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Monitoring *rabi* crop area using multi-year MODIS data: A case study of Gujarat, India

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Abstract: The present study aims at evaluating the feasibility of utilizing MODIS (MODerate resolution Imaging Spectroradiometer) time series data for rabi crop area monitoring of Gujarat state in India. Multi-date MODIS surface reflectance data of 2002-03 to 2011-12 (from October to March) were used for classification after smoothening the data by Harmonic ANalysis of Time Series (HANTS) algorithm. For each rabi season total 23 sets of eight-day composite data were used for deriving NDVI time series. A hybrid approach was used for data classification for multidate NDVI data set. The clusters formed by k-means classifiers were segregated to different spectral classes using a spectral profile matching approach. The analysis of multi-year MODIS time series data showed that area under rabi crop in Gujarat increased considerably from 2002-03 to 2011-12. Total area under wheat crop approximately doubled from 2002-03 to 2011-12 with an average rate of change 12.9% per year. Area under mustard crop initially increased from 2002-03 to 2006-07 with a total increase of 123% was observed within these 5 years. However, later on 2006-07 onward area under mustard crop decreased continuously, with around 41% reduction in 5 years. The rate of increase in rabi crop area was tested statistically and found to be significant at 90% confidence level. Average rate of change in the total area under rabi crop was found to be 8.6%.

Keywords: *Rabi* crop monitoring, Temporal data analysis, Classification, MODIS, HANTS

1. Introduction

Agricultural resources are among the most important renewable dynamic natural resources. Comprehensive, reliable and timely information on agricultural resources is very much necessary for a country like India whose economy is significantly influenced by agriculture. Reliable crop area monitoring and timely production forecasting provide important inputs for formulation of agricultural management and marketing strategies. Satellite remote sensing has the requisite potential to provide this information on a regular, synoptic, timely and objective manner. Remote sensing data is extremely useful in monitoring crop acreage and production at various scales due to its synoptic and repetitive coverage. Pre-harvest estimation of cop acreage and yield prediction is one of the successful activities of Indian Remote Sensing programme (Navalgund et al., 1991; Patnaik and Dadhwal, 1995; Oza et al., 1996 & 2002; Parihar et al., 2010; Rajak et al., 2010).

During past few years Gujarat state of India has witnessed phenomenal growth in the agriculture sector. Gujarat agriculture has recorded the fastest growth rate (above 9.6%) amongst all Indian states. This is more than double the India's agricultural growth rate. Indeed, 9.6% agricultural growth is among the fastest rates recorded anywhere in the world (http://articles.economictimes.indiatimes.com/2009-07-22/news/28485213_1_check-dams-gujarat-india-chak). Many researchers have demonstrated the utility of MODIS data for crop monitoring and assessment (Potgieter et al., 2005; Xiangming et al., 2006; Wardlow et al., 2007). The present study aims to assess the feasibility of using multi-date MODIS data for monitoring annual fluctuations in *rabi* crop area at a regional scale.

2. Study area and data used

Study area comprises of Gujarat state which is located in the west coast of India (Fig. 1). Total geographical area of the state is 19.6 million hectares. The state has 8 agro-climatic zones, with varied soil conditions. Only 34.4% area is irrigated. Almost half of the districts of Gujarat are drought prone. More than 40 crops are grown in the state. Major *rabi* season (November to April) crops grown in the state are wheat, mustard, potato, gram, cumin, and pea. Some minor *rabi* season crops are fennel, fenugreek, coriander, maize, tomato, isabgol, lucerne etc. (Source: http://agri.gujarat.gov.in/informations/sap_final.pdf).

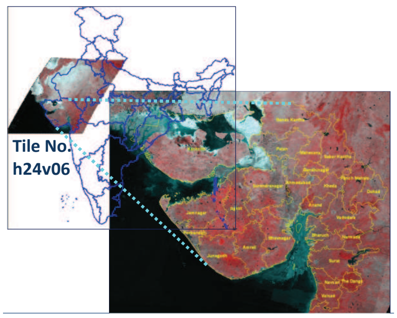

Figure 1: Study area as seen through MODIS sensor

The major satellite and ancillary data used in this study are summarized below.

Satellite data

Terra MODIS surface reflectance 8-day L3 global 250m (MOD09Q1) data (Downloaded from the website: https://lpdaac.usgs.gov) of ten rabi seasons are used in the present study i.e. from 8th October (281 Julian day) to 30th March (89 Julian day) of subsequent year. Thus for each rabi season, the time series contained 23 NDVI composite images (prepared from surface reflectance data) to evaluate rabi season crop spectral profile based on phenological patterns. Hence, total 230 MODIS images were processed and analyzed to monitor changes in rabi crop area over ten years of span.

