



## Deriving Crop Phenology Metrics and Their Trends Using Times Series NOAA-AVHRR NDVI Data

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**Abstract** In this study, an attempt has been made to derive the spatial patterns of temporal trends in phenology metrics and productivity of crops grown, at disaggregated level in Indo-Gangetic Plains of India (IGP), which are helpful in understanding the impact of climatic, ecological and socio-economic drivers. The NOAA-AVHRR NDVI PAL dataset from 1981 to 2001 was stacked as per the crop year and subjected to Savitzky-Golay filtering. For crop pixels, maximum and minimum values of normalized difference vegetation index (NDVI), their time of occurrence and total duration of *kharif* (June–October) and *rabi* (November–April) crop seasons were derived for each crop year and later subjected

to pixel-wise regression with time to derive the rate and direction of change. The maximum NDVI value showed increasing trends across IGP during both *kharif* and *rabi* seasons indicating a general increase in productivity of crops. The trends in time of occurrence of peak NDVI during *kharif* dominated with rice showed that the maximum vegetative growth stage was happening early with time during study period across most of Punjab, North Haryana, Parts of Central and East Uttar Pradesh and some parts of Bihar and West Bengal. Only central parts of Haryana showed a delay in occurrence of maximum vegetative stage with time. During *rabi*, no significant trends in occurrence of peak NDVI were observed in most of Punjab and Haryana except in South Punjab and North Haryana where early occurrence of peak NDVI with time was observed. Most parts of Central and Eastern Uttar Pradesh, North Bihar and West Bengal showed a delay in occurrence of peak NDVI with time. In general, the rice dominating system was showing an increase in duration with time in Punjab, Haryana, Western Uttar Pradesh, Central Uttar Pradesh and South Bihar whereas in some parts of North Bihar and West Bengal a decrease in the duration with time was also observed. During *rabi* season, except Punjab, the wheat dominating system was showing a decreasing trend in crop duration with time.

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## Introduction

Agro-ecosystems are one of the most dynamic systems which are having all pervasive and profound effects on functioning of bio-sphere on earth. Agro ecosystem dynamics in general is determined by meteorological factors, landscape features and human interventions. Many recent studies have shown that agro ecosystems are witnessing a general degradation, declining yields and total factor productivity (Tilman et al. 2002; Aggarwal et al. 2004; Foley et al. 2005). Climate change in general and global warming in particular may be contributing to agro-ecosystem degradation (Aggarwal et al. 2004). In order to detect and study such changes, it is essential to quantify the spatial and temporal trends in agro-ecosystem parameters at regional scales. For such purposes, field data currently available are generally difficult to use because such data are traditionally collected at small spatial and temporal scales and vary in their type and reliability. Satellite derived remote sensing data in this context provides objective and reliable measurements of parameters which can be used for quantification of regional trends (Reed 2006).

Many studies have reported use of time series of normalized difference vegetation index (NDVI) derived from NOAA/AVHRR, SPOT/VEGETATION and TERRA or AQUA/MODIS for quantification of regional trends in agro-ecosystem parameters and modeling response (Myneni et al. 1997; Heumann et al. 2007). Agro-ecosystem parameters derived from NDVI are crop type distribution, leaf area index (LAI), fraction absorbed photosynthetically active radiation (fAPAR), primary productivity and vegetation phenology. The derived data on vegetation phenology is of prime importance to characterize agro-ecosystem dynamics as it is highly sensitive to climatic variability besides being responsive to changes in crop production technology. Vegetation phenology is an effective indicator of intra as well as inter-annual changes in vegetation caused by climatic (van Vliet and Schwartz 2002) and anthropogenic factors. Phenology metrics have also been used to regionally discriminate same crop having differences in sowing date and growth profile (Upadhyay et al. 2008). As a result, the NDVI derived vegetation phenology has recently emerged as a key area of research in biosphere-atmosphere interactions, climate

change and global change biology (Myneni et al. 1997; van Vliet and Schwartz 2002; Heumann et al. 2007; White et al. 2009).

