Formulation of Temporal Profile of Wheat Crop Using Time Series MODIS Satellite Data

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ABSTRACT: The continuous time series Normalized Difference Vegetation Index (NDVI) data is one of the effective indices parameters in visualizing the vegetation seasonal activities and temporal variability. In satellite data, , the presence of cloud, haze, and other atmospheric contaminated data in the time series incorporates some noise data that may affect the crop phenology analysis. The temporal profile of wheat crop phenology from 16-day composite time series MODIS (Moderate Resolution Imaging Spectrometer) satellite data, which were used for deriving NDVI time series at different agro-climatic regions in India during Rabi season. This paper presents the smoothening approach to reconstruct the time series temporal profile of wheat crop using double logistic model (DLM) and HANTs (Harmonic ANalysis of Time Series) algorithm. This method is compared quantitatively with performance indices at spatially different agro-climatic regions and found that DLM technique provides comparatively better smoothened temporal profile of wheat crop.

Keywords: -NDVI, HANTs, DLM, MODIS, and Wheat crop.

I. INTRODUCTION

Remote sensing has the numerous potential to provide the continuous and timely information of crop phenology and vigor. However, the cloud and other contaminated conditions present during acquisition time of satellite data affects the data quality and obscures the monitoring of crop and other land features cover in the visible to infrared wavelengths regions [1] [2]. On the other hand, cloud shadows, ozone or aerosols, atmospheric attenuation, bidirectional effect and certain topographic variations reduces the significance of NDVI value derived from multi-spectral bands [3]. With the launch of fine spatial and high revisit time of remote sensing satellites and availability of satellite data, the time- series NDVI data are widely used to derive the dynamics of crop growth and monitoring its phonological activity. Specifically, NDVI products as time-series data are mostly used in the effective monitoring of crop [4].

However, the lack of a non-cloudy pixel in satellite images or smoothened temporal profile of crops during crop growth season does not allow the monitoring of rapid crop dynamics related to seasonal activities and phenological development. In this context, the method was applied on 16-day composite MODIS NDVI data at spatial resolution 250 m to derive smoothened temporal NDVI profile for a wheat crop at three different agro-climatic regions in India.

II. STUDY AREA AND SATELLITE DATA

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A. Study area:

The three agro-climatic regions of India such as Upper Gangetic Plain Region (UGPR), Uttar Pradesh, Central Plain and Hills Region (CPHR), Madhya Pradesh and Trans-Gangetic Plain Region (TGPR), Punjab were chosen in this study. These regions represent the dominant wheat crop growing belts of central and north India including Uttar Pradesh, Punjab, Haryana and Madhya Pradesh provinces. In these regions, the wheat is grown from November of preceding year to late April (known as "rabi" season) in the following year with varying climatic conditions and irrigation schedules. The study locations in the different agro-climatic regions are shown in Table-I with geographic latitude and longitude.

TABLE I

STUDY AREA OF WHEAT CROP DURING RABI SEASON (2015-2016) IN DIFFERENT AGRO-CLIMATIC REGIONS IN INDIA

Agro-climatic regions	Latitude	Longitude
UGPR	25^0 15' 20.35'' N	82^0 59' 27.76'' E
CPHR	23^0 37' 26.74'' N	77^0 40' 30.66'' E
TGPR	30^0 35' 10.89'' N	75^0 39' 20.67'' E

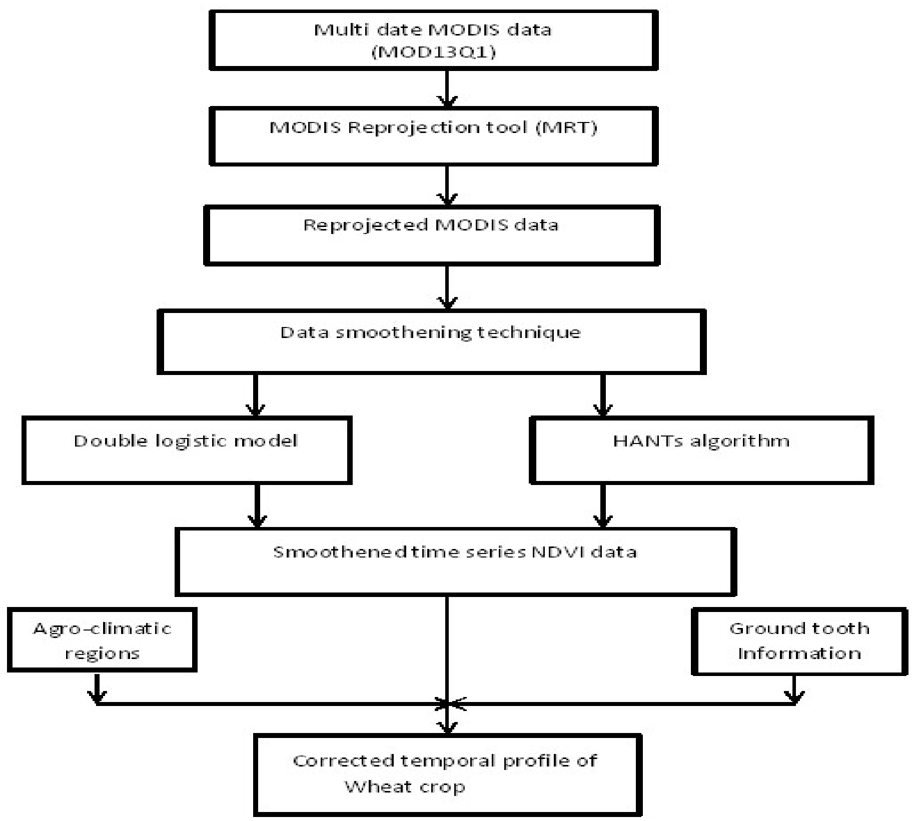
B. Satellite Data:

