Space Agency, MDA - MacDonald Dettwiler Associates Ltd., MSI – Multi-spectral Imager, OLI – Operational Land Imager.

4. Role of Agriculture in Indian Remote Sensing (RS) Programme

Indian RS programme is governed by the principle enunciated by the father of Indian space programme, Dr Vikaram Sarabhai, which states that the nations should be "second to none in the application of advanced technologies to the real problems of man and society". Accordingly, agriculture, which is one of remote sensing for agricultural applications can be summarized as follows (Ray et al, 2020).

(i) Birth of remote sensing in India started with an agricultural experiment, i.e., the coconut root wilt disease detection in 1969.

(ii) Agriculture played a major role in defining the payload specifications (spatial, spectral, temporal and radiometric resolutions) on-board Indian remote sensing satellites.

(iii) It played a significant role in the growth of digital image processing in India, as agricultural applications mostly needed to use the digital numbers (for classification and parameter retrieval), rather than just visual interpretation.

(iv) It led to the development of indigenous software packages, like CAPEMAN (Anon., 1995), CAPEWorks (RRSSC, 1996), SARCROPS (Chakraborty and Panigrahy, 2000) FASALSoft (Manthira Moorthi et al. 2014), etc.

(v) It is one of the themes with the largest number of research activities conducted in the country. A keyword search in the Journal of Indian Society Remote Sensing showed that 'Remote Sensing' and Agriculture is 35.9% of only 'Remote Sensing'. Remote Sensing with other themes, such as Hydrology (11.7%), Forestry (11.5%), Disaster (12.3%), Oceanography (5.0%) and Meteorology (4.8%), had much lower proportion. Similar is the case in the international publication databases, as shown in Table 4.

Crop forecasting activity is one of the biggest users of remote sensing data (Resourcesat-2, Sentinel 1 & 2, and Landsat 8) in India.

5. Remote Sensing Applications in Agriculture

Way back in 1969, a feasibility study to detect root wilt disease in coconut plantations in parts of Kerala was conducted, jointly by ISRO, NASA and IARI. Colour infrared (CIR) photographs, collected using a Hasselblad camera on-board a helicopter, were used to detect the coconut root wilt disease affected plants (Dakshinamurti et al., 1971). Since then, many experiments/projects/programmes have been conducted to explore the role of remote sensing in agriculture, some of which have resulted in national programmes. Initially, aerial CIR images were used for crop inventory in Anantapur District of Andhra Pradesh and Patiala District of Punjab under the ISRO and ICAR joint project, called Agricultural Resource Inventory and Survey Experiment (ARISE) (Dhanju & Shankaranarayana, 1978 and Sahai et al., 1977). Monitoring the crops including their health, developing techniques for machine processing of remote sensing data was the area of attention in early days of development which was demonstrated in a study of paddy and sugarcane crops in Mandya district of Karnataka (Sahai et al., 1977). CIR and multi-band aerial photographs collected in different season using a 2-seater trainer Pushpak aircraft were used to identify crops, digitization of multiband black & white photographs and computer added processing were attempted to learn the use of digital data. Leaf blight affected sugarcane crops were also identified in parts of Mandya using CIR images (Parihar et al., 1977). The first time, Dadhwal & Parihar (1985) used satellite data of Landsat MSS and disgital image analysis for wheat acreage estimation in Karnal district of Haryana and expanded the application to state-level estimates by introducing a segment sampling approach (Dadhwal et al., 1987). With the launching of IRS-1A satellite, in 1988, it became possible to generate crop estimates, operationally, which led to the formulation of national level project called Crop Acreage and Production Estimation (CAPE), under which district-level crop area and production estimation was carried out for major crops like rice, wheat, cotton, groundnut, *rabi* sorghum and rapeseed & mustard (Manjunath et al., 2000 and Dadhwal & Ray, 2000). Dadhwal et al. (2002) have provided a detailed review of remote sensing-based crop

Table 4. Results of the keyword search of "Remote Sensing" and "Remote Sensing" with other themes from various publication databases (as on 21st November 2020).

Database	Only "Remote Sensing"	"Remote Sensing" along with other themes					
		Agriculture	Hydrology	Forestry	Disaster	Oceanography	Meteorology
ScienceDirect	109,260	38,253	13,069	10,351	8,369	10,824	29,325
Google Scholar	21,30,000	11,50,000	5,29,000	4,68,000	1,79,000	2,36,000	5,00,000
Taylor & Francis	59,123	34,107	7,033	19,384	7,869	7,119	13,685
JISRS	2402	862	280	277	296	120	115

