



Monitoring Horizontal and Vertical Cropping Pattern and Dynamics in Bihar over a Decade (2001–2012) Based on Time-Series Satellite Data

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Abstract Increasing population and natural disasters like drought, flood, cyclone etc., has impacted global agriculture area and hence continuously modifying cropping pattern and associated statistics. The present study analysed agriculture dynamics over one of the densely populated and disaster prone state (Bihar) in India and derived vital statistics (single, double and triple cropping area, and monthly, seasonal, annual and long term status at the state and district level) for the years 2001–2012. The study used time-series MODIS vegetation index (EVI; MOD13A2, 1 km, 16 day, 2001–2012), MODIS annual Land Cover product (MCD12Q1, 500 m, 2001–2012) and Global Land Cover map (Scasia_V4, 1 km, 2000; Globcover_V2.2, 300 m, 2005/2006 and V2.3, 2009, 300 m), and extracted horizontal (i.e., area change) and vertical (i.e., cropping intensification) agriculture change pattern. The results were inter-compared, and validated using government reports as well as with high spatial resolution data (IRS-LISS III 23.5 m). From 2001–2006 to 2007–2012, the net horizontal and vertical change in agriculture area is +145.24 and +907.82 km², respectively, and net change in seasonal crop area (winter, summer and monsoon) is +959.21, +1009.84 and –1061.64 km², respectively. The districts which are located along the eastern part of Ganges

experienced maximum positive changes and the districts along Gandak river in the north-western part of the study area experienced maximum negative changes. Overall, the study has quantified and revealed interesting space–time agriculture change patterns over 12 years including impacts caused by droughts and floods in the study area.

Keywords MODIS EVI · Cropping pattern · Spatio-temporal change · Bihar · India

Introduction

Asia is the most populous continent, with its 4.2 billion peoples accounting for over 60 % of the world population which has crossed 7 billion in 2012, and supporting such huge amount of human's food requirement is a grand challenge of this century. Recent Food and Agriculture Organization (FAO) report on crop monitoring for improved food security (Srivastava 2015) stressed for adaptation of remote sensing based advanced crop monitoring by local governments in providing reliable agriculture statistics. With reference to the commitments made in World Food Summit (WFS 1996) and Millennium Development Goal (MDG 2000), FAO (2015) revealed that India didn't reach the target of cutting hunger by half in 2015 and number of people undernourished in India during 1990–1992, 2000–2002, 2005–2007, 2010–2012 and 2014–2016 are 210.1, 185.5, 233.8, 189.9 and 194.6 million, respectively. Crop diversification can help to improve soil fertility, crop productivity and income of the farmers, by improving soil health and to maintain dynamic equilibrium of the agro-ecosystem (GOI 2014). Only with the help of space based routine monitoring framework, in addition to traditional data collection, governments would

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equip themselves to accurately assess annual status, crop diversification scenario and associated impact from natural calamities so as to take viable alternative measures and policies to achieve MDG targets.

Globally, the arable land has not expanded in proportion with growing population. The arable land in the world was 1351 MHa (million hectares) in 1961–1963, 1506 MHa in 1997–1999, 1391.8 MHa in 2005 and 1380.5 MHa in 2008 (FAO 2001; WBD 2012). The population of the Indian subcontinent was about 125 million in 1750, reached 389 million in 1941 and today it is over 1.2 billion people (CIA 2012). According to government statistics, in 2003–2004 the total agricultural land in India was 183.19 MHa which shrunk to 182.39 MHa in 2008–2009. Bihar, Maharashtra, Uttar Pradesh, West Bengal, Andhra Pradesh and Madhya Pradesh states together contribute to half of the Indian population (Census of India 2011). Bihar is the second most populated state in India and it is highly prone to natural disasters like flood and drought. The economy of Bihar is mainly based on agriculture with 88.70 % of its population living in villages (Census of India 2011) and 81 % of the population is associated with agro based work contributing 42 % of GDP of the state (2004–2005) (GOB 2012). Its population in 2001 and 2011 were 82.99 and 103.8 Million respectively, and decadal population grew by 25.07 % (Census of India 2011) and net sown area in 2001–2002 and 2010–2011 were 56,640 and 52,590 sq. km respectively and it has decreased by 4.30 % (GOI 2015). It has been reported that the net sown area statistics from the government seems to be much lesser than the area reported from researchers (Biradar and Xiao 2011; NRSC 2014). Bihar is one of the few region in the globe where agriculture activities happen over three times in a year (i.e., Rabi or Winter Crop, Zaid or Summer Crop and Kharif or Monsoon crop), and hence up to date record of these cropping area require vast efforts from government. Also the state experiences frequent drought and floods affecting agriculture area invariably. But the annual net sown area estimated based on snap-shot remote sensing images does not reveal the real impact of flood and drought in this state. Though the high spatial resolution (HSR) satellite data gives more accurate ground depiction, its spatial coverage is less and their temporal resolution is very coarse, and it is frequently affected by cloud cover during monsoon season affecting the accuracy of area statistics. It would be very difficult to acquire, and time-consuming to analyse HSR data acquired over same time over a vast area like India (3.28 Million sq. km). Hence, an alternative approach utilising coarse spatial resolution data with high temporal resolution is adopted in this study as per the recommendation of FAO to scrutinize the exact state of the agriculture and its changing pattern in different months and seasons in Bihar, India.

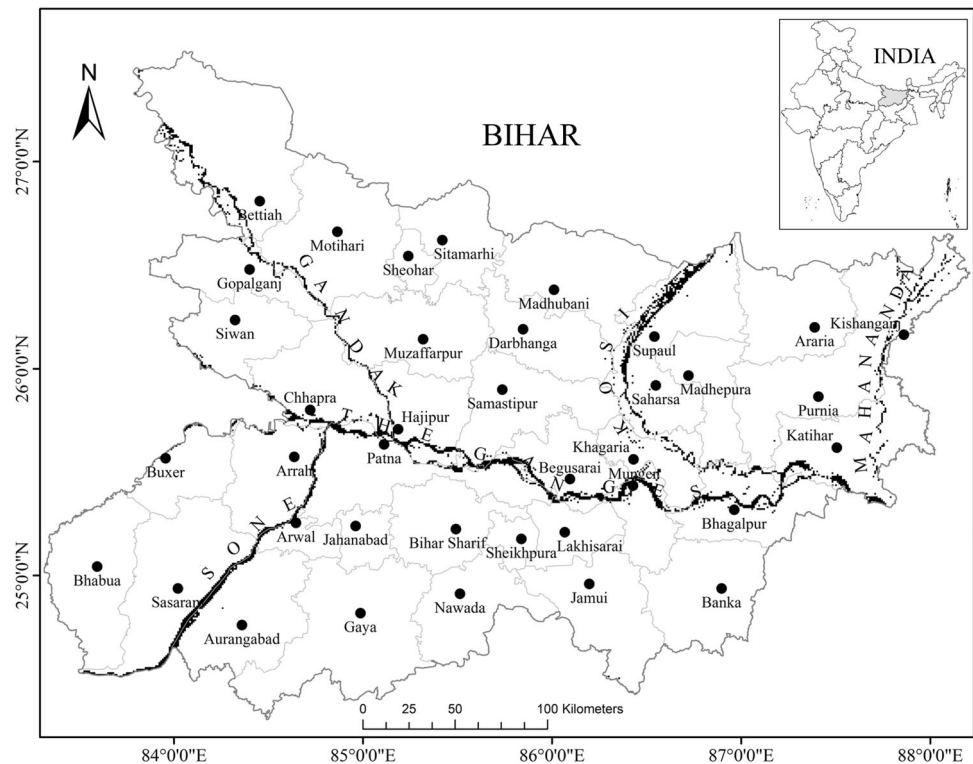
The synoptic and temporal availability of remote sensing data has played a vital role in analysing land cover patterns, extracting cropland area and cropping intensity (Panigrahy et al. 1992; Dash et al. 2010; Li et al. 2014; Sreenivas et al. 2014). Sreenivas et al. (2014) have given detailed description about remote sensing based agriculture information extraction attempts made by different researchers/organisations over the globe and India, and they have successfully utilised Advanced Wide Field Sensor (AWIFS; IRS-P6) temporal data (5 day interval; 56 m spatial resolution; 2005–2012) over full India and accurately quantified cropping pattern and its seasonal diversity mainly based on maximum-likelihood classification techniques along with expert rule-sets. The crops have their own phenological stages: onset, peak and senescence in a cropping season and using high temporal resolution and moderate spatial resolution satellite data it would be possible to detect different stages of agriculture growth (Xiao et al. 2003; Pandya et al. 2004; Sakamoto et al. 2005; Spera et al. 2014). In our study we wanted to mainly utilise automated seasonal crop area extraction approach based on crop-growth characteristics. In this regard, considering the repetivity, consistency and continuous availability, the Moderate Resolution Imaging Spectro-radiometer (MODIS) Terra sensor derived data and products were utilised in this study, for monitoring crop cycles and dynamics over larger area. In addition, the rapidly growing population, natural disasters and lack of knowledge about spatio-temporal dynamism in the agriculture sector in Bihar motivated the current research to study and quantify the changes in horizontal as well as vertical intensification of cropping pattern during 2001–2012.