A time series of MODIS (Terra) NDVI 16-day composite 250 m (MOD13Q1) images of different agro-climatic regions were downloaded from the site of LPDAAC (https://lpdaac.usgs.gov/lpdaac/getdata/data.pool) for November-2015 to May-2016 period. The basic pre-processing steps such as reprojection and conversion to Geotiff format were done in MODIS Reprojection Tool Version 4.0 (MRT) downloaded from LPAAC (https://lpdaac.usgs.gov/lpdaac/tools).

III. METHODOLOGY

The flow chart of the methodology adopted to derive the smoothened temporal profiles of different agro-climatic regions using time series MODIS data is shown in Fig. 1.The major steps of the methodology are described below

Fig. 1 Method Adopted for Wheat Crop to Generate Smoothened Temporal Profile at Different Agro-Climatic Regions in India.



A. HANTs (Harmonic ANalysis of Time Series) algorithm:

The HANTS software can be downloaded free of cost from the website http://www.nlr.org/space/earth-observation/ or http://gdsc.nlr.nl/gdsc/en/tools/hants\ . It can be implemented through MATLAB [5]. The HANTS algorithm can provide a much better smoothing of time series data. Because its algorithm takes only the most significant frequencies present in the time series profiles and applies a nonlinear least squares curve fitting algorithm based on harmonic components [6]. When, it is used in remote sensing to reconstruct the time series with unexpected biases or gaps, the basic formula is:

$$F(t) = a_0 + \sum_{i=1}^{nf} (a_i \cos(2\pi f_i t_j) + b_i \sin(2\pi f_i t_j)) \quad (1)$$

$$f(t) = F(t) + \varepsilon(t) \quad (2)$$

With j=1…., N and where f (t)is the original time series, F(t) is the reconstructed time series, ε(t) is the error in timeseries and $t_j$is the time that f(t)is observed, respectively. Such as, time series of NDVI data derived fromSatellite data are composited to monthly period (16 day), provided an opportunity to acquire numbers of observations in a Rabi season crop year, i.e. N should be 12.

The HANTs algorithm performs two tasks:

(i) Removal of cloud contaminated observations

(ii) Temporal interpolation of the remaining observations to reconstruct continuous images at a given time.

TABLE II

VALUES OF HANTS PARAMETERS USED IN THE STUDY

Sr. No.	HANTs parameters	Value	Description
1	Number of frequency (NOF)	2	Two frequencies are considered in curve fitting
2	Fitting Error Tolerance (FET)	10	Points deviating more than FET from curve fit are rejected.
3	Degree of Over-Determinedness (DOD)	5	Together with the minimum of nine observations this means that each fitted curve is based on a minimum of 19 observations in time.
4	Delta	0.5	Damping Factor
5	Hi/Lo Flag	Lo	For NDVI images, the flag was set at low, as cloudy observations lead to low NDVI values.
6	Scaling factor	2.5	Multiplication factor applied to the amplitude output.
7	Invalid Data Rejection Threshold (IDRT)	(min.) 0 – 200 (max.)	This means that scaled mean NDVI values higher than 200 are rejected.

B. Double logistic model:

The temporal NDVI profile derived from time series satellite data computed over temperate agriculture areas is linear mixing profile. The NDVI values from the coarse resolution satellite are mixed with different species, which were found within a pixel. Several smoothening models have been developed to reconstruction the NDVI time profile of various crops using a semi-empirical model to test the temporal variations of the NDVI with day of year during crop growth [7] [8]. The expression of the model is:

$$NDVI(t) = v_b + \frac{k}{1+\exp[-a(t-p)]} - \frac{k+v_b-v_e}{1+\exp[-b(t-q)]} \quad (3)$$

Where *NDVI (t)* is the remotely sensed NDVI evolution for a given Rabi season of wheat crop and other model parameters details is shown in TABLE III**.**

TABLE III

DESCRIPTION ABOUT MODEL PARAMETERS OF DOUBLE LOGISTIC FUNCTION.

