Effective Crop Monitoring and Yield Estimation Using Emerging Geospatial Techniques

I. Introduction

India is the land of farmers where the maximum proportion of rural population depends on agriculture. The production of food is important to everyone. India as a country has established as a front runner in the area of space based technologies and its usage for various applications. As per the World Bank data, India has some 195 m ha under cultivation of which some 63 percent are rainfed (roughly 125m ha) while 37 percent are irrigated (70m ha). In addition, forests cover some 65m ha of India's land. India is a global agricultural powerhouse. It is the world's largest producer of pulses, and spices, as well as the largest area under wheat, rice and cotton. It is the second largest producer of rice, wheat, cotton and sugarcane. India's food security depends on producing cereal crops, as well as increasing its production of fruits, vegetables and milk to meet the demands of a growing population with rising incomes. Nearly three-quarters of India's families depend on rural incomes.

Agriculture plays a dominant role in Indian economy. A farmer needs to be informed to be efficient, and that includes having the knowledge and information products to forge a viable strategy for farming operations. Due to high growth rates of the industrial and services sectors, over a period of time agriculture's share in India's economy has declined to less than 15%. Many Indian states are vulnerable to heavy rain, unseasonal rain, hailstorm, flood, drought which causes damage to crop in Rabi, Kharif and summer season during the year. The unpredictable loss of crop in the farmlands in the rural India has witnessed many farmers' suicide which is bringing political unrest in the country. The farm lands are not adequately insured to compensate for the losses. Various policies and schemes were launched in the recent past to motivate the farmers to their core profession. Uses of modern day technologies are being encouraged. It has been mentioned in the operational guideline of Pradhan Mantri Fasal Bima Yojana (PMFBY), that the use of technology will be encouraged to a great extent.

Besides providing a synoptic view, remote sensing technologies and data can provide structure information about the health of the vegetation. Smart phones, Remote sensing drone and GPS technologies are the tools and technologies that can be effectively used for Crop Area Estimation and Loss Assessment Using Remote Sensing and Geospatial Technology.

II. Problem Statement

There is multiplicity of problems for low agricultural produce. Only few important parameters are discussed in this paper. The Indian cropping season is classified into Kharif and Rabi seasons based on the monsoon. The kharif cropping season is from July to October during the south-west monsoon and the Rabi cropping season is from October to March (winter). The crops grown between March and June are summer crops. Indian agriculture is mainly dependent on rain. Presently only about 40% of the agricultural land has permanent irrigation facility. Due to improper irrigation facility, farmer can produce one crop only in a year. These are the reasons for low productivity of agriculture.

Another major problem responsible for low agricultural productivity is soil contamination. The farm lands are contaminated by the increasing level of river and canal pollution which is caused by high industrial effluents and toxic metals day by day. Also, the farm lands in India are small. The average size of the fields in India is between 2 acres to 5 acres. The agricultural field is not only less but also dispersed. In some areas the size of the field is so small that they can't even be ploughed easily. Due to the small size of the field, mechanized equipments cannot be used to have faster preparation of the land which leads the machines etc. cannot be used on it and the farmers have to expand more labor, time and energy.

Advance prediction of the natural hazards, identification of the areas having low yield based on the cropping pattern and high risk areas of soil contaminations needs to be identified and suitable prescriptions to be provided at regular intervals.

III. Problem Analysis

First and foremost, accurate mapping of the farm lands and their cropping patterns over a period of time needs to be assessed correctly. For large areas satellite datasets with high spatial resolutions needs to be used. For smaller areas services of drones can be utilized. If the activity needs to be done at a state level then multiple passes of the satellite data is required over the same area of interest in a specific cropping season. Cloud covers during rainy season poses problems in getting clear pictures of the ground from the satellites. While Indian remote sensing satellites are good but the number of passes over a large state wide study for the IRS satellite datasets is limited to very few passes.

The study requires temporal satellite datasets in a season and hence multiple satellite data from different satellites with high resolutions needs to be used for the study. Need based Radar data and UAV data is also required to be supplemented wherein the cloud free coverage is not present. For routine analysis of the datasets it is not practically possible to process the daily data from multiple satellites so the need for Spatial Modeler is required wherein large satellite datasets can be analyzed very fast in a cloud based environment having different analytic which can analyse data from disparate sources and simulate these satellite data with the other thematic datasets like soil data, real time weather datasets like rainfall, temperature, cyclone etc. collected from cloud sources. As the farm lands are not big, instead of agriculture parcel wise study as a least count, ideally village unit to be taken as a minimum unit for the study purposes.