Crop related data

The statistics of *rabi* crop area in Gujarat state was collected from the published data on agriculture by Directorate of Economics and Statistics (DES), India for the period of 10 years from 2002-2012. (Downloaded from the website: *http://apy.dacnet.nic.in/crop_fryr_toyr.aspx*). While calculating DES total *rabi* crop area the crops included are wheat, mustard, potato, gram, cumin, onion, *rabi* pulses and garlic.

Ground truth data

Ground truth data collected under the FASAL (Forecasting Agricultural output using Space, Agrometeorology and Land-based observations) project (Parihar and Oza, 2006) was used in this study to extract information on crop types, their spatial extent, condition and geographical coordinates of the location. Administrative boundaries of the state and the districts vector coverage were also used.

3. Methodology

Flow chart of the methodology adopted for crop area estimation using MODIS data is shown in Fig. 2. The major steps of the data analysis are described below.

3.1 Multi-date NDVI dataset preparation

NDVI (Normalized Difference Vegetation Index) is one of the most commonly used vegetation indices (Joseph, 2003). NDVI responds to changes in amount of green biomass, chlorophyll content and canopy water stress. It is defined as:

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

where NIR = spectral reflectance in near infrared; and Red = spectral reflectance in red.

The value of NDVI ranges from –1.0 to +1.0, but for ease in data handling and storage, it was scaled between 0 to 200, as follows.

$$\text{Scaled NDVI} = 100 + 100 \times (NDVI)$$

The NDVI images of all dates within a *rabi* season were stacked together in time sequence to form time-series dataset of NDVI images

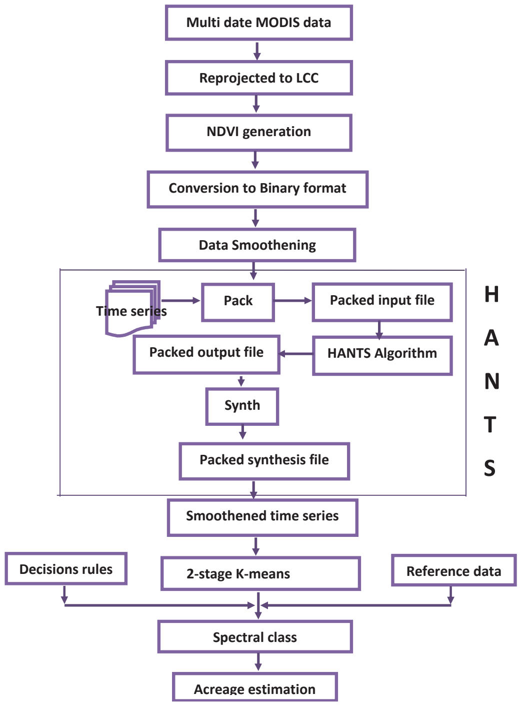

Figure 2: Method adopted for *rabi* season crop area estimation using MODIS data

3.2 Data screening and smoothing through HANTS (Harmonic ANalysis of Time Series)

The HANTS algorithm accomplishes two tasks: (i) screening and removal of cloud contaminated observations; and (ii) temporal interpolation of the remaining observations to reconstruct gapless images at a prescribed time (Verhoef et al., 2005; Roerink et al., 2000; Wen and Ma, 2004). The basic mechanism is to calculate a Fourier series to the data, identify and remove outliers and replaces them with the value produced by the Fourier series (http://remotesensing.nlr.nl). This process is controlled by five parameters, which have to be set at the beginning of each HANTS run. The HANTS algorithm was applied on MODIS 8 day's maximum- NDVI composites. The HANTS control parameters were set as shown in the Table 1.

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Table 1: Values of HANTS parameters used in the study

Parameters	Settings	Description
No. of frequency (NOF)	5	Five frequencies are considered in curve fitting.
HiLo Flag	Low	For NDVI images this flag was set at low, as cloudy observations lead to low NDVI values.
Invalid data rejection threshold (IDRT)	(min.) 0 – 200 (max.)	This means that scaled mean NDVI values higher than 200 are rejected.
Fitting Error Tolerance (FET)	10	Points deviating more than FET from curve fit are rejected.
Degree of over-determinedness (DOD)	10	Together with the minimum of nine observations this means that each fitted curve is based on a minimum of 19 observations in time.