Model Parameters	Description
k	High asymptotical value
a	Slope of the first inflexion point (day^{-1})
b	Slope of the second inflexion point (day^{-1})
p	Location of the first inflexion point (day)
q	Location of the second inflexion point (day)
v_b	NDVI value at early growth of crops
v_e	NDVI value at end seasonal cycle of crops

IV. RESULTS AND DISCUSSION

It is not uncommon to encounter contaminated data or satellite images over a region. Also, an area may experience cloudy and rainy conditions even during Rabi season in India. So it is needed to construct smoothened time series data to minimize the effects of cloudy data or lowering of NDVI in presence of turbid atmosphere which may be due to partial cloud, rain, haze or fog and other atmospheric constituent. These phenomena lead to noise in performing the monitor the crop phenology. So, there is a need to minimize the contaminated effects due to these conditions. This can be achieved by applying HANTs algorithm and Double logistic model to simulate the contaminated data [9] [10] [11].The double logistic model approach implemented in this study to generate the smoothened time series data for wheat crop at different agro-climatic regions .Due to its definition, the double logistic function describes the variation in vegetation phenology with growing cycle more accurately. The model parameters of this function, which helps to derive the temporal profile wheat crop is shown in TABLE III .NDVI value of before growth (v_b) and end seasonal cycle of crops (v_e) was taken 0.2 for this model.

TABLE III

THE DOUBLE LOGISTIC MODEL PARAMETERS FOR WHEAT CROP.

Parameters	Agro-climatic regions		
	UGPR	CPHR	TGPR
k	0.5066	0.6804	0.6985
a	0.0358	0.0474	0.08
p	69.90	64.20	58.88
b	0.0752	0.2160	0.1668
q	121.17	125.34	146.15

The temporal NDVI profile shown in Fig. 2, 3 and 4 indicates the potential of HANTs algorithm and double logistic model in interpolation of cloud contaminated data for wheat crop at different agro-climatic region. It can be seen that these smoothening models achieves the task of smoothening NDVI series and to interpolate efficiently the missing values in the dataset [12].

In these regions, the growth seasonal lengths and NDVI peak strength of temporal profiles of wheat crop are not found similar through retrieval by DLM and HANTs algorithm due to presence of different seasonal activity, climatic conditions, irrigation management and former skills at crop field level.

Fig. 2 Temporal NDVI Profile Shows Potential of Smoothening Method for Wheat Crop at UGPR Region.

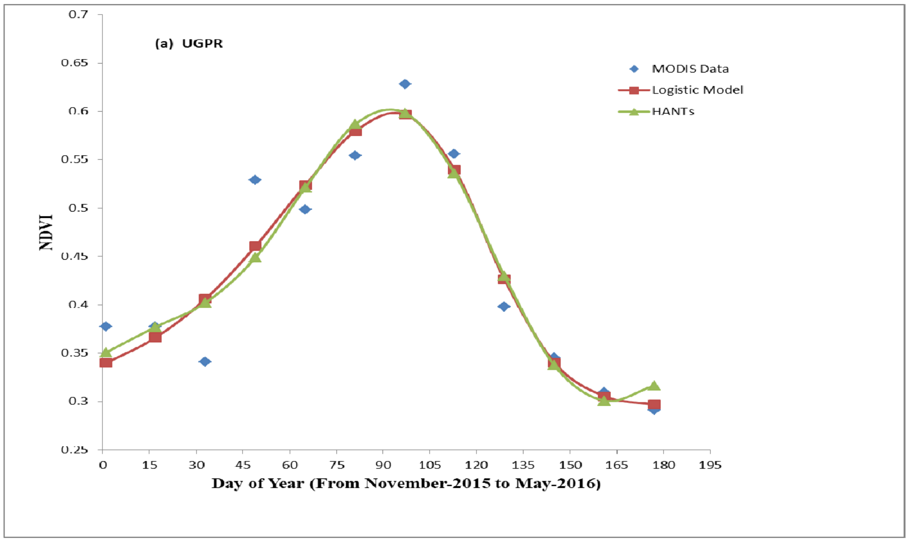


Fig. 3 Temporal NDVI Profile Shows Potential of Smoothening Method for Wheat Crop at CPHR Region.