IV. Approach

The technical approach for effective crop monitoring and yield estimation using emerging Geospatial Techniques is adopted to support State Government to monitor agricultural lands with space based technologies augmented with ground surveys to check the growth of the crops of different types at village level round the year for various seasons namely Kharif, Rabi and summer. The yield data of the crops per village needs to be computed and for any unforeseen reason if destruction/ devastation of the crop happens then the loss of the crop needs to be estimated and the reporting has to be done in a web based environment to all the relevant stakeholders. Modern technologies are to be used for the study. This approach will increase income of farmers by increasing agricultural production, increasing agricultural productivity, giving knowledge of scientific methods to farmers and by implementing various schemes.

V. Framework of Data Collection

Acquisition of data from multiple sources needs to be initiated. Following are the key activities:

1. Collation of datasets and available information on agricultural crops of the study area
2. Spatial datasets available, road map, agro-ecological zones maps and village maps etc.
3. Satellite Data collection
    - First set of satellite imagery tentatively during the beginning of each season
    - Second set of satellite imagery during the mid or later part of the season
    - Third set of Satellite imagery at appropriate time when the harvesting begins for some of the crops during a season

    - Multiple sets of low resolution satellite images wherever available for monitoring the crops having variation in the standard sowing dates of Winter crops

4. Field Visits
    - GPS based 1st reconnaissance during the start of each cropping season to understand the general distribution of different crop types in different parts of the state using Mobile Mapping systems with panoramic cameras and LiDAR sensors to capture the field situation and also for Mobile App based signature collection for the different crops grown during the season.

- 2nd Field Visit for assessment of general crop health for the places showing comparatively lower vegetation indices
- 3rd field visit for the validation and subsequent improvement of crop classification
- 4th field visit for carrying out correlation of the data of 'Crop Cutting Experiments'

VI. Components of the Solution

There are various components of the solution which are described below

Systems Requirement Study

Conducting a Geospatial needs assessment for crop monitoring and loss assessment fosters cooperation and enhanced communication among departments by working together on a common technology and new set of tools. The work plan will constitute study of the existing literatures of the departments, interviewing the officials in different roles and domains, conducting workshop for the stakeholders, followed by the development of the design documents which will include the plans and procedures, data models and systems design. The design documents will have detailed description of data acquisition, processing, preparations and implementation plan. The deliverables are Customer Requirements Specification (CRS), System Requirements Specification (SRS), System Design Document (SDD)

Satellite Data Procurement

High resolution satellite datasets for the entire area of study for all the three seasons (Kharif, Rabi, summer) at appropriate interval is required to be procured. Deliverables constitutes all raw satellite images of high and other lower resolution data on a need basis.