Materials and Methods

Study Area

The study area Bihar state holds the most fertile agricultural lands of India geographically extending between 83°19'50"E to 88°17'40"E and 24°20'10"N to 27°31'15"N covering 94,163 sq. km area (Fig. 1). The Bihar state comprises of 38 administrative units called districts. The river Ganga divides the state in two halves at the middle flowing from west to east. Generally the northern side of Ganges is frequently inundated by flood and on the other hand southern region from Ganges is mainly affected by drought. In Bihar, 41 % cultivatable area is flood prone and another 40 % is drought prone (GOB 2014). As per government of Bihar flood report (DMD 2015) and drought report (DMD 2013) the state is frequently affected by flood and drought. The fertile agriculture lands in the study area extends from the foothills of the Himalayas in the north to

Fig. 1 Study area (Bihar State and its district's headquarters)



south of the river Ganges. Apart from Ganges, the state also has many important rivers like Kosi, Gandak, Sone, Mahananda, Bagmati and Burhi Gandak. Most of the rivers flow into the state from the Himalayan region. The temperature goes up to 44 °C in summer and falls to around 5 °C in winter. The annual rainfall of this region is about 1200 mm and 85 % of the rainfall occur during the month of June–October (Chowdary et al. 2008). Approximately 73–74 % of the geographical area of the state is under flood threats during monsoon period (NBSS&LUP 1997; Chowdary et al. 2008; Kumar et al. 2013).

Satellite Data

MODIS Land Cover data

MODIS Land Cover (LC) product MCD12Q1 is freely available on NASA LP DAAC website from 2001 to 2012 at 500 m spatial resolution (Source: http://reverb.echo.nasa.gov/reverb/#utf8=%E2%9C%93&spatial_map=satellite&spatial_type=rectangle&keywords=MCD12Q1&select ed=C200106111-LPDAAC_ECS). The IGBP classification scheme (Type 1) has been used in this data having 16 classes. The crop land class (class code 12) was extracted from this data for all the years to estimate horizontal areal extent. The detailed algorithm for generating this product can be seen in Friedl et al. (2010).

Globcover (GLC) Data

GLC (Scasia_V4, 1 km, 2000) Land Cover Map for Southern Asia for the Year 2000 was downloaded from the website of European Commission Joint Research Centre. This product was basically derived using SPOT VGT data based on hybrid classification scheme (Bartholome and Belward 2005). It has 47 land use and land cover classes. The four classes (class code 32: irrigated intensive agriculture, class code 33: irrigated agriculture, class code 34: slope agriculture and class code 35: rainfed agriculture) are grouped as agriculture class. The GlobCover 2005–2006 (V2.2, 300 m) and 2009 (V2.3) land cover maps were derived from MERIS sensor on board the ENVISAT satellite. These products were downloaded from the website of the European Space Agency (ESA). The GLC 2005/2006 and 2009 both have 22 classes. The two classes (class code 11: irrigated croplands and class code 14: rainfed croplands) were considered as agriculture class.

MODIS EVI Time-Series Data

The Terra's MODIS EVI time series data (MOD13A2) were downloaded from USGS's Science for a Changing World website during the period of 2001–2012 (Source: <https://lpdaac.usgs.gov/>). Equation (1) reveals EVI estimation procedure. EVI is less susceptible to background reflectance and atmospheric noise, and EVI has better

discriminating ability at higher vegetation density classes than NDVI (Didan et al. 2015).

$$EVI = G * \left(\frac{NIR - Red}{NIR + C1 * Red - C2 * Blue + L} \right) \quad (1)$$

where NIR, Red, and Blue are the full or partially atmospheric-corrected (for Rayleigh scattering and ozone absorption) surface reflectance bands; L is the canopy background adjustment factor (for correcting the nonlinear, differential NIR and red radiant transfer through a canopy); C1 and C2 are the aerosol correction coefficients; and G is a gain factor. The coefficients adopted for the MODIS EVI algorithm are, L = 1, C1 = 6, C2 = 7.5, and G = 2.5 (Didan et al. 2015). MOD13A2 is a level 3 data distributed as tiles covering 1200 × 1200 km having spatial resolution of 1 km and composited at every 16 days. Comparisons with AERONET-corrected data over a range of biomes and seasonality revealed that EVI data error is within ±0.010–0.015 and when the per-pixel quality information is uncertain the overall EVI errors increase to about 0.04–0.1 (VI units) (source: <http://landval.gsfc.nasa.gov/ProductStatus.php?ProductID=MOD13>).

