Use of Multi-Temporal Satellite Data for Crop Identification and Monitoring

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Abstract:- Use of remotely sensed data in crop identification, inventory and management, is a new research area. The identification of a particular crop is difficult and needs many more experimentation and algorithms before it can be operationalized. The demand for the correct identification of crop is increasing due to irrigation water cess calculation, monitoring crop health and vigor, production estimation etc. New algorithms and classification techniques are needed to meet this challenge.

Present paper deals with method for identification of wheat using spectral profile created using multi date satellite data and two stage classification technique. The use of geo-spatial technology like remote sensing, Geographic information system (GIS), global positioning systems (GPS), help in identification of the particular crop and pin-pointing such fields. The spectral profile using Normalised Difference Vegetation Index (NDVI) can be created for the identification of various crops and used for their discrimination and proper delineation. The results obtained suggest that this can be a viable solution to the problem of crop identifiation, inventory and management.

Keywords:- *Remote Sensing (RS), GIS, GPS, Maximum Likelihood Classifier (MXL), Normalized Difference Vegetation Index (NDVI), ISODATA Clustering, Spectral Profile, Temporal Profile.*

I. INTRODUCTION

Food security and land use planning are the topics of immense importance to the Planners and Administrators. Policy decision regarding the pricing of crops, compensation to farmers in case of crop failure due to natural disasters or truant rainfall, crop insurance etc., require the precise identification and monitoring of the crops. Reliable, accurate and timely information on types of crops grown, acreage, crop yield and crop growth conditions are vital components for the planners engaged in formulating and implementing appropriate policies. Traditional methods of production estimation are time consuming, costly and tedious. Remote sensing sensors acquire information in the domain of electro-magnetic spectrum about the object without physical contact. Remote Sensing (RS) technology and spectral indices based classification techniques have opened new avenues for crop discrimination, identification, classification and mapping. Multi-date, multi-spectral data in the form of several vegetation indices have been utilized for crop identification and area estimation worldwide. Crop growth profiles, derived using spectral indices, have been modeled by (Badhwar, 1980) and by (Christ and Malila, 1980) using multi-date Landsat – MSS data. Spectral yield models for corn and soybean based on growth profile for some selected time periods are studied by (Boatwright et. al., 1988).

The sensors on remote sensing platforms, measure the reflected, emitted, transmitted electro-magnetic radiations from the features on the earth surface, which is characteristic of the object. By virtue of large area coverage, synoptic view, repetitive revisit capability, remote sensing is an effective tool for the mapping and monitoring of surface earth features.

Remote sensing data provides dynamic and near real time information in spatial perspective, is potentially less expensive and faster than ground survey methods. Remote sensing data can be used as input into a geographic information system for analysis and synergy with other data. Thus remote sensing in conjunction with Geographical Positioning System (GPS) and Geographic Information System (GIS), together called a geo-spatial technology, serve as a viable alternative to the traditional methods of crop monitoring with limited field checks.

➢ *Classification Technique*

Satellite remote sensing in conjunction with ground survey plays an important role in delivering accurate and timely information regarding the location and area under a particular crop, crop stress and disease, productivity, crop water requirement vis-a-vis irrigation available and needed (Friedl et. al, 1999). Pioneering work in this has been done by (Odenweller and Johnson, 1984) in USA for mapping of crops in the corn belt using multi temporal data. In Indian context, the flagship project by Indian Space Research Organization (ISRO) for "Forecasting Agricultural output using Space, Agro-meteorological and Land based observations (FASAL) has implemented the use of agro-meteorological data and multi date (time series) satellite data for crop acreage and production forecasting.

Multi-date Landsat-8 OLI and IRS Resourcesat-2 LISS4 multispectral data for rabi season (November till March) of 2014-15 have been used. A two-stage classification by unsupervised Iterative Self Organizing Data Analysis Technique (ISODATA) and then labeling of classes based on temporal spectral profiles of wheat and other competing crops, vectorisation of classified image with manual editing and labeling of mixed class polygons and decision rule-based integration were followed to generate final classified image. This hybrid classification technique uses inherent clustering tendency of various land use / land cover classes in feature space in temporal domain. Multi-date Normalized Difference Vegetation Index (NDVI) time series data provides the necessary time series inputs to collaborate the classification techniques. Signatures of known crop classes are also used for labeling the clusters. LISS 4 data with a spatial resolution of 5.8 m and Landsat-8 with spatial resolution of 30 m is sufficient for forecasting at regional level. Intricacies involved in the spatial accuracy are also covered in this study to give acreage estimation.