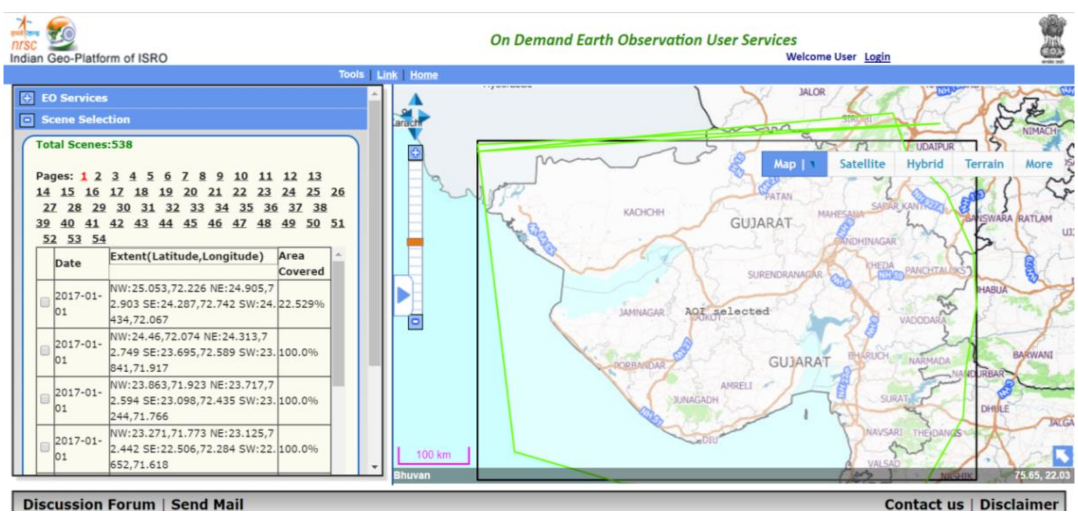


Figure - Screenshot of ISRO Image Procurement Portal

Identification of Crop at District/Taluka/Village Level

No single source image will help to ascertain the actual ground condition using remote sensing technologies as these greatly vary on spatial, spectral, temporal and radiometric resolution. A judicious approach of mixing high and low resolution datasets with intense ground sampling to ascertain the crop type and yield to be adopted. It is required to geo-rectify the procured satellite image using ground control points (GCP) and reference maps to eliminate geometric and radiometric errors. These GCP will be taken across the area of study homogenously.

Crop identification and discrimination is based on the premise that each crop has a distinct and unique spectral response. Spectral response of a crop canopy is influenced by green biomass present, leaf area index (LAI), pigment concentration, growth stage, difference in cultural practices, stress conditions and canopy architecture.

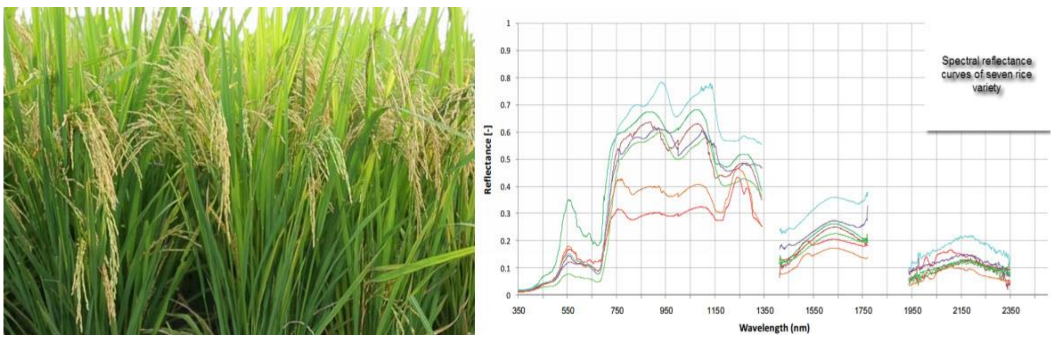


Figure - Spectral Signature/Curve of Seven Different Paddy crop

Deliverables constitute Geo-rectified satellite imagery and classified Crop map of the Area of study (identifying the crops as per the season)

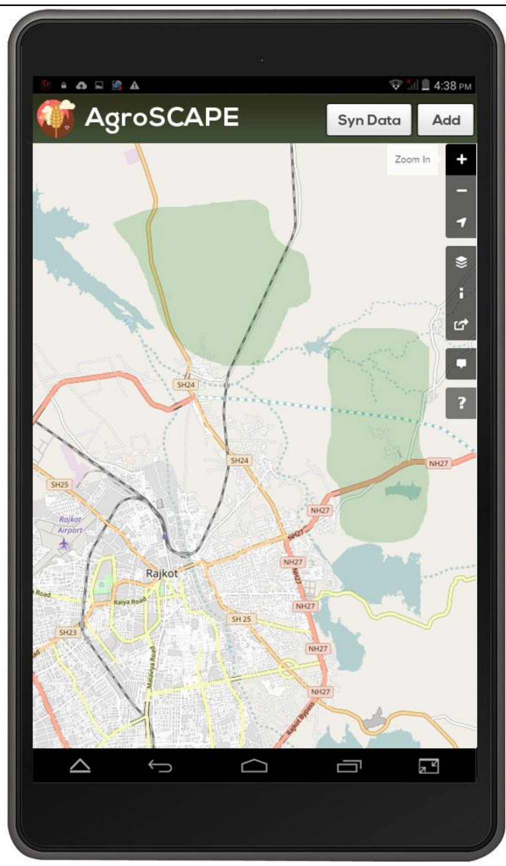
Field Survey

Field survey is one of the essential components of crop classification using remote sensing data. The field surveys need to be conducted using State of the Art survey techniques augmented with field vehicles and mobile data capture devices. Field surveys need to be conducted in different parts of the study area to gather primary as well as secondary information about the crop from the field and various related agencies. The spectral signature of various crop are very significant, so signature of crop will be collected from the field and will be used during classification and visual interpretation of remote sensing image data.