Research Methods

The study utilised a 2-tier approach to extract agriculture areas over the study area (Fig. 2). At the first-tier, the study looked into the global products where agriculture information is already existing, such as MODIS LC, GLC and Globcover data sets. The agriculture related classes from these products were grouped and district-wise agriculture information was extracted for different time-periods. The limitation of these data products is that they could only reveal the horizontal cropping pattern, and vertical cropping pattern could not be revealed. In order to fill this gap, at the 2nd tier, the study did a detailed analysis over time-series EVI data. The EVI data is of 16 days composite and there are 23 layers (i.e., bands) in a year. A pixel having agriculture activity would have seasonal peaks and valleys as per the phenology on the ground. Figure 3 reveals a single, double and triple crop growing patterns at different sample pixels. A major problem in a time-series data is a temporal noises and dropouts. At first the dropouts were removed using mean value from reliable temporal neighbours, and outliers (greater than or less than annual mean ± 2σ) were eliminated using mean of reliable temporal neighbours. Finally the annual data was smoothed using Fourier smoothing procedure considering only initial four harmonics (Jeganathan et al. 2010a, b). The smoothed data was validated for its reliability at random locations for its truthful representation of the annual growth rhythms and its timings. The smoothed data was found to be reliable for

the requirement of the study. Next, the study extracted the timing of the Peak growing time at every pixel. To identify peak, first derivative information (i.e., current minus previous VI value) was calculated from the smoothed data and it was checked for its sign change. It was noticed that the timing of change of sign from positive to negative represent the timing of peak of the crop season. While identifying peak three important conditions were imposed to extract reliable peaks. The first condition was that the EVI value of the peak must be greater than 2500. The Second condition was that the amplitude of the peak must be greater than 350 and the third condition was that the gap between two peaks must be at least 3 months. These conditions helped to remove grass land, bushes, rivers and other unwanted non-agriculture pixels like wasteland area, and to circumvent minor undulations in the smoothed data. The forested area was masked based on IRS LISS III derived land cover data from National Remote Sensing Centre (NRSC 2006). Finally, annual/monthly agriculture area maps, annual net sown area and district-wise area statistics have been generated for the periods 2001–2012 (Fig. 2).

Extracting Vertical Intensification of Cropping Pattern

While analysing peak in a pixel, it was noticed that a pixel can have a maximum of 3 peaks in a year as per the cropping pattern i.e., Rabi, Zaid and Kharif. So the timing of the peak information is recorded in 3 separate bands. 1st band records the timing of first peak, 2nd band records timing of 2nd peak and similarly 3rd band records 3rd peak timing. In addition 4th band was also recorded to reveal total number of peaks in a pixel. The timing of the peak information was extracted at composite level and hence it could be temporally upscaled to monthly or seasonal level information so as to quantify the total crop growing ground area at different months/seasons in a year. Rabi crop is a winter crop which is primarily practiced during November/December to March/April (Prasad et al. 2007; Sehgal et al. 2013) in this region. While carrying out the annual analysis of the cropping season, Rabi cycle was observed in two parts. The first part of Rabi crop is from January to March and the second component is during second half of November to December in the same year. Zaid is a summer crop which is cultivated in this region during April to July between Rabi and Kharif crop seasons. The peaks occurring between April and July in a year is classified as Zaid crop in a particular year. Kharif crop is a rainfall dependent seasonal crop which is primarily cultivated during June to October/November in this region (Biradar and Xiao 2011; Sehgal et al. 2013). From the extracted information the study generated monthly and yearly pattern about single

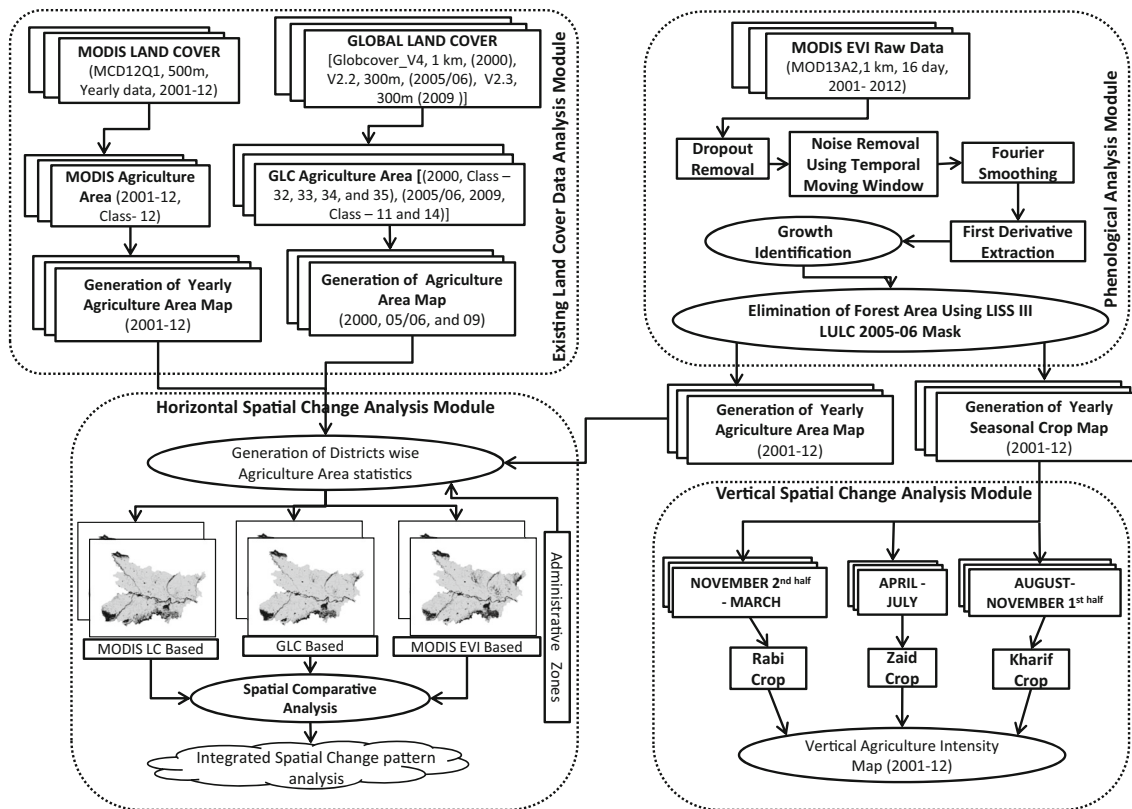


Fig. 2 Research methodology

crop, double crop and triple cropping maps. The districts wise crop area statistics was also generated for different cropping systems.

Comparative Study

Finally, the results from different data sets were compared. The comparative statistics have been generated on the basis of MODIS EVI (MOD13A2), MODIS LC annual product (MCD12Q1) during 2001 to 2012, GLC map (Scasia_V4, 1 km, 2000, Globcover_V2.2, 300 m, 2004/2006 and V2.3, 2009, 300 m), Government and NRSC reports.

Results and Discussion

Horizontal Spatial Extent of the Agriculture Area

At first the net sown area was estimated from the agriculture classes extracted from the already published land cover data products from MODIS LC, GLC 2000, Globcover 2005/2006 and 2009, and out of these data only MODIS LC data was found to be useful in extracting net-sown area on an annual basis continuously over 2001–2012. These results were used to cross check the net-sown area results derived from time-series EVI data. Based

on MODIS EVI data the horizontal and vertical cropping pattern in the study area was extracted and Fig. 4 reveals the spatio-temporal variations in the single, double and triple crop growing regions at every year over 2001–2012.