Multi-date, multi-spectral data in the form of several vegetation indices have been utilized for crop identification and area estimation through- out the world. Crop growth profiles, derived using spectral indices, have been modeled by (Badhwar, 1980) and by (Christ and Malila, 1980) using multi-date Landsat – MSS data. Spectral yield models for corn and soybean based on growth profile for some selected time periods are studied by (Boatwright et. al., 1988).

In digital classification of remotely sensed satellite data, class identifiers are attached to the pixels based on their characteristics of spectral homogeneity. These characteristics are measurements of their spectral response in different wavelengths, often called spectral signatures. The most commonly used classification methodologies used in remote sensing are unsupervised procedures such as Iterative Self Organizing Data Analysis Technique (ISODATA) and supervised methods such as Maximum Likelihood (MXL) with a priori knowledge.

In ISODATA clustering algorithm, reflectance value of each pixel with predefined number of clusters are effectively utilized such that the cluster mean values shift in a way that the majority of the pixels belonging to a cluster gets agglomerated.

The user interaction at the beginning of the procedure indicates the number of the predefined clusters(classes) to be created and the number of iterations to be carried out. At the end of the iterations, user decides which class represents which surface objects and merges or rejects the classes with non-realistic representatives (Manakos et al., 2000).

The drawback of this method is that some ground features are spectrally similar but cannot be separated using ISODATA clustering. Researchers have used various classifiers for classifying the RS data for different applications (Tateishi et al., 1991; Friedl and Brodley, 1997; Hastings, 1997; Friedl et al., 1999). Multi-date IRS WiFS and AWiFS data have been used for various agricultural applications including cropping pattern change monitoring, crop yield modeling and crop classification (Rajak et al., 2002; Rajak et al., 2005; Oza et al., 2008).

Wheat (Triticum aestivum) is prime food crop in the world. In India, it is the second important food crop after rice and contributes to the total food grain production of the country to the extent of about 25%. Wheat has played a very vital role in stabilizing the food grain production in the country over the past few years.

According to the (www.indiaagronet.com) portal the indigenous wheat is sown in last week of October, for dwarf varieties, the sowing period is first fortnight of November and for short duration dwarf wheat, second fortnight is the best sowing time.

Maharashtra is ranked 8th in the list of top 10 largest wheat producing states in India 2016. Wheat produced is grown in the valleys of rivers like Godavari, Krishna and Tapi. In Maharashtra, wheat is grown in area of more than 20 Lakh hectares, which account for four and half (4.5%) of the total area of the country in which wheat is cultivated with average production is 23.010 Lakh Metric Tonnes. Wheat is grown during rabi season and is cultivated in large contiguous areas. Monitoring crop condition, development of crop growth profile and prediction of yield based on remotely sensed multi-spectral data are the new vistas of research and applicability.

The present study is based on a hybrid technique of multi-date RS data classification based on two-stage ISODATA clustering and visual classification. The natural groupings or clustering of pixels based on their spectral properties by ISODATA clustering and discrimination of spectrally similar classes by way of visual vector polygon analysis have been used.

II. STUDY AREA AND SATELLITE DATA USED

The study was carried out over the Pench Right Bank Canal Command Nagpur district of Maharashtra. The total area of the command is around 20,000 ha. The major winter (rabi) crops grown in the area are wheat, gram, vegetables etc. Most of the rabi crops in the region are grown on the residual soil moisture, except, irrigated areas in the command. The major source of irrigation is the Pench canal system. The area is shown in the figure 1.