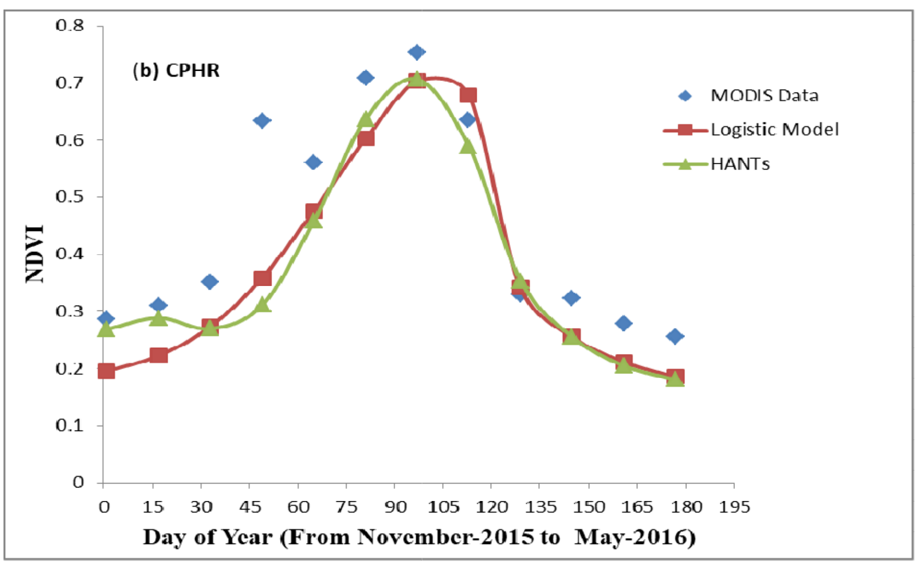


Fig.4Temporal NDVI Profile Shows Potential of Smoothening Method for Wheat Crop at TGPR Region.

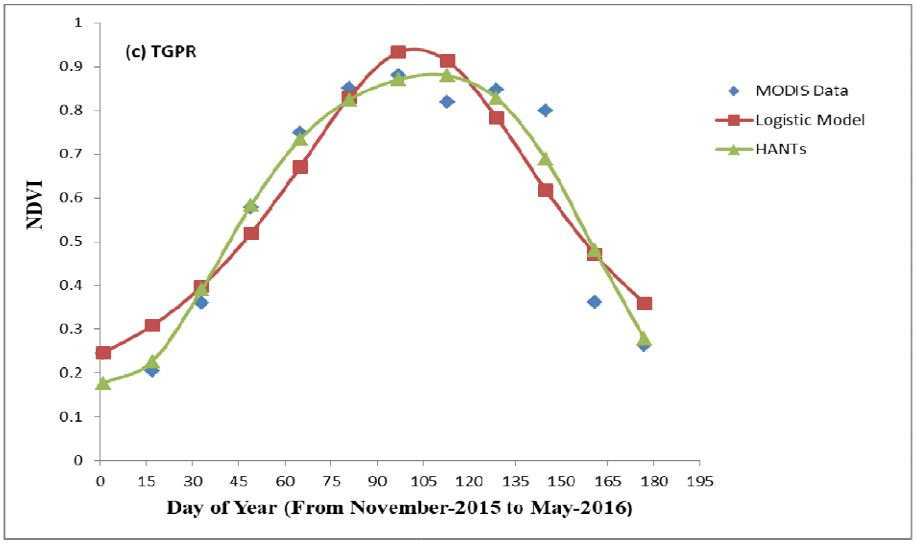


TABLE IV
PERFORMANCE INDICES OF DOUBLE LOGISTIC MODEL (DLM) AND HANTS ALGORITHM FOR WHEAT CROP

Agro-climatic regions	Performance Indices					
	R^2		RMSE		NSE	
	DLM	HANTs	DLM	HANTs	DLM	HANTs
UGPR	0.907	0.867	0.0630	0.096	0.904	0.842
CPHR	0.931	0.883	0.0575	0.081	0.918	0.861
TGPR	0.955	0.903	0.0452	0.064	0.943	0.912

The studied wheat crop represents major crop in the regions during Rabi season in India. NDVI values in TGPR region is found more than the other regions due to difference in canopy architecture, climatic conditions, phenological development and soil variability [12]. The asymptotical value (k) of double logistic model in TGPR region is found high, which is shown in TABLE III. For assessing the accuracy of model performance, some statistical parameters are used to check the accuracy of model generated data. The difference in temporal NDVI profiles from both the model is fairly acceptable. However, in case of TGPR region, the methods R-square was found very high for DLM (R^2 = 0.955) and HANTs algorithm (R^2 = 0.903) due to presence of homogeneity in the crop area and less cloudy, rain or haze effect during Rabi season.

V. CONCLUSION

The present study demonstrates the potential of the techniques of using smoothening algorithms for generalizing the temporal NDVI profile of wheat crop at different agro-climatic regions in India. Both the model performances were found satisfactory in the study regions. The R-square of double logistic model (DLM) was found very good and agreement (R^2> 0.90) with the raw NDVI data of MODIS satellite data. Also, other performances such as root mean square error (RMSE) and Nash Sutcliffe Efficiency (NSE) was found good in both the techniques

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