Traditionally, vegetation phenology refers to the specific life cycle events and their timing based on in-situ observation (Lieth 1974) but phenology from satellite is aggregate information at coarse spatial resolution that relates to the timing and rates of greening (growth) and browning (senescence), timing of maximum photosynthetic activity and duration of active growth phase at seasonal and inter-annual time scales. Many approaches of estimating phenology from time series of NDVI have been published in literature but there is no consensus on the optimal approach for producing vegetation phenology at pixel or regional scales. Zhang et al. (2003) identified key phenological phases of vegetation by fitting a continuous logistic function to time series of MODIS VI data and estimating phenological transition dates based on inflection point of the curve. Based on this approach global maps of annual ecosystem phenologies were produced and their comparison with in-situ measurements showed realistic estimates of phenological dates identified (Zhang et al. 2006). White and Nemani (2006) used phenoregion specific normalized difference vegetation index threshold to analyze the phenological behaviour of group of pixels. Schwartz et al. (2002) employed a simple method of Seasonal Midpoint NDVI (SMN) in which a SMN threshold is defined to determine the start and end of season in case of broad leaf forest. Schwartz and Reed (2004) showed that satellite derived start-of-season (SOS) correlate well with surface phenology model outputs for deciduous trees and mixed woodland but observed lowest correlation of 0.37 for short grasses. Zhang et al. (2006) reported strong correspondence of phenological metrics estimated from MODIS data with temperature pattern in mid and high latitude climates, with rainfall seasonality in dry climates and with cropping patterns in agricultural areas.

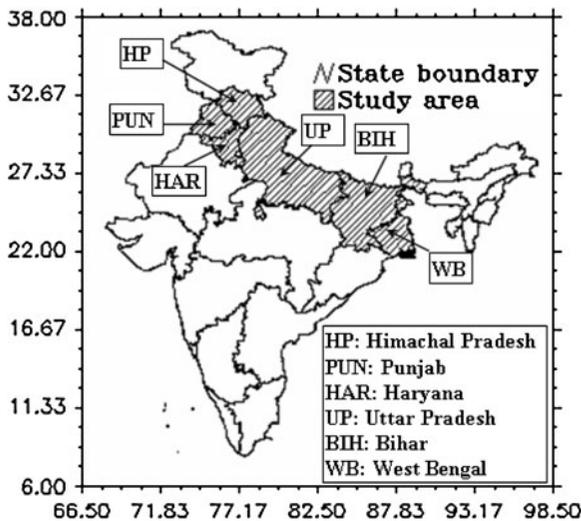
Though many research studies have reported the use of satellite remote sensing based vegetation phenology determination and its application, very few studies exist on long term trends in phenology metrics of crops. So, this study was aimed at deriving the seasonal phenology metrics of agroecosystem dominant in short grasses (cereal crops) from multi-date NOAA AVHRR

PAL dataset for Indo-Gangetic plains of India (IGP) and deriving their spatio-temporal trends to characterize the agroecosystems. The phenology measures were derived separately for *kharif* (June–October) and *rabi* (November–April) crop seasons for 19 years from 1982 to 2001 and dominated by rice and wheat crops, respectively. The spatial patterns of temporal trends in phenology metrics for both the seasons were derived and analyzed at disaggregated level (pixel-wise) and at aggregated level (State wise).