Table S1 reveals district-wise annual variations in the net sown area during 2001–2012. It was observed that out of 38 districts 11 districts have more than 98 % of their area under agriculture, and 32 districts have more than 80 % of area under agriculture. Only Kaimur and Munger districts have the lowest percentage of agriculture which is due to forest coverage under these districts. During 2001–2006 to 2007–2012, the net horizontal change in agriculture area observed from MODIS annual LC product and EVI data is +1092.38 and +145.24 sq. km, respectively, and the net changes in the single, double and triple crop area are –665.52, +858.59, –47.80 sq. km respectively. It is a very positive trend that amidst the growing population and natural calamities the state’s overall net sown did not reduce. The major altering forces in the study area is flood and drought, and the effect of drought can be seen in Fig. 4 where triple and double crop area was drastically reduced due to drought in 2006, and flood in 2007 mainly affected the double crop area (DMD 2013, 2015). Differences in the results from MODIS LC and EVI were scrutinised, and comparative analysis revealed that the MODIS LC based results matched with

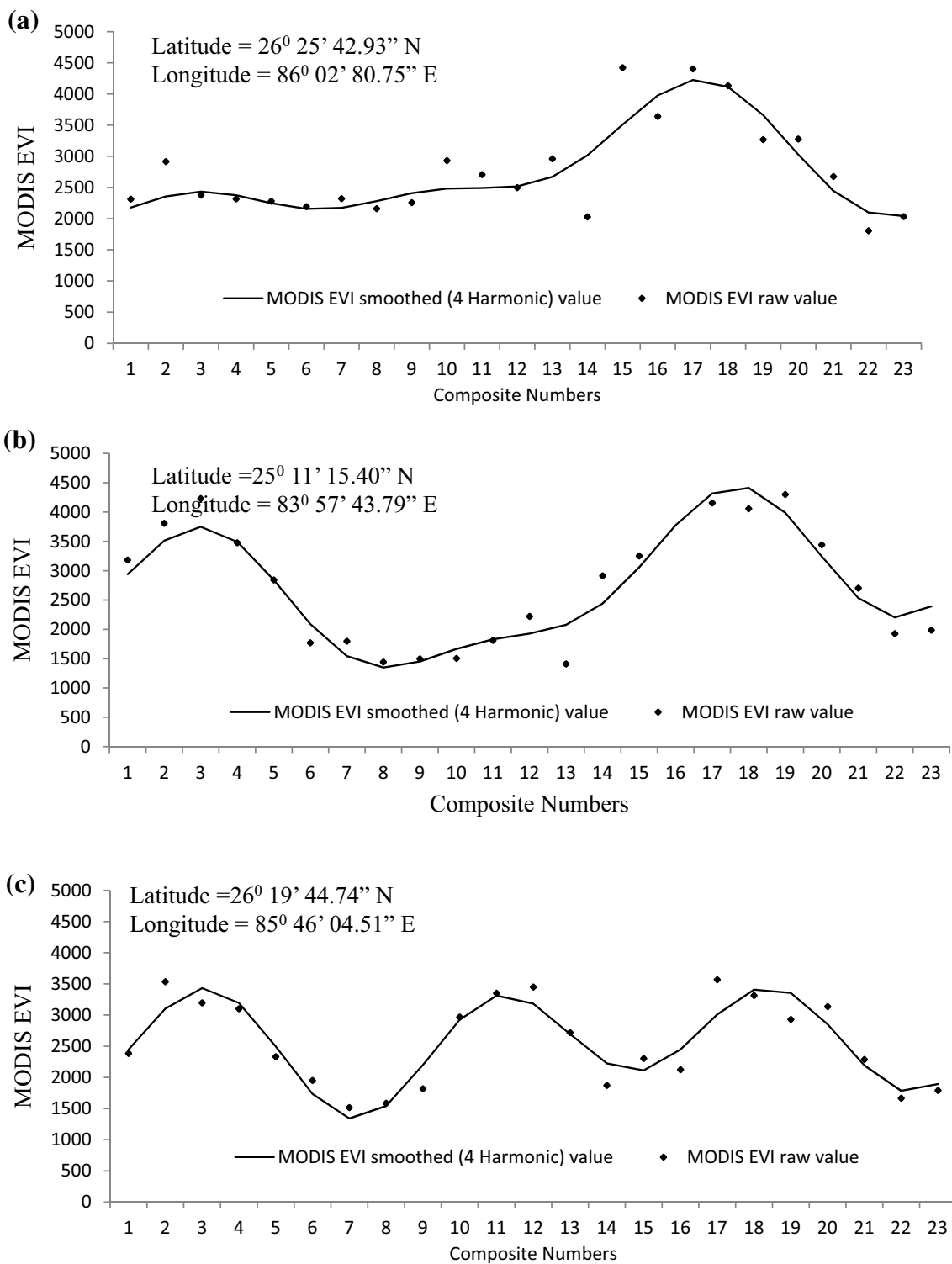


Fig. 3 Vertical cropping scenario in Bihar (raw and smoothed) as revealed in MDDIS EVI 2001 (MOD13A2) data for Single peak (a), Double peak (b) and Triple peak (c)

EVI results for most of the districts but exhibited high inconsistency in few districts like Kishanganj, Jamui and Nawada. Interestingly, Table S1 shows that the year 2007

(flood) and 2010 (drought) have higher net sown area of Bihar respect to other years revealing weakness of the annual statistics for the areas where more than one