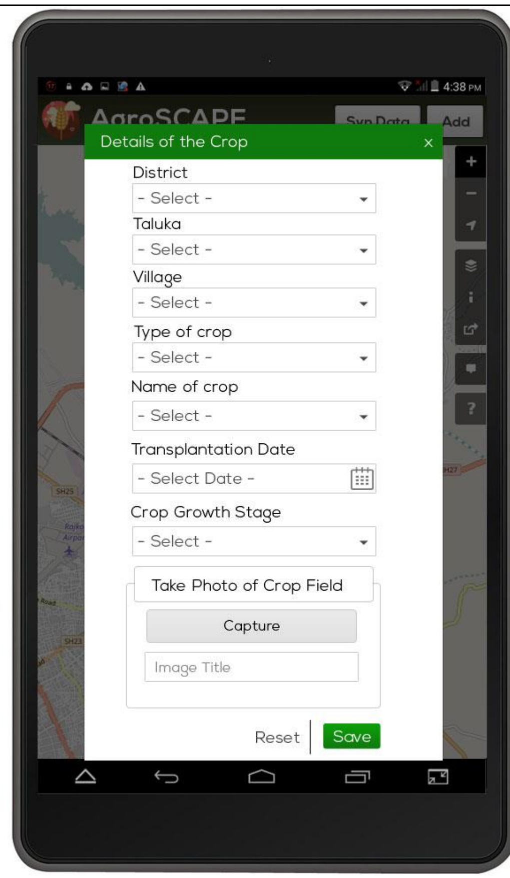
The fieldwork to be carried out to have a general understanding of crop distribution pattern in different part of the study area, know and investigate the sowing date and probable harvesting dates of different crops in the study area, assess the health of the crop during the growing season, validate the crop classification in order to further improve it and carryout Crop Cutting Exercise (CCE) for yield estimation.

Field survey in Mobile mapping system equipped with LiDAR and optical sensor for capturing seamless point clouds with 360 degree panoramic images and integrated with Dual-frequency based GNSS receiver capable of providing accurate ground positioning in kinematic mode using user selectable data is required. All sensors will be integrated and tightly coupled on to a single time clock. This will ensure to receive seamless record of the traverse with time stamped data integrated with the route of the survey. This data needs to be disseminated in the web portal (intranet application) for quality checking and monitoring purpose.

In the field the AgroSCAPE hand held GPS based Mobile application can be used for Agri-Solution/Digital Crop mapping. Mobile user can use offline map to report work status in an offline mode i.e. without having connections to internet. Later on they can sync their data when connected. Deliverables include hand held Mobile/ tablet application with features of attribute capture from field, corresponding photographs and GPS locations and fast transmission of data to selected stakeholders and Web based application for disseminating field survey routes displaying 360 degree pano-images of the roads showing agricultural fields with crops along with GPS points and road network.