JISRS-Journal of Indian Society of Remote Sensing

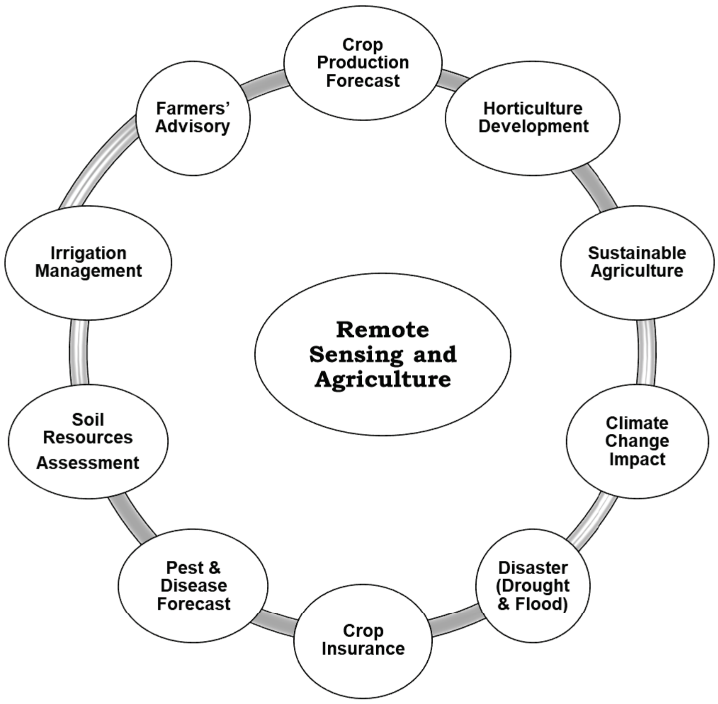

Figure 2: Agricultural applications of remote sensing in India.

land use/land cover mapping, soil resources mapping, irrigation management, precision farming, cropping system analysis, horticultural development, potential fishing zone forecasting, etc. (Figure 2). Only a few of these applications are briefly mentioned in the following sections.

5.1 Crop production forecasting

Reliable and timely information on area and production of each major crop grown in the country is very essential for taking policy decisions on several issues such as export-import, minimum support price, transportation requirements, storage facilities, crop insurance, etc. Considering this, satellite remote sensing data has been used to generate crop estimates at various spatial scales. As a part of Remote Sensing Applications Mission, CAPE (Crop Acreage and Production Estimation) project was developed and tested by Space Applications Centre in collaboration with many State Remote Sensing Centres, ICAR Institutes, Agricultural Universities and State Agriculture

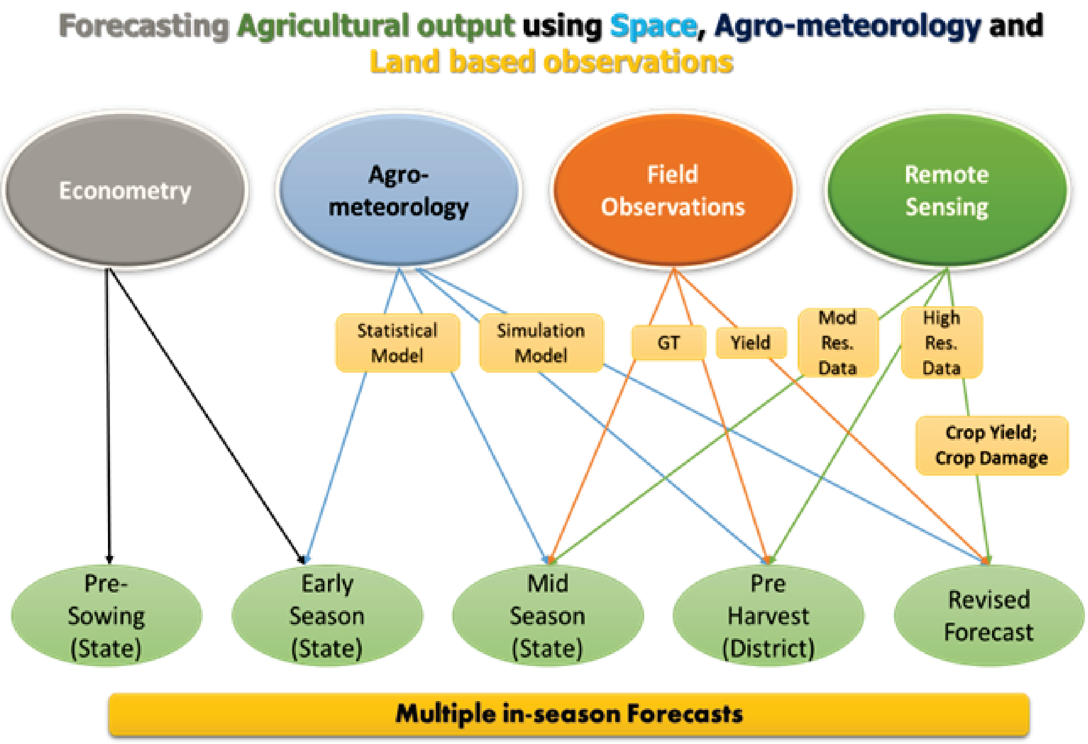

Figure 3: Approach of crop production forecasting under FASAL project (Source: Ray & Neetu, 2017).