**Methodology**

**Study Area**

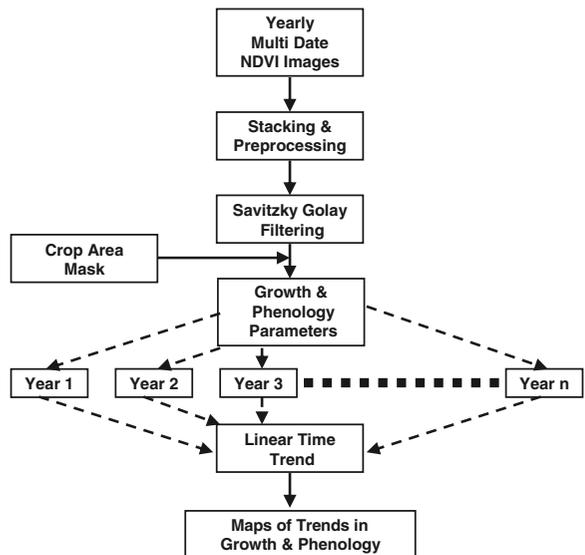
The study was carried out for Indo-Gangetic Plains (IGP) of India which are under intensive cultivation for long period. The states which falls in the Indian IGP are Punjab, Haryana, Himachal Pradesh, Uttar Pradesh (including present day Uttarakhand), Bihar (including present day Jharkhand) and West Bengal covering a total area of 57.66 Mha (Aggarwal et al. 2000) (Fig. 1). During *kharif* season, rice is the dominant crop throughout IGP with some area under cotton and maize also, whereas, during *rabi* season wheat is the dominant crop in all States except in West Bengal where rice and potato dominate.



**Fig. 1** India State map showing study area (shaded) falling in Indo-Gangetic Plains

**Satellite Data Pre-Processing**

The overall methodology followed in this study is shown in Fig. 2 as flowchart. The study used NDVI Land data set produced as a part of NOAA/NASA Pathfinder AVHRR 8 km land (PAL) project generated from series of NOAA satellites (Smith et al. 1997). The PAL dataset provides a continuous and uniformly processed daily and 10 days composite dataset from July 1981 to September 2001. This dataset incorporates normalization with respect to sensor calibrations, solar illumination conditions and noise due to atmospheric constituents such as aerosols, ozone etc. The dataset was downloaded from the website of distributed active archive of Goddard space flight centre. The 10-day NDVI regional dataset available for Asia continent in Goods-Homosoline projection were stacked together corresponding to each crop year i.e. June of first year to May of next year and the area corresponding to Indo-Gangetic plains of India were extracted. Though the NDVI is composited on the 10 day interval, many studies have reported diminished utility of PAL NDVI dataset due to significant residual cloud contamination, atmospheric variability, and bi-directional effects (Lovell and Graetz 2001; Chen et al. 2004). So the yearly NDVI time series images were subjected to pixel wise filtering by following Savitzky-Golay filter based technique (Chen et al. 2004). The algorithm for Savitzky-Golay filter based technique was coded in



**Fig. 2** Methodology flowchart for the study

IDL-ENVI™. Savitzky-Golay filter is a simple robust method to smooth out noise in NDVI time series specifically that caused primarily by cloud contamination and atmospheric variability. This method make data approach the upper NDVI envelope and to portray the NDVI change to an iteration process. The IGBP DISCover 1 km global land cover dataset (Loveland et al. 2001) aggregated to 8 km pixel size was used to develop cropland mask based on cropland class (no. 12) for the study area. Same crop mask was used for all the years in the study.

Computing Phenology Metrics

The phenology metrics derived for each crop pixel in the two crop seasons (*kharif* and *rabi*) across the years in this study were (Fig. 3):

1. Peak value of NDVI ( $Y_m$ )
2. Time of the peak NDVI ( $X_m$ )
3. Time of start of the season ( $X_{left}$ )
4. Time of end of the season ( $X_{right}$ )
5. Duration of the active growth season (FWHM)

As there is no consensus on the optimal approach for deriving vegetation phenology especially for agricultural crops, a simple approach based on fitting a second order parabolic curve to seasonal filtered NDVI profile was proposed and implemented in this study. This approach is illustrated in Fig. 3. A parabolic curve was fitted to the seasonal NDVI values as given by the following equation:

$$aX^2 + bX + c = 0 \tag{1}$$

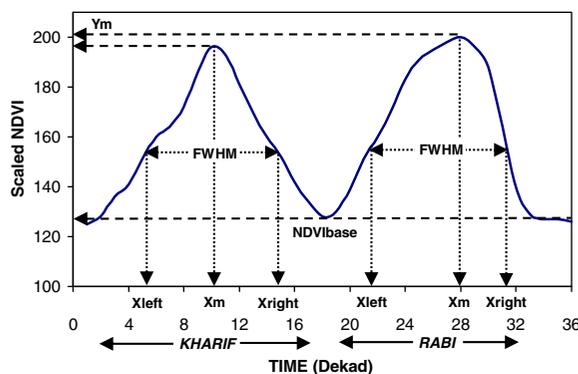


Fig. 3 Schematic diagram showing phenology metrics for *kharif* and *rabi* seasons