Mobile Tablet for updating crop information



Capturing crop detail

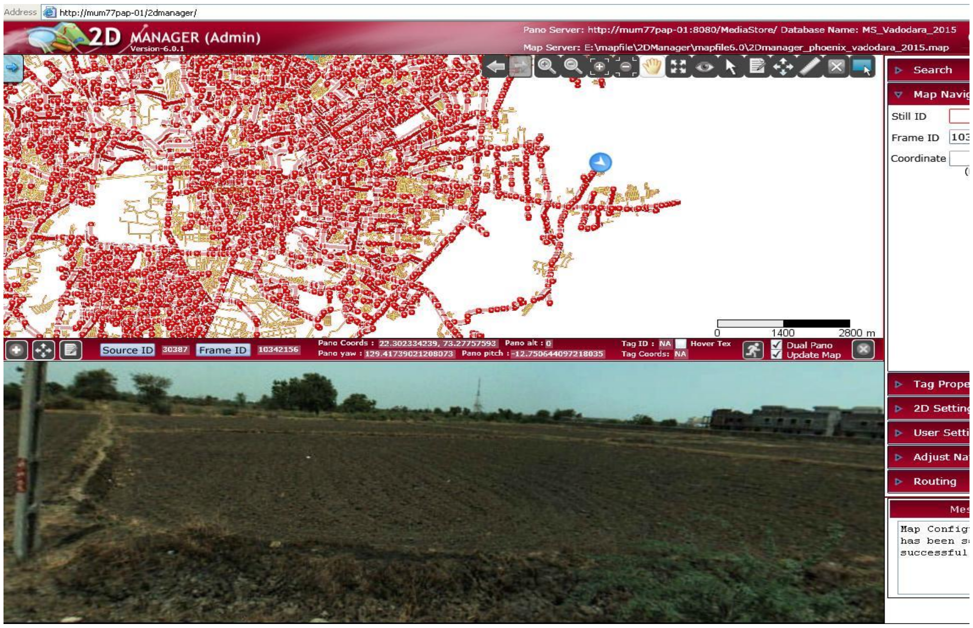


Figure - Sample screenshot of application showing agriculture filed with relevant map data

After generating first level of crop map, Genesys will perform ground- truth/verification using hand held GPS with mobile application for validation of crop map and enhance the accuracy of crop map. This ground-truth data will be updated in the crop map. Deliverables include Field Traverse plan document, capture of 360 degree panoramic datasets of the traverse routes for the sample collection, ground photographs/ signature collection of the crops with GPS points and field report with coordinates, photographs, tracks & records.

Crop Acreage Estimation

The crop acreage estimation needs to be done in each village separately. The village wise report of acreage, crop conditions, yield and production estimates needs to be prepared. The methodology for crop acreage estimation includes Spectral Classification, Hybrid Classification, Time Series Based Classification and NDVI Slicing Techniques. In general, one or more methods are used in combination to map different crops.

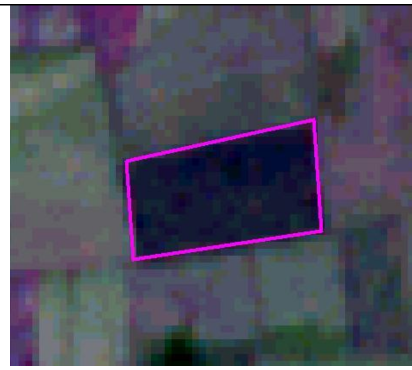
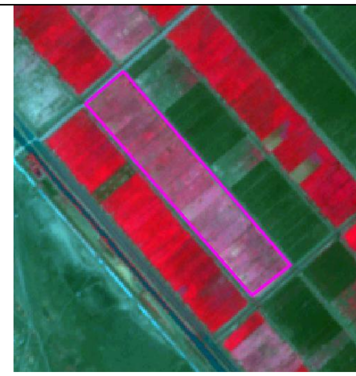
		
Sesame in 432 Band Combination (1st Set)	Millet in 432 Band Combination (1st Set)	Sorghum in 532 Band Combination (2nd Set)

Figure - Vegetation Classification using Hyperspectral Imagery

Crop Yield and Production Estimation

Remote sensing has the potential of not only identifying the crop classes but also to estimate the acreage and predict the produce based on the yield information collected either through CCE (Crop cutting experiments) data collected from the field or modeled through various statistical techniques. As yield of a crop varies from region to region depending on several factors such as, crop variety, geographical location, temperature, timely availability of irrigated water, local agricultural practices, crop transplanting, harvesting dates etc., therefore, crop variety wise average yield values will be collected from field or other sources. Different methods like Statistical data on crop yield, crop sowing time, temperature in the study area, Crop Cutting Experiments etc. are used as a standard practice.

General NDVI value of Crop Type

Chlorophyll content of plants reflects general health of crops. The NDVI value, which is a 'Normalized Differential Vegetation Index', represents crop vigor as a result of various factors including seed variety, soil type and pH value, temperature, timely and sufficient water availability, and farming practices, etc. The formula given below shows the method for the calculation of estimated produce.

Estimated Produce (Kg) = ((Acreage of 'Above Normal Crop' x Yield of 'Above Normal Crop') + (Acreage of 'Normal Crop' x Yield of 'Normal Crop') + (Acreage of 'Below Normal Crop' x Yield of 'Below Normal Crop')).