3.3 Crop classification

A multidate stacked smoothened NDVI image was classified using K-means clustering approach. K-means clustering is a simple unsupervised clustering algorithm that can be used to determine the natural spectral groupings present in a data set. (Lillesand and Kiefer, 2000; Joseph, 2003; Mather and Koch, 2011). The assigning of unknown clusters to known classes was based on the comparison of temporal spectral profiles of unknown clusters and the temporal spectral profiles of *rabi* season crops. The clusters which do not represent expected temporal pattern of *rabi* crops were masked out. A second stage clustering was done to differentiate among *rabi* season agricultural classes. Discrimination between different *rabi* crops was achieved by applying threshold, obtained from field data, based decision rules. Final *rabi* crop classified image was prepared which included wheat, potato, mustard and other major *rabi* crops.

4. Results and discussion

It is not uncommon to encounter bad data (decoded from MODIS quality flag) over a region. Also, an area may experience cloudy conditions even during *rabi* season. So it is necessary to smooth the time series to minimize the effects of absence of data or lowering of NDVI in presence of turbid atmosphere which may be due to partial cloud, haze or fog. These phenomena act as noise in performing the task of crop inventory. So there is a need to minimize the adverse effects due to these conditions. This can be achieved by applying HANTS algorithm. Illustrative temporal NDVI profile showing effectiveness of HANTS algorithm in removal of cloud contaminated observations and in producing gapless series is shown in fig 3 and 4, respectively. It can be seen that HANTS achieves the task of smoothing NDVI series and to interpolate the missing values in the dataset.

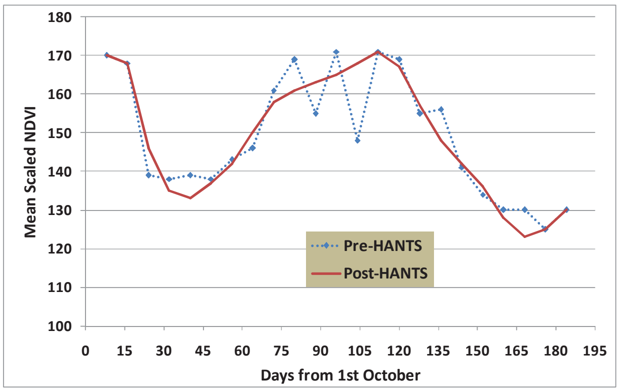

Figure 3: Illustrative temporal NDVI profile showing effectiveness of HANTS algorithm in removal of cloud contaminated observations

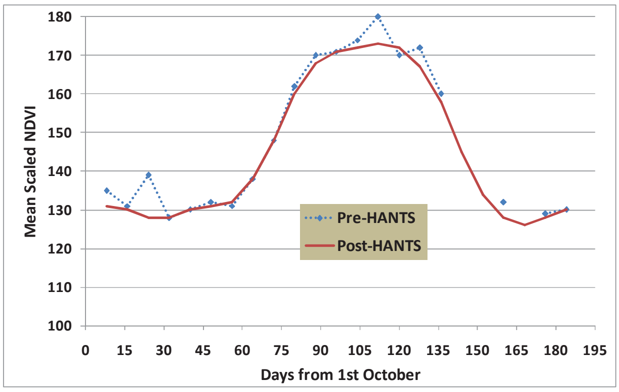

Figure 4: Illustrative temporal NDVI profile showing effectiveness of HANTS algorithm in producing gapless series

The classified images using MODIS data of rabi season of 2011-12 is shown in Fig. 5. Similar classified images were prepared using MODIS data for 2002-03 to 2010-11 seasons. The results of multi-year MODIS time series data are summarised in Table 2. It can be seen that there is considerable increase in area under rabi season crops in Gujarat from 2002-03 to 2011-12.

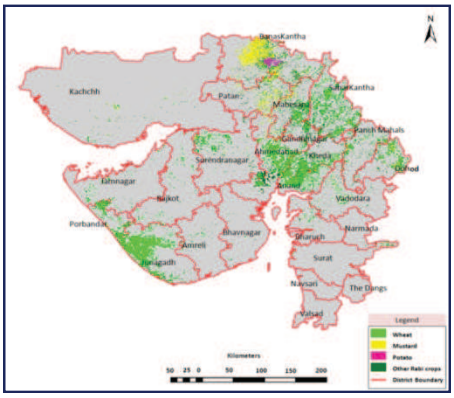

Figure 5: Classified image of 2011-12 using MODIS data

Comparison between the crop statistics generated using MODIS data and government statistics taken from the website of Directorate of Economics and Statistics (DES) was carried out and is shown in Fig. 6. While Fig. 6 (a) compares DES statistics with MODIS derived wheat area from 2002-03 to 2011-12; mustard and rabi crop statistics are compared in Fig. 6(b) and (c), respectively.