inventory in the country. Apart from crop inventory, many large operational applications in the agriculture and related field have been carried in last two to three decades, which include drought assessment, watershed development, Departments, during the late eighties and nineties. Under the CAPE project, sponsored by Ministry of Agriculture, area and production estimates were generated, at the district level, using data from IRS satellites. In the early years, when the remote sensing data available was of medium resolution 80 m (Landsat MSS), estimates of wheat grown in single crop-dominated geographic regions could be made satisfactorily. As the spatial and temporal resolutions of remote sensing data improved, many crops such as mustard, rabi-sorghum, sugarcane, cotton, potato etc. could be assessed (Navalgund et al., 1991; Sahai & Dadhwal, 1990). In the case of Paddy, which is generally grown in Kharif season, use of optical data for crop area estimation has been problematic, because of cloud cover. Towards this microwave SAR data was successfully utilised for making reliable estimates (Panigrahy et al. 1997; 2000; Parihar et al. 1998). Procedure for state and national level kharif rice estimation including S/W for digital analysis of SAR were developed, validated and implemented (Chakraborty and Panigrahy, 2000, Chakraborty et al. 2006). Under CAPE project, the crop area was estimated using sample segment approach (Manjunath et al., 2001), while crop yield was estimated using both empirical models involving spectral and agrometeorological indices and also process-based models based on physical principles (Dadhwal and Ray, 2000). Following the launch of IRS-1C and with WiFS payload providing every 5-day coverage at 188m spatial resolution, the temporal analysis-based approach was developed, tested and operationalized for wheat crop (Oza et al., 2002). The success of this approach laid the foundation for upgrading the RS-based crop forecasting to continuous assessment with the integration of multiple sources of data (Navalgund et al., 2007; Dadhwal et al., 2002). Later on, with the requirement of multiple pre-harvest production forecasts, at national and state level, a new programme called Forecasting Agricultural output using Space, Agrometeorology and Land based observations (FASAL) was developed (Parihar and Oza, 2006). FASAL envisaged the use of multiple approaches for crop assessment and production forecasting. Accordingly, in the beginning, econometric based forecasts are generated at the pre-sowing stage or early season. During the mid-season moderate spatial resolution, temporal remote sensing (e.g., Resourcesat AWiFS) data is used for state-level estimation, while high-resolution data is used for district-level estimates, before harvest (Parihar and Oza, 2006). Figure 3 provides a schematic diagram of the FASAL approaches. Pilot testing and evaluation of FASAL concept was carried out in Odisha state (Patel et al., 2004). It was followed by extending the coverage to other states for methodology development and testing. FASALsoft a software package supporting the image analysis for FASAL was developed and used (Manthira Moorthi et al. 2014).

After establishing the methodology for FASAL, and development of required software package for digital image analysis at Space Applications Centre (ISRO), the technology was transferred to the new centre (Mahalanobis National Crop Forecast Centre) under Department of Agriculture, Cooperation & Farmers' Welfare (DAC&FW) for its operationalization (Parihar, 2016). Currently, MNCFC provides crop production forecasts for 9 major crops (Rice, Wheat, Rabi Pulses, Tur, Rabi Jowar, Rapeseed & Mustard, Cotton, Sugarcane and Jute) using the FASAL concept (Ray & Neetu, 2017). While state-level crop area is estimated using AWiFS multi-temporal NDVI products, the district level area is estimated using a combination of Sentinel 2 MSI, Resourcesat 2 LISS III and Landsat 8 OLI multi-spectral data. Rice Area is estimated using Sentinel 1 SAR data. The yield is estimated using a combination of empirical models using remote sensing & meteorological parameters, semi-physical (Production Efficiency) model, crop simulation models and selected crop cutting experiments (Ray et al., 2019). The major organizations involved in FASAL project include Directorate of Economics & Statistics (for budget management and use of estimates), Institute of Economic Growth (econometric forecasts), India Meteorological Department & Agromet Field Units (Agromet model-based estimates), SAC (ISRO) (R&D activities for new crops), State Agricultural Departments (Field Data Collection), State Remote Sensing Centres (support to analysis and validation), and MNCFC (operational crop forecasts & project management).

The success of FASAL programme and the requirement of horticulture database, resulted in the launching of another programme by Ministry of Agriculture & Farmers Welfare, called CHAMAN (Coordinated Horticulture Assessment and MAnagement using geoiNformatics), under which procedures were developed for generating operational National-State-District production estimates for seven major horticultural crops, namely, Potato, Onion, Tomato, Chili, Mango, Banana and Citrus (Ray et al., 2018). In Phase-I of the project, i.e. during 2015-18, technology for horticultural crops was developed jointly by MNCFC and ISRO Centres (SAC, NRSC & NESAC). Since 2018 operational district-state-national level estimates of above seven horticultural crops are being generated under CHAMAN project.