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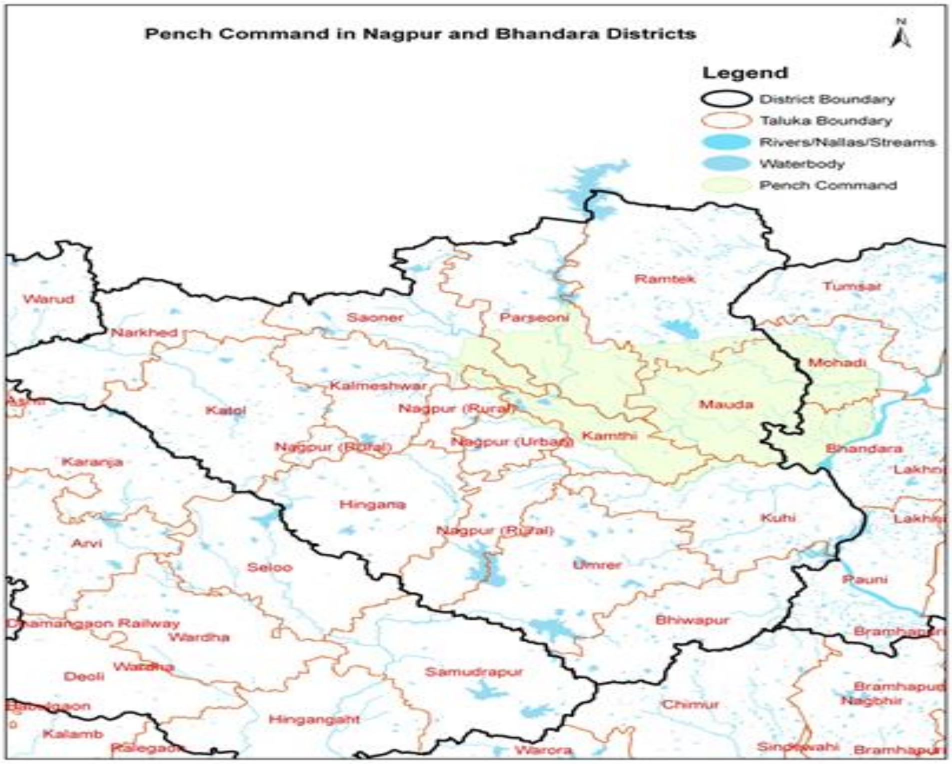

Fig 1:- Pench command area spread in Nagpur and Bhandara districts.

The satellite dataset used in the study comprised of Landsat- 8 Operational Land Imager (OLI) image. Along with this data Resourcesat- 2, LISS 4 (multi spectral) is used along with in-season ground truth information. The area being small, sampling grid is not required. However, data set used in this study comprised of district boundary, Pench RBC command area, settlement location, etc., in the form of vector layers. Along with satellite data, images from the field are collected through GPS enabled camera SONY Cybershot -DSC-HX10V.

The Landsat-8, Resourcesat-8 data covering rabi seasons of 20014-15 (October/November/December/Jan/Feb/March) used is shown in (Table 1).

Satellite	**Sensor**	**Path/Row**	**Date of Pass**	**Spatial Resolution**
Resourcesat-2	L4FMx	100/57 A	24.10.2014	5.8 m
Resourcesat-2	L4FMx	100/57 C	24.10.2014	5.8 m
Resourcesat-2	L4FMx	99/57 B	12.11.2014	5.8 m
Resourcesat-2	L4FMx	99/57 D	12.11.2014	5.8 m
Resourcesat-2	L4FMx	99/57 B	30.12.2014	5.8 m
Resourcesat-2	L4FMx	99/57 D	30.12.2014	5.8 m
Resourcesat-2	LISS-III	100/57	17.11.2014	23 m
Landsat-8	OLI	144/45	23.09.2014	30 m
Landsat-8	OLI	144/45	26.11.2014	30 m
Landsat-8	OLI	144/45	28.12.2014	30 m
Landsat-8	OLI	144/45	13.01.2015	30 m
Landsat-8	OLI	144/45	29.01.2015	30 m
Landsat-8	OLI	144/45	14.02.2015	30 m

Table 1:- Multi date satellite data used for crop identification

III. METHODOLOGY

The methodology consists of multi-date Landsat-8 OLI or Radarsat-2 L4FMx data analysis using time series temporal profile, adopting hybrid approach for winter (rabi) wheat identification is carried out. As crop grows, the reflectance in the Near Infrared (NIR) begins to increase due to an increase in the spongy mesophyll structure and decreases in the red spectral region due to an increased absorption by chlorophyll. Ground based experiments under controlled environment indicate that spectral index of the crop canopy at any given point of time is a measure of the total green biomass. This description when extended to the entire temporal domain of the crop growth reveals that, maximum leaf area index during peak vegetative growth is analogous to peak value of the crop growth profile and rate of senescence can be an average slope of the profile in post-heading time domain. The spectral response of crop and other earth feature is shown in the figure 2.