Deliverables include preliminary standing crop acreage report and final acreage report after crop type classification and field verification. Final acreage reports are provided for District/Taluk/Village level.

Use of UAV Data for Crop Analysis

Unmanned Aerial Vehicle (UAV) provides flexibility to capture high resolution image of a particular area of interest under the cloud and during the disaster like hailstorm, flood, etc. Exclusive and enormous use of Unmanned Aerial Vehicle could be used for crop damage or loss assessment. Within the defined boundaries and in order to cover the maximum area in shortest period of time with the maximum transparency, practice of UAV is essential. Through UAVs it is not only possible to capture very high resolution images, it also provides flexibility to capture only the specific areas where we are interested and also can fly under clouds. Deliverables include processed UAV to prepare crop map and loss estimates, on a need basis.

Crop Forecasting Schedule

There are several methods of yield forecasting. The objective of the yield forecast is to give a precise, scientific sound and independent forecasts of crops' yield as early as possible during the crops' growing season by considering the effect of the weather and climate. Forecasts are made before the entire crop has been harvested whereas estimates are made after the crop has been harvested. Indications are the result of applying a statistical estimator to the survey data and the resulting point estimates are interpreted by commodity statisticians to make forecasts and estimates. Deliverables include forecasts of Crop acreage, yield and production in a web enabled system.

Crop Monitoring Model for Growth and Damage

The monitoring of growth and health of crops is one of major part of the project. The satellite data of multi-dates during crop growing season helps in better crop discrimination. The difference in crop growth pattern of various crops can help in better crop discrimination using multi-date satellite data. There are various methods for crop monitoring like change detection, NDVI, UAV images, NDVI recording by handheld sensor and digital photography. One of the most critical factors in making imagery useful to farmers is a quick turnaround time from data acquisition to distribution of crop information. Receiving an image that reflects crop conditions of two weeks earlier does not help real time management nor damage mitigation. Images are also required at specific times during the growing season, and on a frequent basis.

Remote sensing doesn't replace the field work performed by farmers to monitor their fields, but it does direct them to the areas in need of immediate attention. Currently the trend is to use automated cloud based system for crop growth and health monitoring. The functions used in data mining process include Spatiotemporal analysis of remote sensing data, analysis of archive and up-to-date meteorological data, object similarity analysis, outliers (artifacts) detection, classification of objects by a set of parameters, clustering and generation of models based on standard rules.

The following major outputs are provided by Processed Satellite imagery: Radiometric, atmospheric and geometric calibration; spectral bands combination, Maps of Plant Health, Maps of local topographic conditions based on SRTM like slopes, aspects, topographic wetness index and risk of soil erosion.