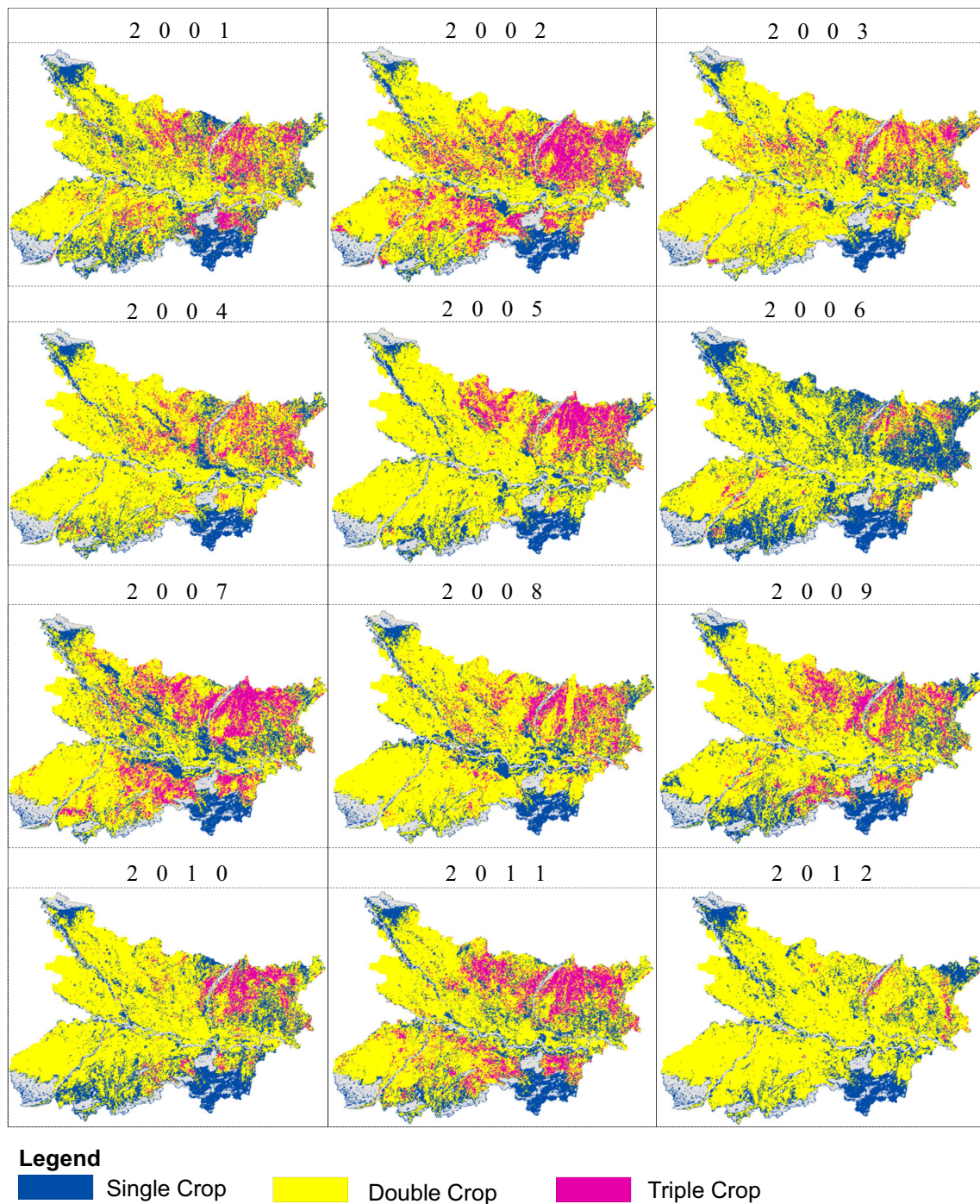


Fig. 4 Spatio-temporal distribution of vertical agricultural growth pattern in Bihar during 2001–2012

cropping pattern is followed. This is because the natural calamities would affect any one season, and net sown area estimation uses all the three season and hence the disaster effect is nullified from other season cropping area. The W. Champaran district in north western region and southern districts Munger, Kaimur, Rohtas, Jamui and Nawada had lower net sown area which is mainly due to forest cover in

these districts. Due to varying levels of water during monsoon in the major rivers of the state (like Ganges, Gandak, Kosi, Mahananda, Kamla and Balan) the districts over which these river flow get inundated invariably. The districts Vaishali, Katihar, Khagaria, Kishanganj and Munger fall victim frequently to the calamities of flood (DMD 2014, 2015).

Vertical Cropping Pattern

Annual variation in the vertical cropping pattern in Bihar at an annual scale can be seen in the Fig. 4, and at the monthly scale in Figs. 6, 7 and 8. The variations in the associated colours of single (Blue), double (Yellow) and triple (Magenta) cropped pixels in annual images (Fig. 4) depict fluctuating scenario of vertical intensification pattern in the region. Estimated net vertical change is $+907.82 \text{ km}^2$ based on time-series EVI analysis with individual seasonal changes during Rabi, Zaid and Kharif are $+959.21$, $+1009.84$ and -1061.64 km^2 respectively during 2001–2012 (Table 1).

It can be seen that the triple crop area is mainly situated in the north eastern part of the state mainly covering Bhagalpur, Kishanganj, Sitamarhi, Darbhanga, and Madhubani districts and the main reason for this is due to fertile soil and drainage system gifted by rivers like Kosi and Mahananda. These areas have good farming practices with good irrigation system (GOB 2015) which gives an opportunity for third crop during summer (Zaid). The districts Jamui, Banka and the some part of West Champaran districts are mainly single cropping areas which is due to hilly and sloppy topographical condition and usually Kharif crop is cultivated here.

Figure 5 reveals the state level variations in the cropping area during Rabi, Zaid and Kharif seasons, and over the northern and southern regions from Ganges. It was observed that average total area cropped during Rabi, Zaid and Kharif, during the last 12 years is 66.34, 19.68 and 79.74 % respectively (Fig. 5a). The seasonal (Rabi, Zaid and Kharif periods) crop area in the northern and southern regions are 43.16, 15.54, 45.65 % (Fig. 5b) and 28.71, 4.13, 34.09 % respectively (Fig. 5c). In the year 2001, the single, double, and triple crop occupied the ground area of 22.37, 58.13, and 10.02 % respectively. The year 2002 was found to have the maximum triple crop area (18.16 %) over the decade, and the years 2006 and 2012 had the least triple crop area (2.63 and 1.21 %, respectively). The year 2006 showed more of single crop area (33.59 %) but less of double (55.19 %) and triple crop (2.63 %) in the region in comparison to 12 years average from single (19.9 %), double (62.04 %) and triple (9.11 %) crop area. The decline was mainly observed in the Rabi crop due to complete absence of rainfall with dry cold spell during January to March period in 2006 which can be clearly seen in Fig. 5 (Source: <http://www.thehindu.com/todays-paper/tp-national/cold-wave-in-the-north-hits-crops/article3238599.ece>). The year 2008 had a major embankment breach in the Kosi River on 18th August 2008 and consecutive flooding of the region resulted in the loss of third crop (Kharif crop) with major impact in Madhepura and Supaul districts (Figs. 4, 8). The Kharif crop area was reduced to

45.76 and 64.09 % due to this breach in Madhepura and Supaul districts respectively in comparison to their 12 years mean (81.87 and 74.26 % respectively). The year 2012 revealed a major fall in the Zaid crop which was mainly due to consistent dry spells during April to August which resulted in second least triple crop period over the decade. The area occupied by single, double, and triple crop in 2012 is 18.39, 71.55, and 1.21 % respectively. Years 2001, 2006, 2009, 2010 and 2011 had revealed relatively less cropped area during Rabi (Fig. 5a) and we observed an interesting relationship with rainfall as in these years the winter months rainfall was very low (Table S4) (DSV 2014) in comparison to other years. In 2009 there was no bumper production in any season and hence there was overall decline which could be seen in Fig. 9c. These varying climatic impact on agriculture area was captured in the EVI based results (Fig. 5 and Table S4).

Figure 6 illustrates spatio-temporal distribution of peak growth period of Rabi crop in Bihar over 2001–2012. In a year, the first Rabi crop time span usually happens during January to March months and second Rabi crop period is during second half of November to December. It could be seen that the majority of the area attain peak growth in the month of February followed by January. The mean percentage of Rabi crop area in Bihar over 2001–2012 is 66.34 %. Whenever there is an absence of rainfall during winter, the agriculture production goes down which is clearly observed in our study as well. Due to relatively low/scanty winter rainfall in 2006, 2010, 2001, the Rabi crop area was affected badly and resulted in lowest area covering 57.86, 68.99, and 69.80 %, respectively, in comparison to years 2002, 2003, 2005, 2007 and 2008 which produced high Rabi crop covering 76.69, 76.66, 74.30, 75.33 and 77.29 % of area respectively. Majority of the districts revealed a positive growth during the later half of over a decade. The districts which exhibited highest positive change are Madhubani, Gaya, Darbhanga, Bhagalpur, Samastipur and Muzaffarpur ($+209.17$, $+174.62$, $+121.29$, $+117.66$, $+115.42$ and $+115.19 \text{ sq. km}$ respectively). The districts Purnia, Kishanganj, Araria, W. Champaran, and Madhepura had experienced a negative change during 2001–2006 to 2007–2012 with a decline in area -507.56 , -296.33 , -148.24 , -86.74 and -37.37 sq. km respectively.