5.2 Agriculture Risk Assessment

Indian agriculture, because of its diverse growing agro-ecological conditions and dependence on rainfall and other weather parameters, is subject to various natural disasters/hazards, such as drought, floods, cyclone, heavy rainfall, frost, extreme temperatures, hailstorm and pest & diseases. These disasters/hazards cause significant loss to agricultural production. This results in direct economic loss to farmers, which can cascade along the entire value chain, affecting agricultural growth and rural livelihoods (FAO, 2018). Mausam journal brought out a special issue in January 2016 (Volume 67, No 1) on Extreme Weather Events and Indian Agriculture. The readers may refer to that issue for details on various extreme events (https://metnet.imd.gov.in/imdmausam/). Satellite remote sensing because of its variety of measurements of earth, ocean and atmosphere, has provided extremely important information for studying the impact of disasters (Kiran Kumar, 2016). Due to paucity of space, it is difficult to discuss each disaster, separately. Hence, only major agricultural disaster (drought) and one risk management programme (crop insurance) have been discussed in this section.

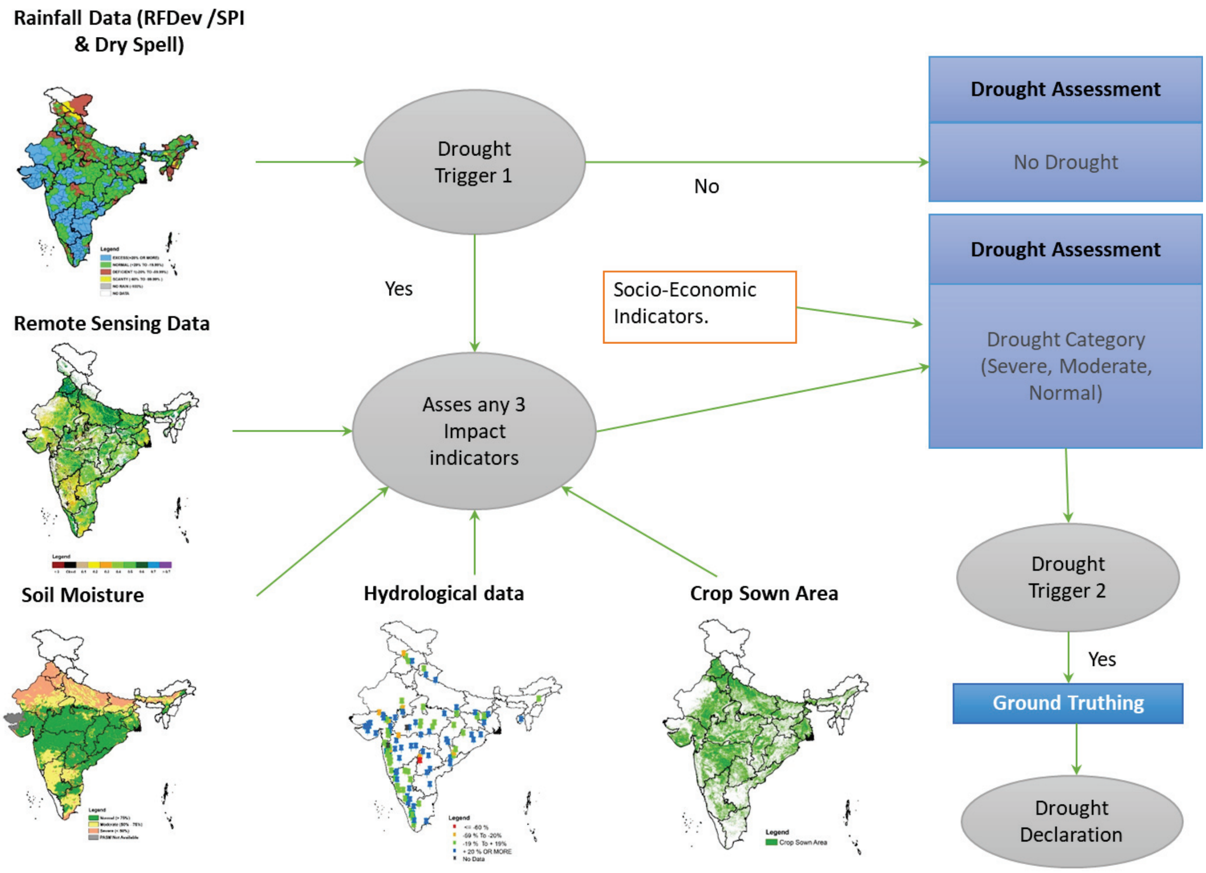

Figure 4. Flow diagram of procedures of Drought Assessment as per new drought manual (Saxena et al., 2019).

5.2.1 Drought assessment

Since a large part of the agriculture in the country is dependent upon rainfall and there is a high variability of rainfall (amount and distribution), drought is a recurring phenomenon in India. Drought is a complex phenomenon, with a very gradual onset, with multiplicative impacts and large area coverage. Because of its complex and composite nature, no single index/indicator is enough to completely characterize the drought. National Remote Sensing Centre, ISRO a developed satellite remote sensing-based drought assessment programme, called the National Agricultural Drought Assessment and Monitoring System (NADAMS) (Sesha Sai et al., 2016). Under NADAMS remote sensing data from multiple satellites (NOAA, MODIS and Resourcesat 2) were used along with rainfall, soil moisture, irrigation crop sowing data, to periodically assess the drought situation, at district/sub-district level, for 14 major agricultural and drought-prone states of the country.