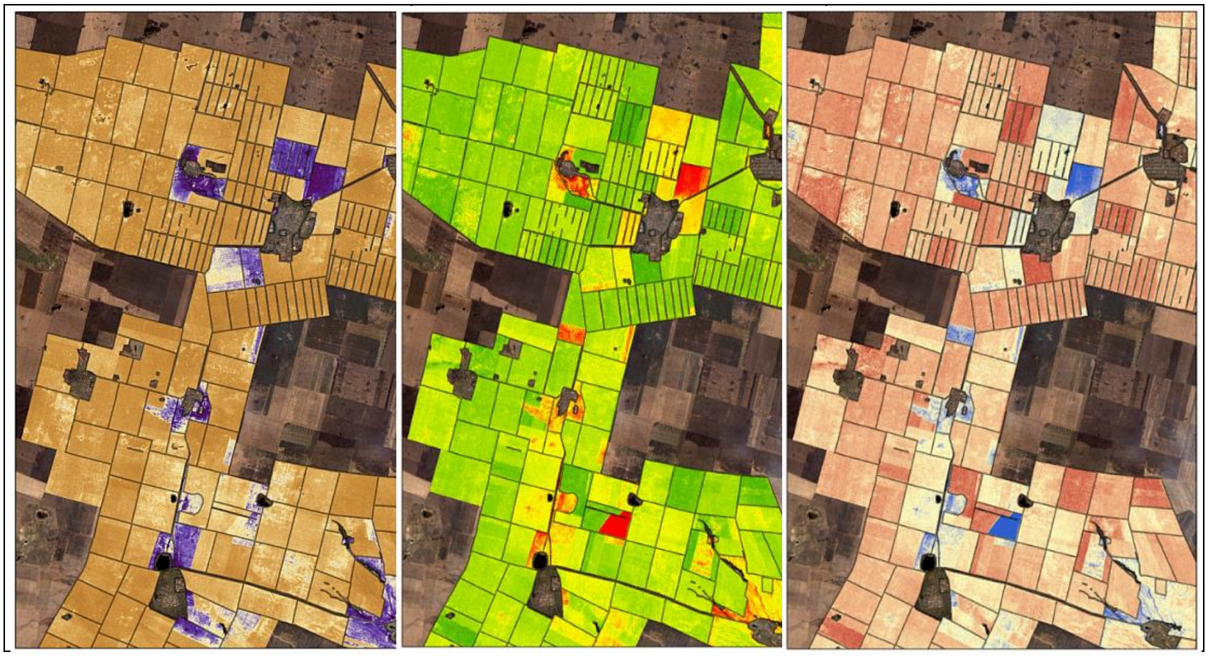


Figure - Comprehensive information about crops growth stages can be effectively monitored

Deliverables include NDVI values of crop during whole monitoring period for finding out growth & damage at different stages of growth.

Crop Loss Assessment at Village level

Change detection techniques are used to assess the crop loss at a village level by periodic monitoring of the satellite datasets using NDVI and temporal images for a specific seasons coupled with field visits. The interpreted damaged crops datasets are overlaid on the village boundary maps obtained from the department and loss estimates are e-computed through GIS analysis. Deliverables include loss assessment report if required due to spread of disease and / or disaster per village.

Geo-enabled Web based Crop Portal

The geo-enabled web based crop portal needs to be designed based on the specific requirement of the department and stakeholders use. The main objective of the web portal is to share crop information to all stakeholders. The application ideally needs to be hosted in a state data center having requisite infrastructure. The back end data processing of the satellite datasets happens using machine learning techniques and using big data analytics with very less human intervention, so chances of biasness is negligible. Algorithms are already developed by experts in the field of Agriculture and Image processing and Maps of cultivated areas, agricultural land structure, harvested fields can be automatically generated. It has the capability to process different types of images through API.

Variety of inputs like satellite images, meteorological data can be provided and variety of Vegetation Indices can be created which helps in assessing the crop health from different aspects (not only NDVI based). Even Crop Health Map can be created which shows the spatial distribution of crop performance. Maps of Crop Growing Condition can be visualized and the analytical interface helps in viewing different statistics, graphs and reports from Farm Level to any other Administrative Level which helps in decision making.