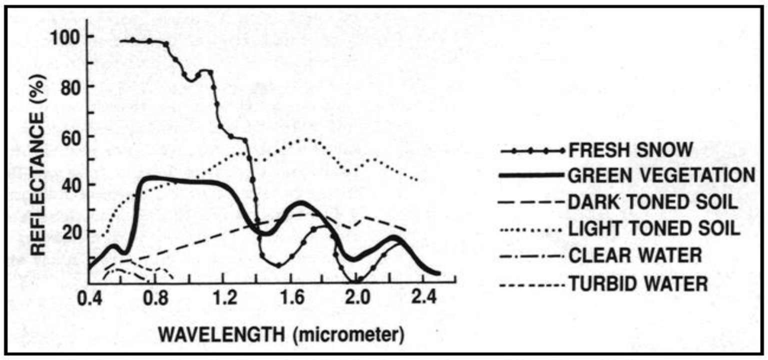

Figure showing Spectral Reflectance Curves of various features
(Source: National Wetland Atlas: Maharashtra, 2009)

Fig 2:- Spectral Response curve of various Earth features

The flow diagram of the methodology for preparation of spectral profile of different crops and for multi temporal data analysis is shown in Figure 3 and figure 4.

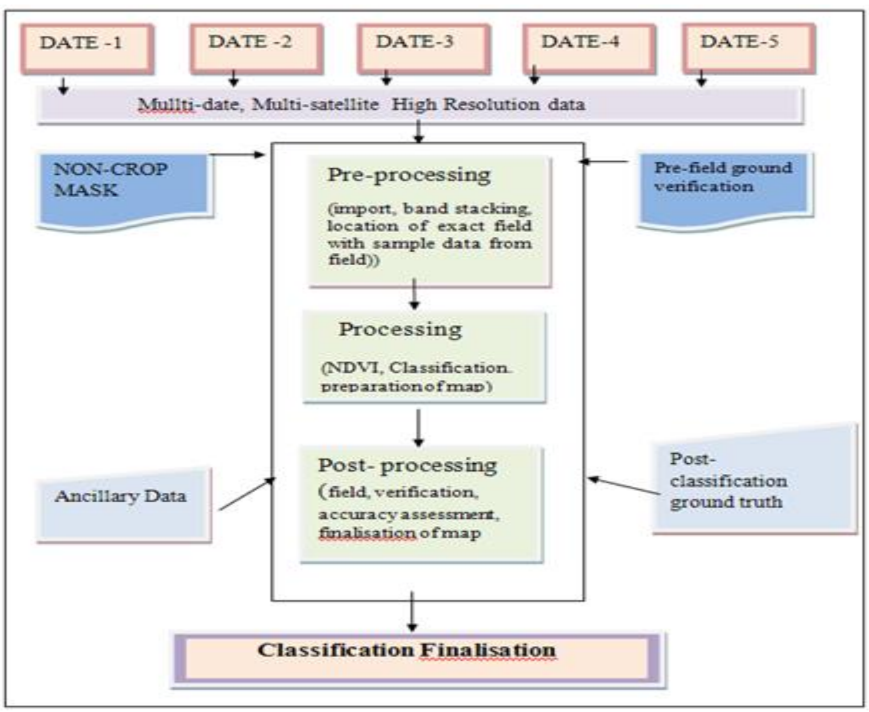

Fig 3:- Process flow for preparation of spectral profile and identification of different crops.