Since 2012, NADAMS project was operationalized at MNCFC, after technology transfer from NRSC (Ray et al., 2015). In December 2016 the Ministry of Agriculture and Farmers' Welfare brought out a new Drought Manual (Singh et al., 2016) under which drought assessment procedure was made more objective and scientific. Mandatory indicators, such as Rainfall Deviation (or Standardized Precipitation Index) and Dry Spell and Impact Indicators, like crop sown area, satellite vegetation index, soil moisture and hydrological parameters (streamflow, reservoir storage or groundwater) are evaluated to assess the drought situation as Normal/Mild, Moderate or Severe, which is validated using ground truth (Figure 4). Since Kharif 2016, MNCFC provides district-level drought assessment of 17 states, following the new drought manual (Saxena et al., 2019).

In 2018, the protocol for Rabi season drought assessment was developed. Under this, the country is divided into four cropping situations, such as rainfed, surface irrigated, groundwater irrigated and northeast monsoon area. For each cropping situation, separate mandatory and impact indicators are identified. In Rabi, 2020-21, district-level drought assessment was carried out by MNCFC using data such as rainfall, soil moisture vegetation indices, satellite-derived sown area and groundwater levels (Saxena et al., 2020).

Satellite remote sensing is also used to assess the impact of other abiotic/biotic disasters, such as hailstorms (Singh et al, 2017; Prabhakar et al., 2019), floods (Rao et al., 1998), cyclones (Chakraborty et al., 2014), crop disease (Dutta et al., 2006, 2008, Bhattacharya et al., 2007; Das et al., 2015 and Ray et al., 2011) and pest (Dutta et al., 2008 and Nageswara Rao & Lakshmikantha, 2020) infestation, etc. However, most of these assessments are more of qualitative (mild/moderate/severe) in nature. Additionally, there is a requirement of early warning of these disasters, for which, there is a need to identify the precursors of these disasters and develop procedures for assessing these pre-cursors.

5.2.2 Crop insurance

Crop insurance is essential to protect farmers from different agricultural uncertainties and risks. Government of India started providing widespread crop insurance in 1985, with the Comprehensive Crop Insurance Scheme, which was later on replaced by the National Agriculture Insurance Scheme (Mishra, 2014). In 2016, the government launched a highly improved and farmer-oriented crop insurance programme, called Pradhan Mantri Fasal Bima Yojana (PMFBY) (DAC&FW, 2016). Crop insurance, in India, is a yield- based insurance, where crop yield data of current year and previous years are compared for computing the claims. Crop yield is estimated by conducting crop cutting experiments (CCEs). Carrying out a large number of CCEs, as required by the crop insurance programme, is extremely labour intensive, highly time-consuming and subject to human bias. Hence, this results not only delay in claim settlement but also may cause errors in yield estimates (Gulati et al. 2018). Government is exploring various modern technologies, such as smartphones, satellites and UAVs for better implementation of the crop insurance programme. In this context, the PMFBY proposes to use remote sensing from satellite and UAV data, for area estimation, yield estimation, loss assessment, risk zoning, etc., to ensure early settlement of claims to eligible farmers against their crop yield loss (Ray, 2018). Among these, the applicable remote sensing-based approaches have already been made operational and protocols have been developed and included in the revised guidelines (e.g., area discrepancy, yield dispute resolution, risk zoning, etc.). Some of the major operational use of remote sensing in PMFBY, carried out by MNCFC, included: i) yield dispute (between state governments and insurance companies) resolution using RS and weather-based models for 5133 Insurance units during 2016-2020; ii) block level crop area estimation using satellite data for 8 crops in 5480 blocks, during 2018-19, which was used to check the discrepancy between actual sown area and insured area, and iii) remote sensing-based smart sampling of CCEs for major crops (rice, wheat, rabi-sorghum, and mustard) in a large number of districts during 2019-20. To overcome the issues related to conducting a large number of CCEs, the government proposes to migrate to technology-based yield estimation. Towards this, Ministry of Agriculture is engaging large number of technical agencies (government/private; national/international) for conducting large-scale pilot studies for use of advanced technology (satellite, UAV, IoT, AI, crop models, etc.) for gram panchayat level yield estimation.

5.3 Remote sensing for agricultural development

Satellite remote sensing data has been used for various applications towards enhancing the sustainability of agricultural production system. Some of these applications, such as cropping system analysis, precision agriculture and crop intensification in rice-fallow areas are described below.