where, a and b are coefficients, c is the constant and X refers to time. The time of maximum NDVI ( $X_m$ ) was calculated as follows:

$$X_m = (-b/2a) \tag{2}$$

The value of maximum NDVI ( $Y_m$ ) was computed by substituting value of  $X_m$  in Eq. 1. As the NDVI profiles were not starting from the origin but having an offset in values, so a base NDVI value ( $NDVI_{base}$ ) was chosen for each season depending on the minimum NDVI obtained between the *kharif* and *rabi* season profiles. The reason for choosing different  $NDVI_{base}$  for each pixel was to account for differences in NDVI of background soil cover which vary across study region. Though across years,  $NDVI_{base}$  was not varying much for a pixel and a mean value could have been taken, but a different value for each year was taken as it may be superior in accounting for variation in NDVI profile data fitting for that year. The half of peak NDVI value ( $Y_{1/2}$ ) was computed as follows:

$$Y_{1/2} = (Y_m - NDVI_{base})/2 + NDVI_{base} \tag{3}$$

Now in order to determine the time when the  $Y_{1/2}$  value intersect the left side and right side of NDVI profile, straight line equation was fitted separately for left and right sides such that this line pass through  $Y_{1/2}$ .

$$Y_{left} = M_{left} * X + C_{left} \tag{4}$$

$$Y_{right} = M_{right} * X + C_{right} \tag{5}$$

where,  $M_{left}$  and  $M_{right}$  are slopes and  $C_{left}$  and  $C_{right}$  are intercepts of straight lines for left and right sides of NDVI profile, respectively. The time of start of the season ( $X_{left}$ ), end of the season ( $X_{right}$ ) and duration of active growth season (FWHM) were calculated as follows:

$$X_{left} = (Y_{1/2} - C_{left})/M_{left} \tag{6}$$

$$X_{right} = (Y_{1/2} - C_{right})/M_{right} \tag{7}$$

$$FWHM = X_{right} - X_{left} \tag{8}$$

It may be noted that  $X_{left}$  and  $X_{right}$  are indicator of start and end of season, respectively, but are not

actually start and end of season in true sense. These phenology metrics were computed for *kharif* and *rabi* season of each year of the study period at pixel level and were also aggregated for crop pixels at state level by computing their mean value under State mask.

### Spatial Trends in Phenology Metrics

The year-wise seasonal five phenology metrics were subjected to linear regression with time to derive the rate and direction of change in them as well as their Pearson's correlation coefficient. Based on degrees of freedom ( $n=19$ ) and 90% confidence level (2-tailed), a correlation coefficient between  $-0.3$  to  $0.3$  was considered no change in parameter, whereas value less than  $-0.3$  showed a significant decreasing trend in parameter over time and a value above  $0.3$  showed a significant increasing trend in parameter over time at  $p < 0.1$ . The pixel wise correlation coefficient images for each parameter were density sliced as per this criteria and direction of change maps were generated for *kharif* and *rabi* seasons. Range and mean statistics of the phenology metrics were calculated at State level and for the whole IGP, separately for pixels showing significant decreasing and increasing trends.

## Results

State-wise percentage of net sown area (NSA) showing significant increasing and decreasing trends in different phenology metrics for *kharif* and *rabi* seasons are given in Table 1. The density sliced maps of trends in phenology metrics are shown in Fig. 4 for both *kharif* and *rabi* seasons.