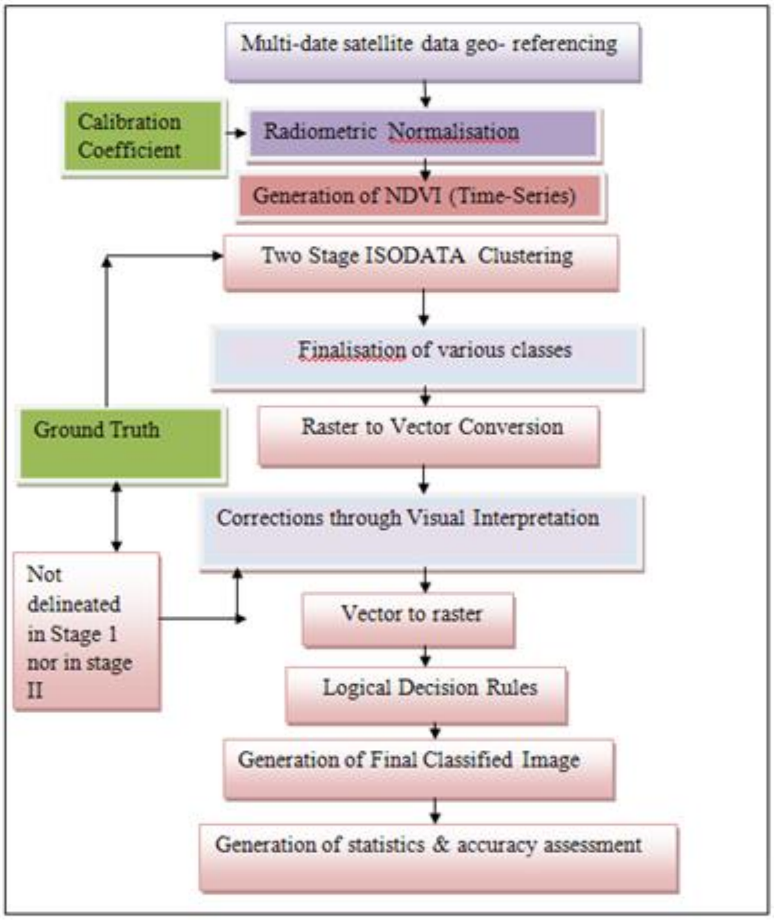

Fig 4:- Schematic depiction of methodology adopted

A. Geo-Referencing and Image Stacking

The multi date Resourcesat-2 L4FMx data and Landsat-8 data is first geo-referenced by image-to-image registration with master image having LCC-WGS84 projection. The geo-referenced L4FMx data are stacked to form a single image. All the registrations are carried out to meet the accuracy requirement in terms of root mean square error less than 0.5 pixels.

B. Radiometric Normalisation

The raw digital numbers (DN) images from Landsat-8 data are converted to radiance images using the calibration coefficients. The relationship between DN and radiance (L) is given by:

L = Lmin + DN (Lmax-Lmin) / DNmax Eqn. 1

Where, Lmin = minimum radiance
Lmax = saturation radiance/maximum radiance
DNmax = Radiometric resolution

The values of Lmax and Lmin for different spectral bands of sensors are given in Table 2. The levels of DNmax are taken as 1024 (10-bit data).

Sensor	Spectral Band	Band λ Range (µm)	Lmax#	Lmin
Landsat8	Green	0.52 - 0.59	53.0*	0
Landsat8	Red	0.62 - 0.68	47.0*	0
Landsat8	NIR	0.77 - 0.86	31.5*	0
Landsat8	SWIR	1.55 - 1.70	07.5*	0
* Source: NRSA, 2003				
# Lmax in mw/sq.cm/sr/micron				

Table 2:- Calibration coefficients used for computing radiance values

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C. Preparation of Reference Temporal Spectral Profile (RTSP) and Scaling of NDVI

The intensity or digital number (DN) value, of each visible RED band is subtracted from the NIR band on a pixel-by-pixel basis. The value is then divided by the sum of the two NDVI derived from the radiance values of two spectral bands, and defined as:

$$\textbf{NDVI} = \frac{\textbf{LNIR - LR}}{\textbf{LNIR + LR}} \qquad \text{Eqn. 2}$$

where, LNIR is radiance value for NIR band
LR is radiance value for Red band.

The result of NDVI consists of continuous floating-point data that ranges from -1 to 1, including decimal and negative values. To simplify the values to scalable numbers, in the range of 0 to 200, the NDVI values were converted using Eqn. 3, i.e., multiplying NDVI values by 100 and then adding 100 to them.

Scaled NDVI = 100 + 100 x (NDVI) Eqn. 3

The geographical locations of field surveys are then transferred to the images. Based on the details collected during field visits, training windows are marked on the images of acquisition date close to field observation date. Multi date signatures and vegetation indices values are extracted from these training windows. These signatures provide RTSPs of wheat and other competing crops with non-crop features (Figure 5).