5.3.1 Cropping system analysis

Cropping System Analysis is essential to study the sustainability of an agricultural system by taking into account all the components involved in crop

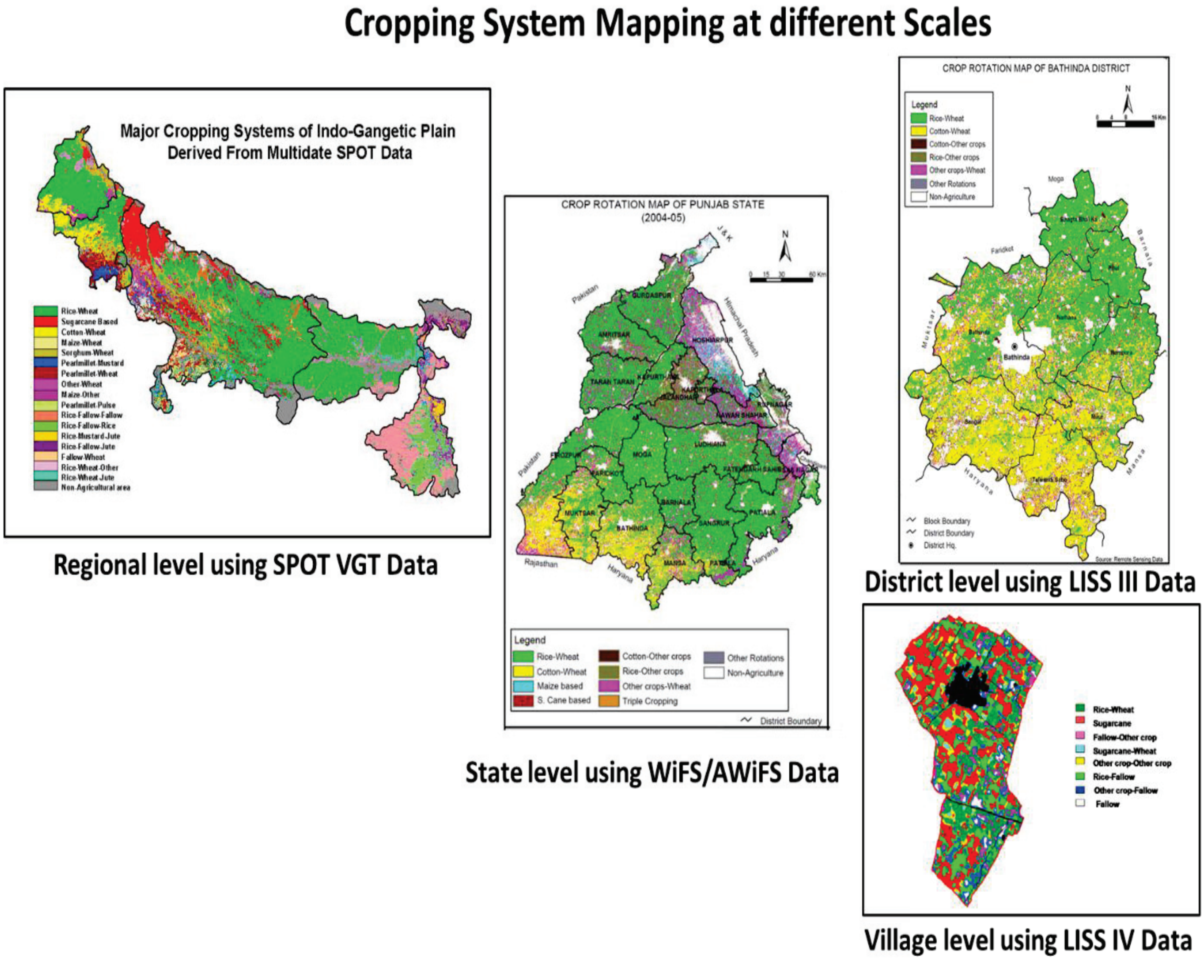

Figure 5: Use of satellite data of different resolutions for cropping system mapping at different levels.

production. Satellite remote sensing data is used to map the various components of cropping systems, such as cropping pattern, crop rotation and sowing and harvesting pattern maps and cropping system performance indices. Availability of long-term satellite data can help in assessing long-term changes in the cropping system, through which it is possible to spatially delineate the areas, which have lost the crop diversity. Panigrahy et al. (2011) assessed the cropping system in five states of Indo-Gangetic Plains (IGP) of India, i.e., Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. Multi-date remote sensing data of IRS-AWiFS and Radarsat ScanSAR was used for state and district level cropping system mapping. To characterize the cropping system, analysis of moderate spatial resolution multi-date remote sensing data (SPOT VGT NDVI) was carried out along with the ground survey. Remote sensing data were used to compute three cropping system performance indices (Multiple Cropping Index, Area Diversity Index and Cultivated Land Utilization Index), which could be used for prioritizing areas for crop diversification and crop intensification (Panigrahy et al., 2005). Satellite data of various spatial resolutions can be used for cropping system mapping at different levels. While low-resolution SPOT VGT (1 km resolution) data is used for cropping system/crop rotation mapping at the regional level, WiFS (188 m)/AWIFS (56m) data is used for state-level, LISS III (23.5m) data for district level and LISS IV (5.8m) data for village level mapping (Figure 5).