The peak value of NDVI ( $Y_m$ ) showed increasing trend in both *kharif* and *rabi* seasons. Of the net sown area of IGP, about 68% in *kharif* and 53% in *rabi* was showing significant increasing trend in peak NDVI, whereas, 31% in *kharif* and 45% in *rabi* did not show any significant trend. The area showing decreasing trend in both the seasons was negligible. It indicates that crop vigour and hence crop yields (Dadhwal and Ray 2000; Rajak et al. 2002) have increased in majority of the area in IGP in both *kharif* and *rabi* seasons. The improvement in production technology leading to better management of crops is mainly responsible for increase in crop yields during the

study period. Pathak et al. (2003) have also mentioned that rice and wheat production in IGP have shown tremendous increase during this study period.

The trends in time of occurrence of peak NDVI ( $X_m$ ) during *kharif* dominated with rice showed that the maximum vegetative growth stage is occurring early across most of Punjab, North Haryana, Parts of Central and East Uttar Pradesh and some parts of Bihar and West Bengal. Only central parts of Haryana showed a delay in occurrence of maximum vegetative stage. Singh et al. (2006) also reported an early shift of about 27 days in peak vegetative stage of rice in Ludhiana district of Punjab using PAL NDVI dataset over 1981–82 to 1999–2000 period. During *rabi*, no significant trends in time of occurrence of peak NDVI were observed in most of Punjab and Haryana except in South Punjab and North Haryana where early occurrence of peak NDVI was observed. Most parts of Central and Eastern UP, North Bihar and West Bengal showed a delay in occurrence of peak NDVI. Overall, across IGP 26% of NSA (Net sown area) showed early occurrence of peak NDVI during *kharif* whereas 30% of NSA showed delay in occurrence of peak NDVI during *rabi* for the study period. On the average for IGP, time of peak NDVI happened 16 days early during *kharif* and was delayed by 19 days during *rabi* across IGP during 1982–2001 period.

The trends in time of start of the season ( $X_{left}$ ) during *kharif* indicated that season was starting early across Punjab, Haryana and Uttar Pradesh, whereas, in some areas of East Bihar and West Bengal, it was getting delayed. The early starting is in tandem with early occurrence of peak vegetative growth stage though their magnitudes may differ. A four-week early shift in rice puddling/transplanting activity from 1988 to 1998 in Ludhiana district of Punjab was also inferred by Singh et al. (2006) using SSM/I passive microwave data. During *rabi*, the time of start of season was getting delayed across most of Uttar Pradesh, Bihar and West Bengal but was happening early in south Punjab and north Haryana. The delay in start of *rabi* season matches with the similar shift in occurrence of maximum vegetative stage. In parts of Punjab and Haryana, the early start of *rabi* season in some areas matches with early occurrence of peak growth stage showing a clear early shift in season while in some areas it matches with no significant trend in peak growth stage indicating introduction of cultivars with longer vegetative growth stage over

**Table 1** Percentage of net sown area of States and IGP showing significant decreasing and increasing trends in different phenology metrics during *kharif* and *rabi* seasons

STATE	SEASON	PHENOLOGY METRIC							
		Ym		Xm		Xleft		FWHM	
		DT	IT	DT	IT	DT	IT	DT	IT
Punjab	<i>Kharif</i>	0.5	70.5	63.6	1.3	59.2	2.1	10.2	33.7
	<i>Rabi</i>	1.2	62.5	43.2	0.7	52.0	2.7	3.1	47.7
Himachal Pradesh	<i>Kharif</i>	0.0	51.8	20.3	5.1	28.5	2.7	6.4	28.1
	<i>Rabi</i>	3.0	12.3	2.7	24.7	12.7	5.8	7.4	5.6
Haryana	<i>Kharif</i>	0.4	63.1	14.6	18.2	46.7	1.0	2.5	54.5
	<i>Rabi</i>	0.1	92.2	28.0	4.9	9.6	22.4	14.7	12.0
Uttar Pradesh	<i>Kharif</i>	0.8	71.7	22.7	6.3	25.4	3.3	7.6	38.5
	<i>Rabi</i>	0.8	54.2	5.3	30.4	3.9	38.9	24.3	7.1
Bihar	<i>Kharif</i>	1.4	65.4	25.8	3.4	5.3	19.6	9.1	22.5
	<i>Rabi</i>	6.2	35.0	2.0	38.4	6.4	20.2	22.7	5.4
West Bengal	<i>Kharif</i>	0.8	65.1	22.8	4.5	7.7	28.1	17.9	17.4
	<i>Rabi</i>	2.7	56.1	4.1	45.8	11.4	20.9	26.5	7.5
Indo-Gangetic Plains	<i>Kharif</i>	0.9	68.1	25.8	5.8	22.9	10.3	9.1	32.4
	<i>Rabi</i>	2.4	52.7	9.5	29.6	10.4	26.7	21.2	10.7