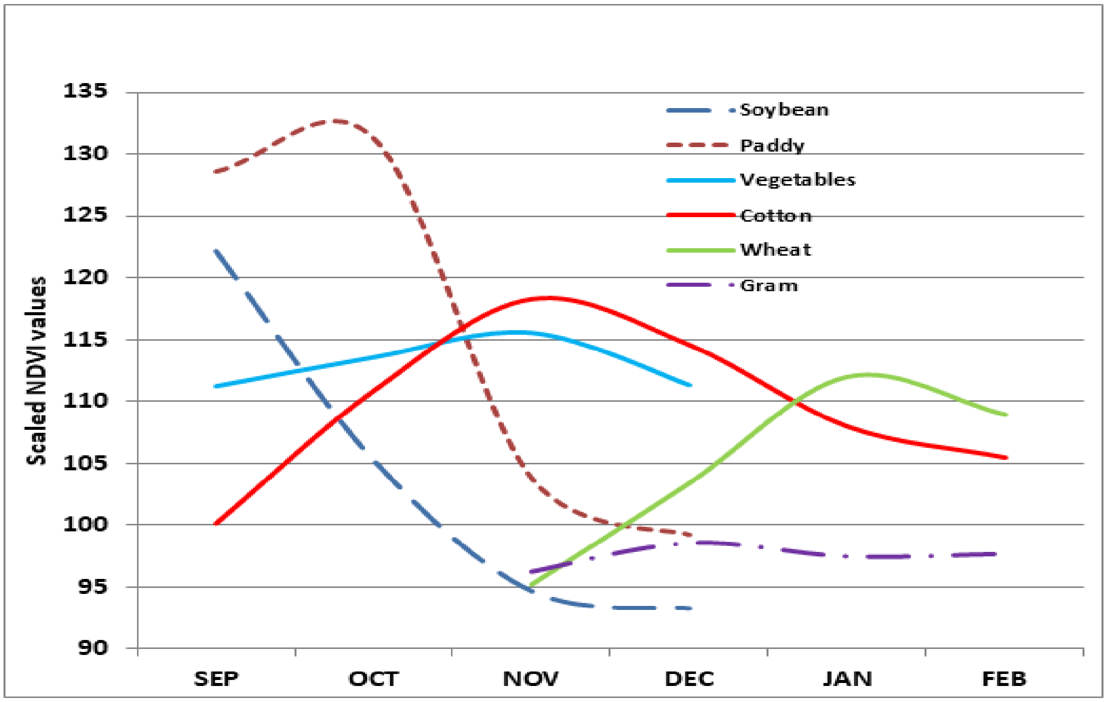

Fig 5:- Spectral Temporal Profile using scaled NDVI

D. Data Load Reduction of Multi-Date Remote Sensing Data:

Non-Crop Mask (NCM) has been prepared using already available information on wasteland, forest, slope, built-up areas etc. To reduce the number of data pixels to be subjected for ISODATA clustering, all pixels belonging to non-agricultural areas are masked out. This is done by multiplying NDVI stacked data with NCM image. The NCM image contains 1 and 0 for all pixels belonging to crops and non-agriculture, respectively. The output multi-layer dataset is then used for further processing for ISODATA clustering stage-I and stage-II.

E. Isodata Clustering and Labelling for Stage I & Stage II :

A thorough ground truth is done in the field to determine the fields which contain wheat, gram and other competing crops using hand held smart mobile phone with GPS and photographs taken with GPS enabled camera. This gives exact location of the field with any of these crops. These fields are marked on the high-resolution satellite data so that their exact locations are known. They form the exact crop wise field database. Multi-date Landsat-8 images spanning through November 2014 to February 2015 are shown in (Figure 6).

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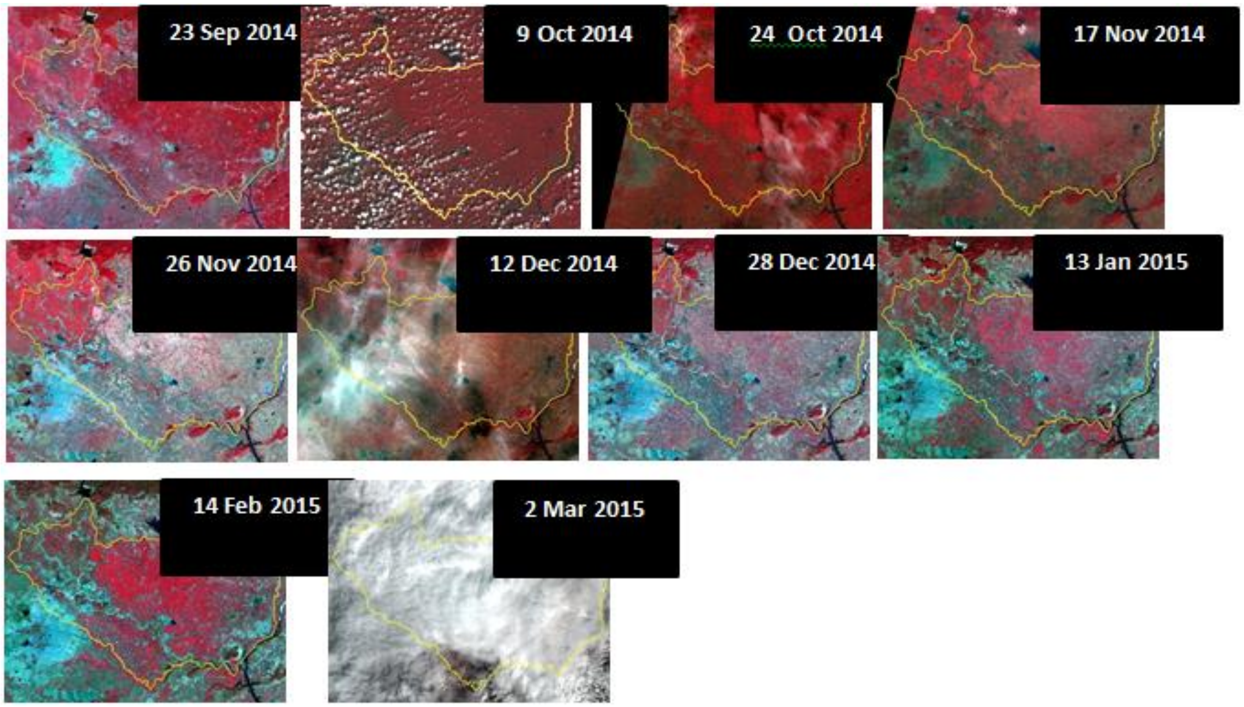