5.3.2 Precision Agriculture

Precision Agriculture (PA) or site-specific agriculture, aims to cater to the spatial and temporal variability existing within the field for carrying out site-specific crop management. By adjusting the management (water, nutrient and pest & diseases) practices to the actual requirements, PA archives dual objectives of increasing input use efficiency and reducing environmental impact (Sahoo et al., 2007). The report on Doubling Farmers' Income has recommended PA as one of the technologies for increasing the agricultural income. Advanced technologies, such as geospatial technologies (GIS, GPS and Remote Sensing), Internet of Things (IoT), Big data analysis, and artificial intelligence (AI), can be utilized for PA to optimize agricultural inputs to increase agricultural production and reduce input losses (Sishodia et al. 2020). Availability of satellite data with high resolutions (spatial, spectral, and temporal) has helped to enhance the role of remote sensing in PA. Remote sensing is useful for PA in three ways, i.e., within-field crop and soil variability mapping, anomaly (disease/pest, weed growth, water stress, nutrient deficiency) detection and derivation of biophysical/biochemical parameters (e.g., LAI, chlorophyll, nutrient content, biomass, etc.) which can be integrated into crop models for site-specific crop yield estimations. All these help in creating site-specific management zones. Remote sensing for PA can be done using high-resolution satellite data, UAVs or ground-based instruments, such as spectroradiometer, green seekers, etc. Ray et al. (2007) carried out many precision farming studies, taking sites both in intensive agriculture (Jalandhar, Punjab and Modipuram, UP) and subsistence agriculture (Dindigul, Tamil Nadu) and high resolution and hyperspectral data for variability mapping, parameter retrieval and management zone creation. Similar studies were conducted under CHAMAN project in grape farms of Nashik.

5.3.3 Site suitability for crop intensification

In major parts of Eastern India, rice is the principal Kharif season crop, which is grown primarily as a rainfed crop. Post Kharif rice large tract of this land remains fallow during Rabi season, mostly due to unavailability of irrigation. To increase the cropping intensity and also to reduce the import of pulses and oilseeds, the government is targeting the rice-fallow areas for growing short-duration pulses/oilseeds. In early 2000, a joint study was carried by ICRISAT and NRSC to identify rice-fallow areas of the country, which was assessed to occupy, nearly, 12 million ha, i.e. around 30% of the rice-grown area in the country (Subbarao et al., 2001). In a recent study, under National Food Security Mission, MNCFC and NRSC jointly assessed rice fallow areas, for 6 East Indian states (Assam, Bihar, Chhattisgarh, Odisha, Jharkhand and West Bengal) and found out their suitability for growing short-duration pulses (Ray et al. 2019). This study used the microwave and optical remote sensing data for rice, rabi season crop and fallow area mapping and other agro-physical parameters (soil moisture, soil texture, temperature, drainage network and waterbody map) for crop intensification suitability assessment. The assessment was carried out at block level and was delivered to district agriculture officials of concerned state governments for their implementation. The study showed that there is 8.34 million hectare post Kharif rice fallow area in these six states, out of which 3.261 million ha is suitable for growing short duration rabi season crops (pulses and oilseeds).

In another similar study, the Jhum lands (shifting cultivation areas) of 8 districts of 8 northeastern states were identified using satellite data and assessed for the suitability of growing different horticultural crops. The maps were generated at village level and shared with the horticulture departments for their use (CHAMAN, 2018).

In the above sections, we have discussed a few applications areas of satellite remote sensing in agriculture. However, there are a large number of various other successful remote sensing application programmes. A summary of this has been given in Table 5.

6. Limitations and Gap Areas

The satellite remote sensing technology has made significant advancements in data availability, processing, analysis and utilization. This has given rise to many newer applications in agriculture. Many applications have become completely operational with user departments adopting the technology, which include crop forecasting and drought assessment. Government manual and protocols (e.g. PMFBY guidelines, Drought manual), have extensively dealt with remote sensing data use. In a landmark judgment of the Supreme Court of India, the satellite-based vegetation index was widely referred (Lokur & Ramana, 2016).

However, there are still many issues, which limits the use of remote sensing data for agriculture. Some of these are discussed below.

(i) During major parts of the Kharif season, which is a major cropping season of the country, optical remote sensing data is not available due to persistent cloud cover.

(ii) Assessment of minor crops, mixed crops and spectrally similar crops have been difficult.

(iii) The use of microwave SAR data, which is an alternate source of data during Kharif season, has been mostly restricted to the assessment of rice crop, especially transplanted and rice grown under wetland conditions .

(iv) For many crops, especially for non-cereals, the correlation between spectral vegetation indices and crop parameters (especially, crop yield) is very low.

(v) RS based indicators for quantifying the effect of pest and diseases on yield are not available during the early stages.

(vi) A large number of satellite-derived parameters, such as soil moisture, rainfall, evapotranspiration, have low spatial resolution making it difficult for use at field level.

The other related parameters, which need to be used along with satellite data, such as soil, weather, crop management, etc. are not available at matching resolution as satellite data.