Figure 7 illustrates spatio-temporal distribution of Zaid crop grown during the month of April to July. The Zaid crops are mainly grown in the Kosi and Mahananda river basins, and it occupied maximum area during the years 2001, 2002, 2007 and 2011 is 28.92, 29.18, 30.38 and 29.63 % respectively. As per the water resources department, eastern Kosi canal system has contributed for a well developed irrigation system (GOB 2015) and it is the primary cause of consistently higher Zaid cropping in this

Table 1 District-wise mean agriculture area (in %) (using MODIS EVI) in Bihar under different growth patterns (i.e., single, double and triple crop), and in different seasons (i.e., Rabi, Zaid and Kharif crop) during 2001–2006 and 2007–2012

Districts	Year																	
	Single			Double			Triple			Rabi			Zaid			Kharif		
	2001–2006	2007–2012	2001–2006	2007–2012	2001–2006	2007–2012	2001–2006	2007–2012	2001–2006	2007–2012	2001–2006	2007–2012	2001–2006	2007–2012	2001–2006	2007–2012		
W. Champaran	29.76	29.38	49.98	49.24	0.45	1.00	50.35	50.85	5.14	7.90	75.60	72.11						
E. Champaran	9.31	9.36	88.10	86.96	0.92	2.04	90.69	92.52	3.45	5.00	94.11	91.88						
Sitamarhi	10.01	7.68	80.09	76.47	9.67	15.71	91.26	93.76	11.96	19.39	95.97	94.61						
Madhubani	20.50	12.82	62.03	66.18	16.96	20.68	78.99	86.68	23.39	25.76	93.06	94.79						
Gopalganj	10.24	8.62	85.23	87.02	1.89	0.88	88.65	89.56	8.77	5.47	88.96	90.27						
Sheohar	11.37	7.99	77.41	78.88	10.27	12.79	90.47	92.99	14.98	16.14	91.57	94.98						
Araria	12.08	10.85	52.28	48.86	35.63	40.29	85.58	83.09	56.16	61.07	81.80	85.28						
Supaul	10.39	10.70	38.64	35.47	40.89	43.55	78.05	77.92	56.88	61.27	75.41	73.11						
Kishanganj	34.84	34.68	40.81	49.89	21.19	12.55	34.84	20.44	55.94	59.65	89.23	92.02						
Darbhanga	14.56	9.86	69.07	70.03	16.17	19.99	88.70	94.03	30.41	36.27	82.09	79.60						
Muzaffarpur	17.17	17.05	70.44	73.64	10.93	7.67	85.90	89.07	20.61	16.68	84.36	81.59						
Siwan	7.00	5.64	88.72	91.40	2.38	0.66	92.68	94.80	5.62	1.82	93.28	93.81						
Saran	11.33	12.90	77.46	78.84	4.02	1.62	87.17	88.86	12.65	6.99	78.49	79.56						
Purnia	24.95	26.34	51.79	56.32	22.20	16.57	65.51	52.87	52.18	55.19	77.45	80.61						
Madhepura	15.77	14.85	53.64	57.89	30.06	26.69	74.63	74.11	53.97	57.47	84.61	79.12						
Samastipur	16.88	17.59	72.42	75.78	8.56	4.65	90.05	92.50	24.68	19.41	72.68	71.20						
Saharsa	18.14	15.74	53.61	57.62	23.00	21.68	65.52	69.67	48.56	46.86	80.28	79.49						
Vaishali	15.27	15.83	70.19	70.64	6.48	5.50	80.50	84.44	15.99	15.89	78.58	73.27						
Katihar	31.58	27.00	48.58	56.85	12.33	9.81	47.50	48.89	56.66	53.58	61.53	67.61						
Begusarai	10.54	14.78	81.16	76.91	0.42	0.23	86.14	87.15	10.78	11.21	77.21	70.94						
Buxar	6.19	5.14	89.82	91.56	1.93	1.31	94.04	96.18	3.76	2.80	93.82	93.20						
Bhojpur	7.96	8.57	84.29	86.58	4.97	2.48	92.53	94.66	8.14	5.16	90.76	89.36						
Patna	13.87	17.63	72.83	69.00	5.11	5.12	86.90	86.79	9.31	11.66	78.64	72.53						
Khagaria	23.13	24.98	69.61	71.12	3.36	1.62	86.47	90.79	28.14	23.82	57.82	57.48						
Bhagalpur	22.41	23.70	62.33	59.93	6.70	8.19	73.48	75.62	31.31	32.71	62.37	59.79						
Munger	19.47	23.68	35.77	34.60	9.72	8.41	50.04	53.35	19.22	16.11	50.92	48.62						
Nalanda	8.51	9.75	77.98	76.66	11.02	11.11	93.58	94.19	14.08	16.40	89.89	85.83						
Bhabua	12.49	12.51	52.97	53.36	1.10	0.67	54.72	55.67	1.34	1.07	65.64	64.51						
Rohtas	8.03	7.84	67.04	68.66	1.79	0.65	69.21	69.68	2.27	1.05	75.98	76.40						
Lakhisarai	24.96	22.99	52.64	53.18	8.86	10.56	73.78	75.75	13.52	18.48	69.49	66.82						
Jehanabad	12.03	12.07	78.08	82.14	9.44	5.24	89.80	90.06	13.57	11.49	93.12	90.51						
Sheikhpura	17.65	12.63	74.31	68.15	7.59	19.20	86.03	91.36	11.17	26.96	91.83	88.20						

Table 1 continued

Districts	Year																	
	Single			Double			Triple			Rabi			Zaid			Kharif		
	2001–2006	2007–2012	2001–2006	2007–2012	2001–2006	2007–2012	2001–2006	2007–2012	2001–2006	2007–2012	2001–2006	2007–2012	2001–2006	2007–2012	2001–2006	2007–2012		
Jamui	62.90	62.07	14.20	13.46	2.27	4.08	15.84	16.76	5.64	8.48	76.63	75.97						
Aurangabad	24.26	22.97	63.39	64.74	3.16	3.92	68.41	69.49	4.94	6.38	87.13	88.30						
Banka	56.66	55.80	26.76	26.80	6.16	7.39	31.12	32.95	9.66	10.52	87.87	88.10						
Nawada	18.24	15.94	53.95	50.86	7.77	13.10	63.83	66.23	9.89	22.68	75.72	68.05						
Gaya	32.06	28.50	49.45	52.26	1.87	2.43	53.95	56.77	3.44	5.43	79.17	78.10						
Arwal	6.26	8.04	83.69	82.15	4.27	4.60	89.01	89.06	5.47	6.26	91.96	90.83						

region compared to other areas of the study region. The north-eastern districts Araria, Supaul, Kishanganj, Purnia, Madhepura, Saharsa, and Katihar produced more Zaid crops and in the south, the districts Sheikhpura, Nalanda, Lakhisarai, Nawada, and Bhagalpur produced Zaid crop especially in the years 2001, 2002, 2007, 2009, 2010 and 2011. The main peak growing period of Zaid crop is in the month of June and July. In the year 2004 and 2012 the Zaid peak was found in the month of April and May. The year 2012 resulted in the lowest Zaid crop scenario (5.27 % of area) in comparison to 12 years average (19.68 %). As per government of India report (GOI 2012) the entire state (Bihar) faced the worst drought condition with scanty rainfall condition during June and July 2012 as compared to normal monsoon year of 2011.