Fig 6:- Temporal satellite data used

A temporal logic based on the field condition is also developed using current field condition, the colour and texture on image and the existing crop on field whose information is gathered during the ground truth, as shown in figure 7.

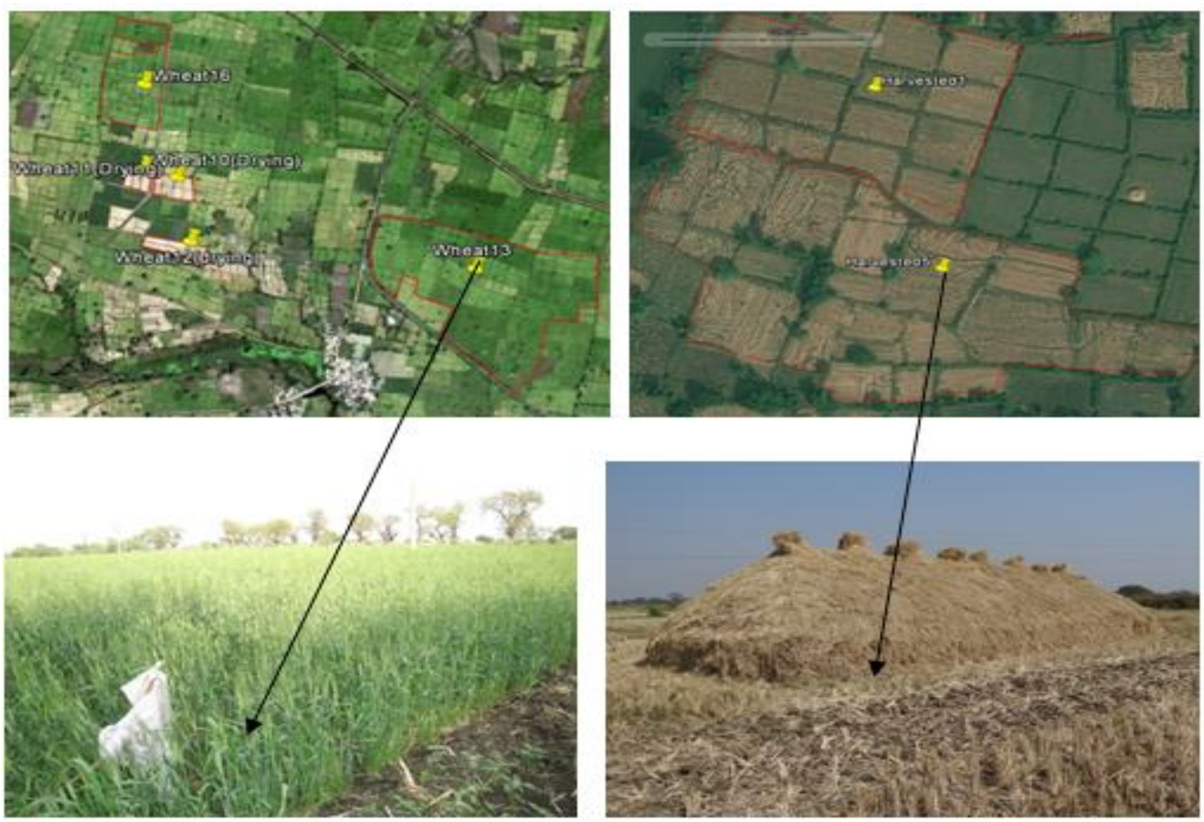

Fig 7:- Wheat Fields on satellite data and harvested fields with locations

The Stage I classification using unsupervised Iterative Self Organizing Data Analysis Technique (ISODATA), is performed and pixels are analyzed. The method is done internally by the software (ERDAS IMAGINE 2013) in block-by-block method. The number of classes is defined by the user as well as number of iterations. The spectral distance between the candidate pixels and each cluster mean is calculated in ISODATA clustering. This clustering method uses spectral distance as in sequential method, but iteratively classifies the pixels, redefines the criteria for each class, and classifies again, so that the spectral distance pattern in the data gradually emerges. The pixels are assigned to the cluster whose mean is the closest. The ISODATA function creates an output image file with a thematic raster layer and/or a signature file as a result of the clustering. The signature file so generated has been used to generate Temporal Spectral Profile (TSPs) for each class. Each of these TSPs of classes is then compared with all available RTSPs of crop of the study area. The TSP of cluster class is assigned to the RTSP with which it matches most in temporal domain within threshold limit of RTSP. Matching of TSPs with RTSPs is carried out visually using the analyst's expert knowledge of the region.

All the inherent crop classes present in the multi-date image may not be discriminated in the first attempt of ISODATA clustering itself (Stage I). Consequently, there may remain some clusters that may not be assigned to any of the RTSPs. Such clusters are put under "Mix crop" class. Due to lack of RTSPs some cluster classes may remain "unclassified" in the classified image. The pixels belonging to "Mix crop" class and "unclassified" class are further fed to ISODATA clustering (stage-II) and same procedure is repeated as in the case of ISODATA (stage-I). Final output of ISODATA stage-I and Stage-II are stored separately.

F. Visual Interpretation of Residual Pixels:

Unclassified pixels and/or pixels which interpreter cannot assign to any crop class with confidence using available RTSPs even after ISODATA Stage-I and Stage-II, are smoothened using median filter and are converted to vector layer. This vector layer is then overlaid on multi-date RS images and polygon are visually analysed. Based on the image, these polygons are labeled. In case of spatially uniform polygons, TSP of pixels belonging to these polygons are visually compared with RTSPs and the polygons attributes are modified accordingly.

G. Integration of Classified Images:

The output of ISODATA stage-I and stage-II analysis and visually interpreted polygons are integrated and combined into a single layer to create the final classified map. This integration is based on simple decision rules that take into account the class label of each pixel in three different layers. The field visits are then done to verify if the crops are identified properly through this process. The earlier database of exact location of type of crop (wheat) can be used in-conjunction with the data classified. The database available can be used to prepare a spectral library and classify the images based on this spectral library. The classification can be improved by this method.

IV. RESULTS AND DISCUSSION

The temporal NDVI patterns of major land use / land cover classes of the study area have been shown in Figure 3. Temporal profile indicates, the spectral pattern of wheat, which is clearly different from that of other competing crops like gram and non-crop classes. This wide difference in temporal profiles of non-crop classes from that of crop classes helps ISODATA clustering in separating non-crop clusters from crop clusters. The analyst can easily assign the different land use classes to the unknown clusters using basic knowledge of signatures and comparing the spatial distribution of unknown classes with respect to False Color Composite images of different dates.

V. CONCLUSIONS

The hybrid technique demonstrates the utility of multi-date RS data classification, using integrated two-stage ISODATA clustering and visual classification of unknown vector polygons. The two-stage ISODATA clustering yielded in a classified image having 94 percent pure-class pixels and 6 percent mixed-class pixels. The labeling of unknown classes in first stage clustering (Stage-I) is based on analyst's knowledge of basic signatures of land use / land cover classes. The pixels belonging to non-crop classes were masked out in Stage-I before the second stage clustering is used (Stage-II). Thus, the number of pixels used is reduced by this process to speed up the processing time for classification.

The labeling of unknown classes of the second stage clustering was based on visual matching of temporal NDVI patterns of unknown classes with those of known crops in the study area. For this the database created with field wise crop inventory using GPS is also very useful. The mixed classes after second stage clustering are vectorised and then class polygons are manually edited for assigning pure crop classes to them. The final classified image is prepared by integrating the pure classes from second stage clustering output and edited vector output.

The database created with the spectral signature of crop (of interest), can be further used for the classification of larger and similar areas. Thus it acts as a spectral library for classifying any area with similar characteristics and for same temporal period. The method can be very well used as useful tool for crop discrimination and mapping.

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