7. Way Forward

Satellite remote sensing has made tremendous progress. Some of the advancements which have strengthened the use of remote sensing data in agriculture, include: i) availability of free data from moderately high-resolution satellites like Sentinel and Landsat, ii) launching of high-resolution satellite constellation like PlanetLab, iii) possibility of getting very high- resolution remote sensing data from Unmanned aerial vehicles, iv) open data analysis platforms such as Google Earth Engine, v) free and open RS&GIS processing tools, like QGIS, SNAP, etc. These developments have been complemented by other advancements, such as Internet of Things (IoT), Cloud Computing, Big Data Analytics, Machine Learning (ML), Artificial Intelligence (AI), etc. coupled with satellite communication and navigation. All these have made a paradigm shift in the application of RS data. Large number start-ups have come up in the country to provide RS based services. Indian Space Research Organization has also planned many satellites for agricultural applications, in optical and microwave domain, with a unique plan to provide medium resolution (<50m) data from the geostationary platform.

Hyperspectral remote sensors and the constellation of satellites carrying optical, thermal and SAR sensors are going to provide data at different resolutions and domains. However, there is a need to generate high resolution, well-calibrated and usable products for biophysical and agro-meteorological parameters. These satellite products would be complemented with data from other sources such as weather and soil sensors, crowdsourcing of data through mobile Apps and UAV based images. These Big Data, along with physical and AI driven models are expected to forecast better agrometeorological conditions, provide improved estimates of crop productivity and generate information at farm level. Hence, the time is not far off, when remote sensing technology is going to play a decisive role in Indian agriculture, especially for doubling farmers' income.

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Table 5. Examples of some remote sensing applications in agriculture in India.

Application	Reference	Brief Description
Soil Resources Mapping	Sehgal, 1995 Dwivedi, 2001	These papers discuss how remote sensing has augmented the efficiency of soil survey programmes in the country.
Sodic Soil Reclamation	Singh et al., 2004	Environmental monitoring and impact of Uttar Pradesh Sodic Land Reclamation Programme (UPSLRP) (World Bank funded)
Soil Moisture	Srivastava et al., 2009; Singh et al., 2005	Satellite-based large area soil moisture estimation using microwave SAR or radiometer data
Agroclimatic Crop Suitability	Kumar et al., 2013	Agroclimatic indices integrated through GIS for crop suitability
Watershed Development	Sharma & Thakur, 2007; Chowdary et al., 2013; Ranganath & Diwakar (2012)	RS data is used for watershed delineation, prioritization, development and monitoring; Monitoring & Evaluation of Sujala Watershed Programme of Karnataka
Irrigation Management	Brahmbhatt et al., 2000; Ray et al., 2002; Raju et al., 2013	RS is used for LU/LC mapping, assessing salt-affected and waterlogged area and performance evaluation of irrigated command areas.
Fishery Forecasting	Solanki et al., 2005	Satellite-based potential fishing zones (PFZs) forecasts were generated using integration of Ocean Colour Monitor (OCM) derived chlorophyll concentration and Advanced Very High Resolution Radiometer (AVHRR) derived sea surface temperatures (SST).
Climate Change Studies	Navalgund & Singh, 2011	Space-based records over more than three decades have provided important information on essential climatic variables of the atmosphere, ocean and land.
Methane Emission from rice fields	Manjunath et al., 2006	RS data was used for rice crop mapping and rice strata generating for developing a methane emission inventory of the country using field-based experiments.
Crop Residue Burning	Singh et al., 2009; Bhadauriya, et al., 2020	Burning event and burnt area mapping and monitoring; and the relationship of residue burning and air pollution.
Primary productivity	Patel et al., 2010; Wani et al., 2010	RS based NPP model and geospatial analysis of agricultural carbon pools (crop biomass and soil organic matter) of Madhya Pradesh, India for the year 2005-06 are reported.
Biophysical parameter retrieval	Sehgal et al., 2016; Rastogi et al., 2000; Singh et al., 2005; Pandya et al., 2006	Retrieval of crop biophysical variables such as leaf chlorophyll, leaf area index, from satellite data using image-based, radiative transfer, statistical and VI-empirical models.
Crop Phenology	Rajak et al., 2002; Das et al., 2008; Gaur et al., 2019	Multi-date vegetation index spectral profile-based retrieval of crop phenology (spectral emergence, peak VI/Heading/flowering), maturity; and derivation of rice phenology using scatterometer data.
Satellite Agrometeorology	Joshi et al. 2011	INSAT data along with in-situ and other satellite data generating various products, such as NDVI, Land surface albedo, rainfall, temperature, insolation, evapotranspiration have played a key role for agrometeorological applications, especially farmers' advisory.
Hyperspectral Remote Sensing Applications	Sahoo et al., 2015 Das et al., 2015	Hyperspectral remote sensing provides significant information useful for discrimination of soil and crop types, crop stress detection, and quantitative estimation of different physical and chemical parameters through empirical and physical modelling.

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