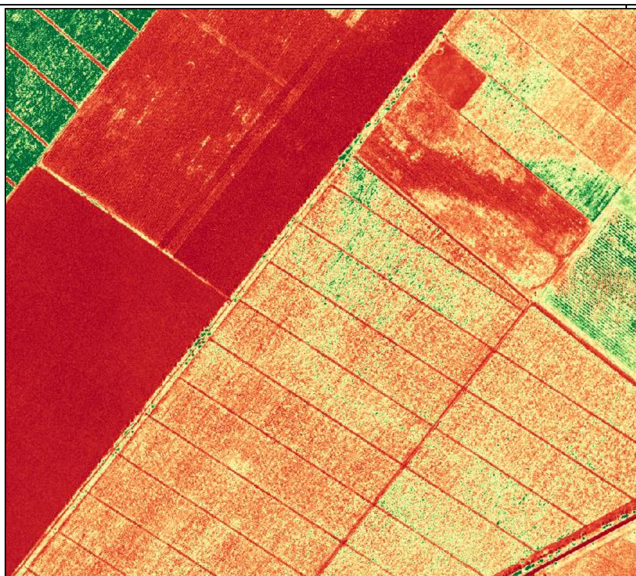


Figure - Automatic remote sensing thematic data and processing

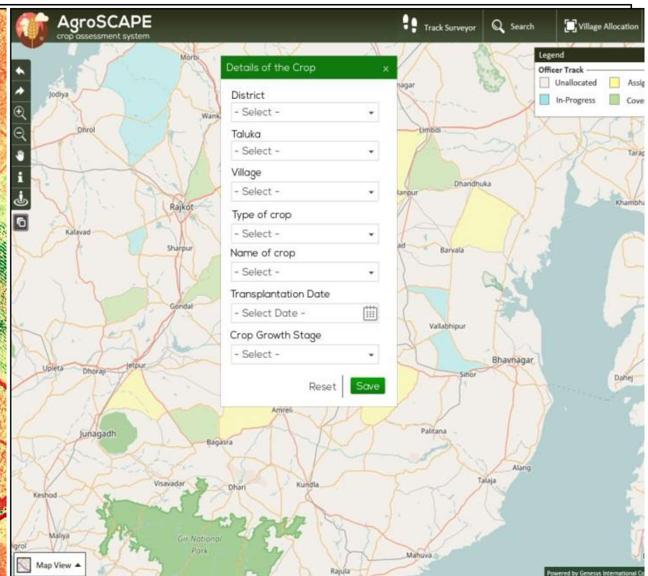


Figure - Screen capturing the crop information details

5. Benefits to the Stakeholders

- Space based technologies integrated with geographic information system tools helps the researchers, practitioners and decision makers to understand the health of his crop, extent of infestation or stress damage, or potential yield and soil conditions.
- The government department gets support from the satellite data interpretation to correlate the actual field data and statistics of the crop yields can be forecasted based on the interpretation of the satellite datasets at Village,Taluka/ District level for different types of crop.
- A digital crop map is a spatial map derived from various remote sensing image data of an agricultural land with the help of GIS, Image Processing technology and utilizing cadastral map & RoR data. The signature or spectral reflectance for each crop is different for different spectral bands. Their differences in spectral reflectance allows carrying out (curves) digital crop analysis, which includes Crop Estimation, Crop scheduling, Crop Types, Crop Statistical Analysis, Crop change analysis, Crop Damage analysis and reports/maps
- For ground truth collection of crop data, usage of LiDAR data captured from the vehicle mounted Laser scanner, provides geo-coordinates of the adjacent crop fields along with 360 degree panoramic datasets. This helps in establishing quick reconnaissance of the field data collection.

- The solution acts as an early warning system and provides alerts the hydro-meteorological hazards which can cause damage to the crops. The damage assessments can be made fairly accurate through the area calculations from UAV data or study and analysis of the high resolution satellite datasets. The crop insurance schemes can be directly co-related with the system.
- The unique cloud based state-of-the-art agriculture solution enables to get the satellite data products like Rapideye, Sentinel, MODIS, LandSat etc and simulate the data with the other datasets like soil data, real time weather datasets like rainfall, temperature, cyclone etc. collected from disparate sources.
- The solution enables agricultural monitoring and automated analysis to foster effective business decisions. Key benefits of using the Geoenabled web based AgroSCAPE platform are for Data storage, Data mining, Automated processing, Knowledge engineering, Modeling and forecasting.

6. Summary

In Indian scenario, Agriculture is risky business and is susceptible to volatility in production and commodity prices. Hence, it's important to encourage farmers to use innovative agriculture services and technology, which in turn will improve farm productivity and income, and help them deal with post-harvest challenges. All States have been directed by Ministry of Agriculture, Govt of India to use "Space based Technologies" to solve farmer's problem so that they get suitable compensation from the insurance companies for their crop losses.

Remote sensing offers an efficient and reliable means of collecting the information required, in order to map crop type and acreage. Bulk processing of the datasets from various satellite sensors is required for monitoring the growth of the crops at village level. This can be achieved very efficiently through ground based surveys to identify different crops in the agricultural fields at village level using mobile hand held devices with customized data inputs forms to capture details. The mobile mapping systems also help to capture the activities of the field force through GPS connectivity by tracking the vehicle movement. The mobile mapping system fitted with optical panoramic camera sensors also captures 360 degree views of the field sites. The satellite data from different satellites are processed using cloud based system with known ground coordinates of the crops which acts as a training set. This provides quick assessment of the crop health. The model also integrates various other parameters like soil, elevation, atmospheric conditions like rain, cyclone etc. and also acts as a real time early warning system.

The acreage estimation of the produce at village level can be done very easily and online statistical reports and charts can be generated through the geo-enabled Agro Portal which is very useful to the domain experts, and administrators for taking timely decision.