DT: Decreasing trend; IT: Increasing trend;

time. Across IGP, 26% of NSA showed that *kharif* season was happening early but getting delayed in 6% of NSA. In *rabi* season, 10% of NSA was showing season starting early but getting delayed in 27% of NSA. On the average across IGP, *kharif* season was starting 15 days early, whereas start of *rabi* season was advancing by 25 days during 1982–2001 period.

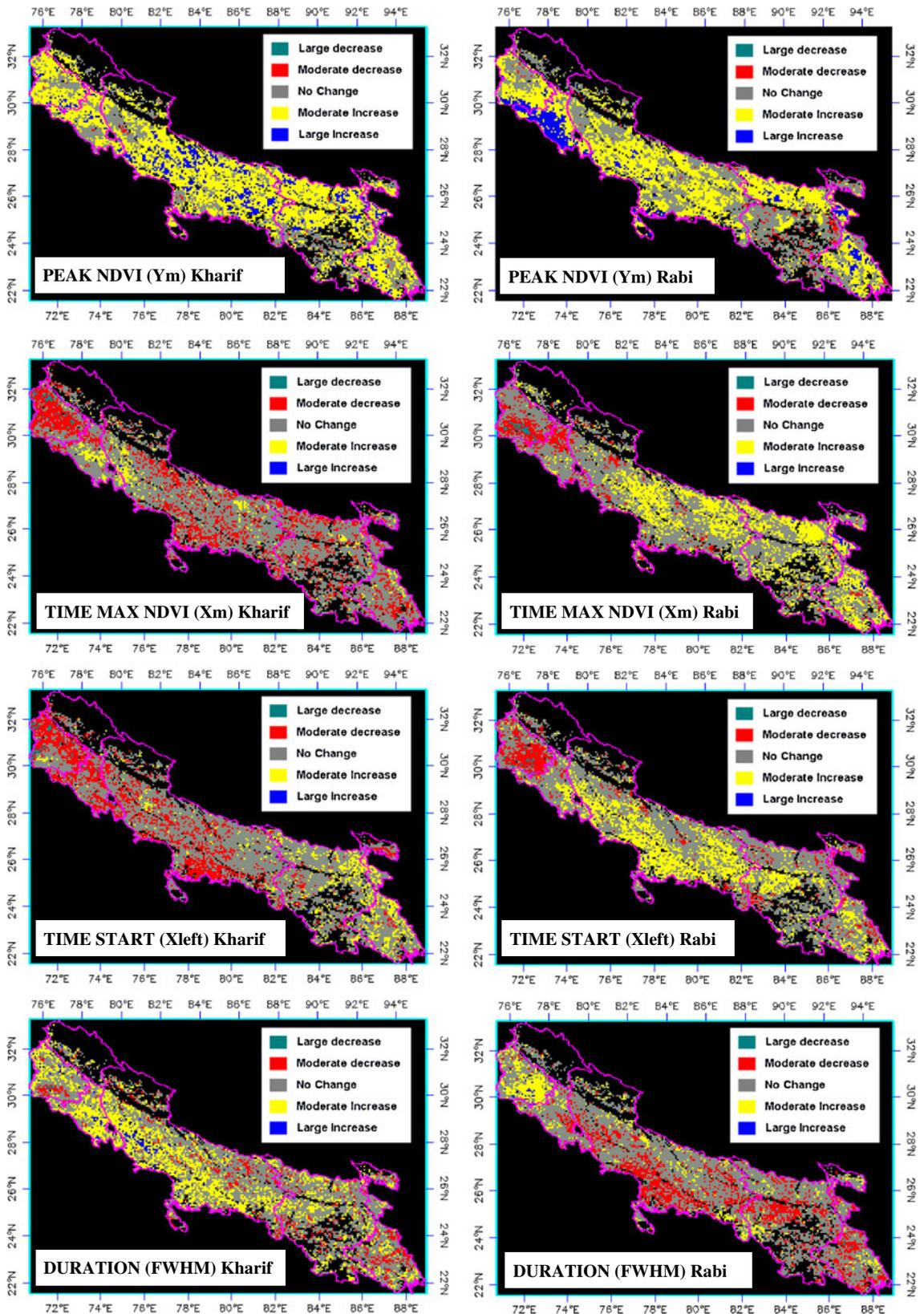
The duration of *kharif* season (FWHM) showed increasing trend across Punjab, Haryana, Western UP, Central UP and South Bihar whereas in some parts of South Punjab, North Bihar and West Bengal a decrease in the duration was also observed. During *rabi* season, except Punjab and some pockets of Haryana in Kurukshetra, Karnal and Bhiwani districts, the wheat dominating system showed a significant decreasing trend in crop duration. During *kharif*, 9% of NSA in IGP was showing decreasing trend and 32% of NSA was showing increasing trend in duration, whereas, during *rabi*, 21% of NSA was showing decreasing trend and 11% of NSA was showing increasing trend in duration. On the average across IGP, the duration of *kharif* season was increasing by 40 days whereas duration of *rabi* season was reducing by 24 days during the study period. The increase in *kharif* season duration may be mainly on account of increase in replacement of area under coarse rice varieties with *Basmati* (aromatic)