Figure 8 illustrates spatio-temporal distribution of Kharif crop in the study region grown mainly during August to first half of November month. The colours associated with each month in the annual figures show variation in peak growing period of Kharif crop over the decade. It was found that the majority of peak growth during Kharif crop happened in the months of September and October. The year 2001 and 2007 produced low Kharif crop area respectively 70.01 and 72.72 % as compared to 12 years average (79.74 %). In the year 2008, due to the Kosi embankment breach (DMD 2009) and consecutive flooding in this region destroyed the Kharif crop. It is clearly depicted in the Fig. 8. Interestingly the inundation and impact due to flood in the year 2007 was much higher than the kosi embankment breach effect. Hence, in the Fig. 5b the reduction in the percentage of Kharif crop during 2007 is higher than 2008. About 5 districts of Kosi fan region was mainly affected in 2008 but in the year 2007 approximately 262 blocks were inundated by flood (DMD 2014). As per government flood report (DMD 2014) approximately 153 blocks were inundated by flood in the Year 2001 during monsoon which affected Kharif crops, and at the same year there was rainfall deficiency induced decline in the Rabi crop area as well (DMD 2013). The districts Khagaria, Samastipur, Begusarai, Muzaffarpur, Darbhanga, W. Champaran, and E. Champaran produced low Kharif crop area in the year 2007 because of flood (DMD 2014) which is clearly visible in the Fig. 8. In 2011, the districts Bhojpur, Patna and Bhagalpur produced low Kharif crop area due to flood in the Ganges (DMD 2013, 2014, 2015).

Discussion

Table 2 reveals the district-wise monthly mean percentage of peak crop growing area estimated using MODIS EVI time series data in Bihar. It could be inferred that the

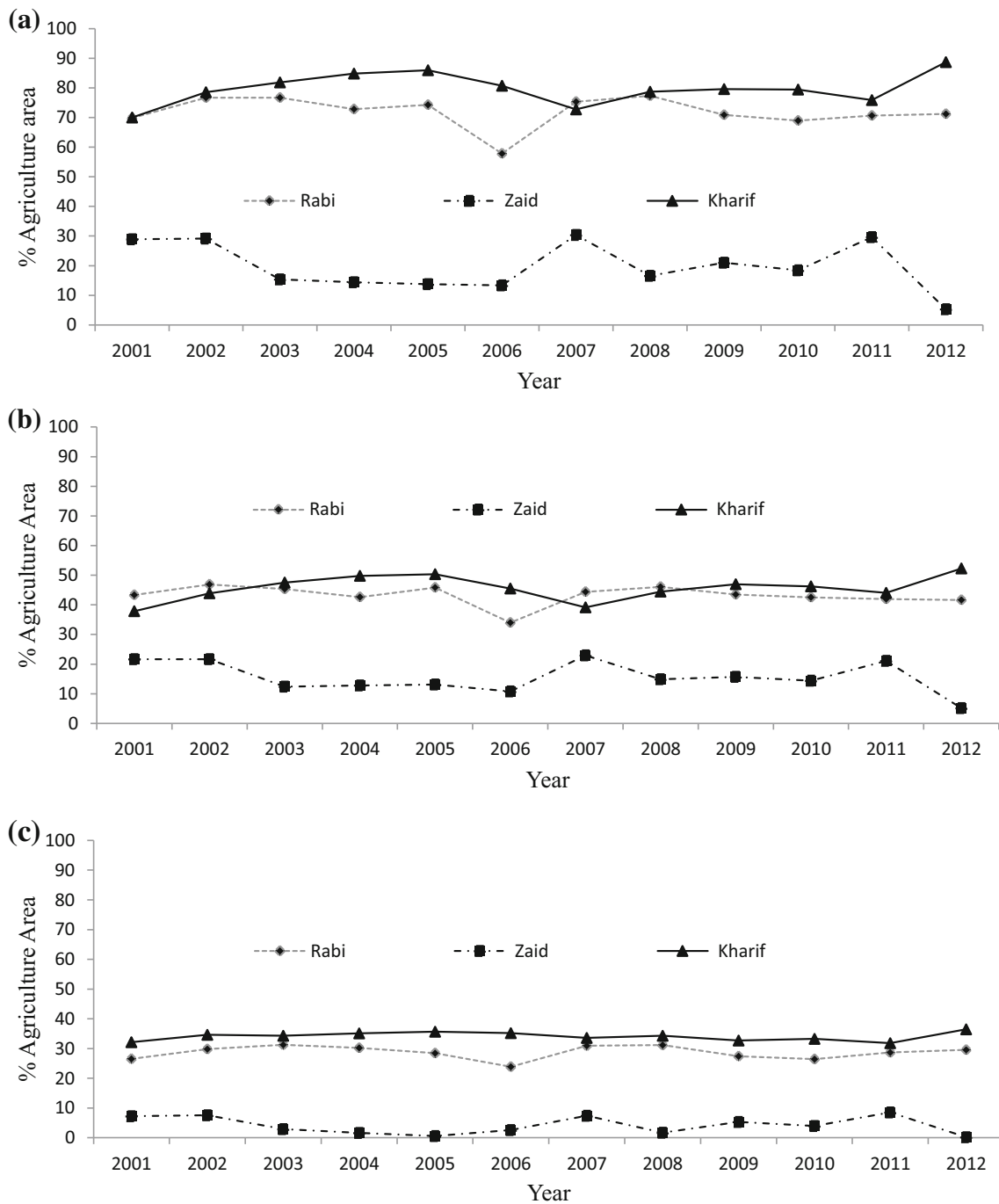


Fig. 5 Annual temporal variation in the % agriculture area of Rabi, Zaid and Kharif crop based on MODIS EVI time series (MOD13A2, 1 km, 16 days composite) data during 2001 to 2012 of Entire Bihar (a), Northern districts from Ganges (b), and Southern districts from Ganges (c)

important months for identifying major extent of crop growth in Bihar are September (39.07 %), October (30.73 %) (for Kharif crop), February (60.12 %) (for Rabi crop), and May (10.30 %) (for Zaid crop). Table 2 would be very helpful in selecting a temporal window for carrying out further studies using very high spatial resolution data.

In the years 2001, 2007 and 2011, Zaid crop area was higher than the other years and interestingly the Kharif

crop extent was the lowest in the same years. The reason for this peculiar results could be due to the good summer rainfall during May/June (Table S3) (DSV, 2014), and unexpected floods during monsoon which could be easily seen in the Figs. 5 and 8. In the year 2007 (Fig. 8) the state experienced a worst flood and approximately 262 blocks in the northern districts were inundated (DMD 2014). District-wise agriculture changes in the growing areas during