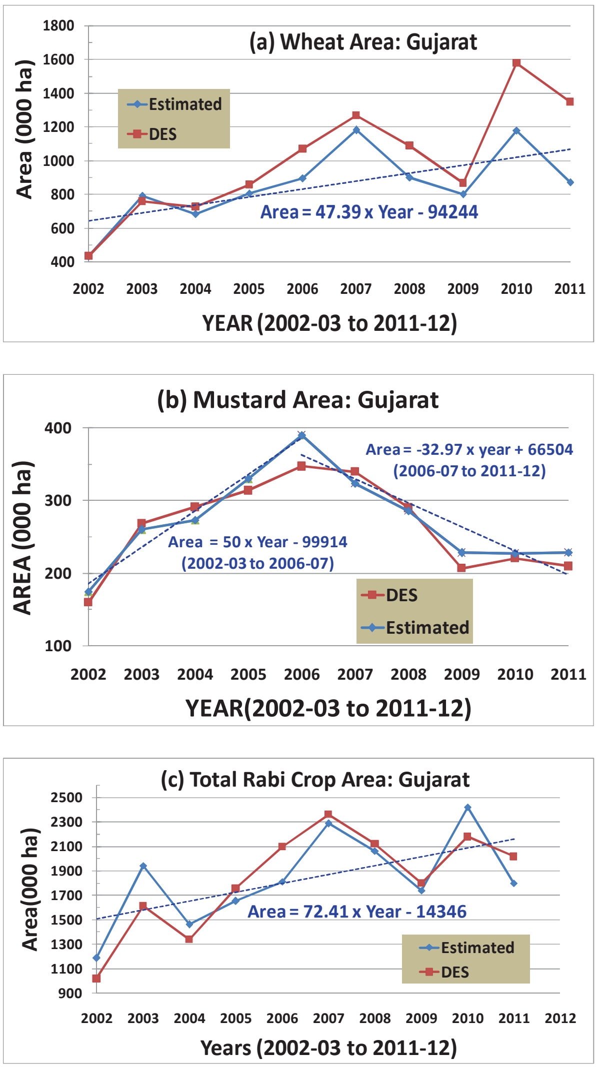

Figure 6: Comparison between DES and Estimated area of (a) Wheat, (b) Mustard, and (c) Total Rabi Crop area of Gujarat state (2002-03 to 2011-12)

The rate of increase in rabi crop area was tested statistically and found significant at 90% confidence level with t statistics of slope being 2.10. Average rate of change in the total area under rabi crop was found to be 8.6% (Table 2). Total area under wheat crop approximately doubled from 2002-03 to 2011-12 with an average change rate of 12.9% per year (calculated as per Table 2 shown for rabi crop area). Area under mustard crop first increased from 2002-03 to 2006-07. Total increase of 123% was observed within these 5 years. However, after 2006-07 area under mustard crop decreased continuously and around 41% mustard area decreased from 2006-07 to 2011-12.

From this study, it can be seen that MODIS data can be used for monitoring gross annual changes in area under major rabi crops at regional scale.

Table 2: Rabi season crop statistics of Gujarat from 2002-03 to 2011-12

Year	Wheat	Mustard	Potato	Other rabi crops	Total rabi crop	
	000 ha	000 ha	000 ha	000 ha	000 ha	Change (%)
2002-03	435.44	174.89	25.32	545.15	1180.79	-
2003-04	792.87	242.43	25.65	862.79	1923.74	62.92
2004-05	685.85	271.44	24.13	472.16	1453.57	-24.44
2005-06	808.61	329.86	34.63	453.92	1627.01	11.93
2006-07	899.00	390.00	32.90	513.00	1834.00	12.72
2007-08	1188.00	323.00	31.70	745.00	2288.00	24.75
2008-09	903.00	286.00	27.80	848.00	2065.00	-9.75
2009-10	802.10	226.80	28.32	616.80	1674.00	-18.93
2010-11	1181.14	226.37	32.07	968.48	2408.61	43.88
2011-12	874.76	228.95	29.85	665.13	1798.63	-25.32
Average Change in Total Rabi Crop Area -->						**8.64**

5. Conclusion

From the analysis of multi-year NDVI time series data from 2002-03 to 2011-12, it can be concluded that (i) temporal smoothing of the time series data is required; (ii) performance of HANTS algorithm over this data was found to be satisfactory; (iii) there is considerable increase in area under rabi season crops in Gujarat from 2002-03 to 2011-12; and (iv) MODIS data can be used for monitoring gross annual changes of major rabi crops at regional scale.

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