type varieties which have 30–40 days more long duration. The area showing decrease in *kharif* duration in Punjab mainly corresponds to cotton growing belt. During *rabi*, the decrease in duration may be caused by two factors: (a) late start of season to accommodate extended *kharif* season and which may also result in early end of season caused by higher temperatures during reproductive stage of crops, and/or (b) increase in temperatures due to climate change adversely affect the duration of crop (Aggarwal 2008). The area showing increase in *rabi* season duration is mainly concentrated in Punjab. It indicates that in Punjab the extended *kharif* season has not resulted in delay in start of *rabi* season. In that case, increase in *kharif* duration may be mainly on account of early start of season.

## Conclusions

The study presented a methodology of preprocessing of AVHRR-NDVI images, deriving season-wise various phenology metrics for croplands and generating

**Fig. 4** Maps showing trends in different crop phenology metrics for *kharif* and *rabi* seasons in Indo-Gangetic Plains of India



their trends during 1982–2001 period in IGP of India. Productivity of crops showed increasing trend throughout the IGP during both the seasons. The phenology metrics of time of start of season, time of peak vegetative stage and duration of season were showing significant trend (either increasing or decreasing) in about 40% of NSA.

In general, the *khari*f season dominated with rice showed an increase in duration which is the result of early start of season resulting in early occurrence of peak vegetative stage. In contrast, the *rabi* season showed a decrease in duration. It was due to clear delay in start of *rabi* season which was also resulting in delay in time of occurrence of peak vegetative stage. Exception is Punjab state where *rabi* season duration showed moderate increase and an early start of season with early happening of peak vegetative stage. These trends in phenology metrics are result of a complex interaction of changes in crop varieties with different durations, changes in production technology, especially those related to fertilizer and irrigation management and changes caused due to increasing temperatures on account of global warming.

This study demonstrates usefulness of multi-temporal satellite dataset for studying long term changes in agroecosystems with respect to deriving spatial patterns in trends of crop phenology metrics. Such spatial and temporal patterns are important source of information to study the impact of natural causes as well as anthropogenic interventions on agro-ecosystem in long run. Further, long term changes in climatic parameters can be related to spatial and temporal pattern of crop phenology to quantify the impact of climate change and variability on functioning of agro-ecosystem at regional scales.

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