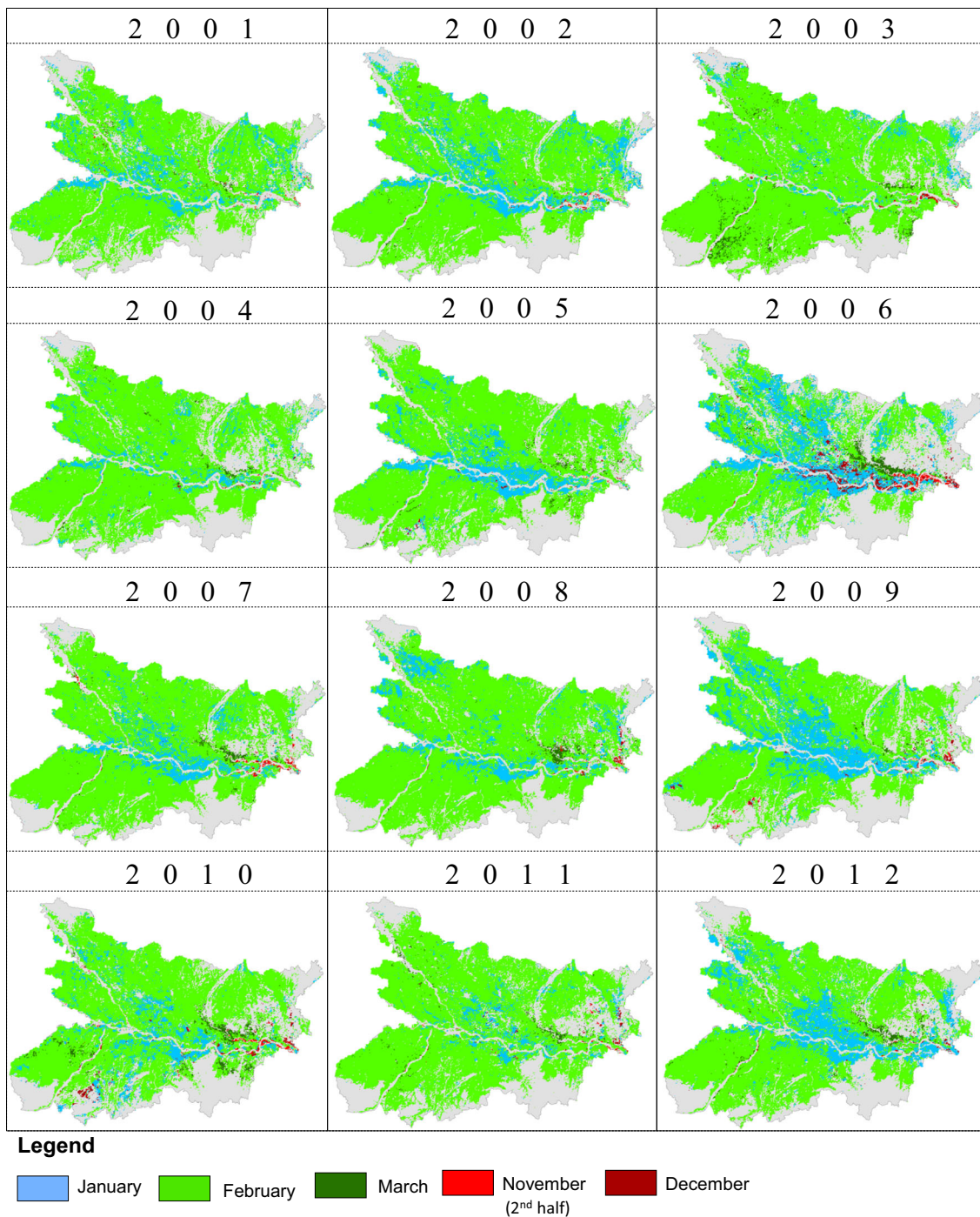


Fig. 6 Spatio-temporal distribution of Rabi crop (2nd half of November to March) in Bihar during 2001–2012

the years 2001–2006 to 2007–2012 was carried out in terms of single, double and triple crops and seasonal crops (Table 1) were estimated. On an average the net single crop area has decreased by 0.71 %, double crop area has increased by 0.91 % and triple crop area has decreased by 0.05 % during the second half (i.e., 2007–2012) compared to first half (i.e., 2001–2006).

The area estimated using MODIS EVI was compared with net sown area extracted from GLC and MODIS LC data sets for the years 2001 (Fig. 9a), 2005 (Fig. 9b) and 2009 (Fig. 9c). The results matched for most of the district and for few districts there was a major difference. For example, in Fig. 9a–c for Jamui district the MODIS EVI estimate was higher than results from GLC and LC. When

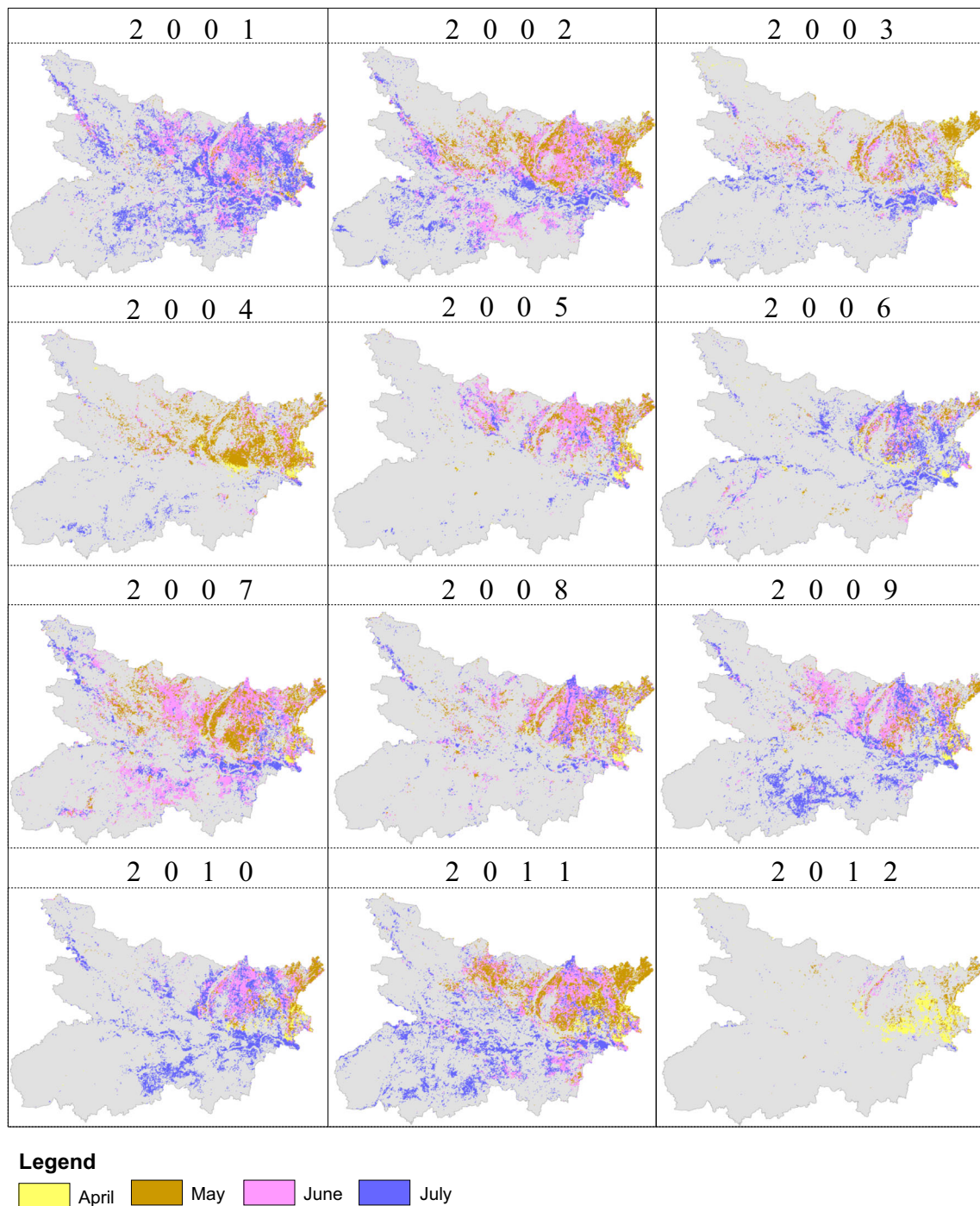


Fig. 7 Spatio-temporal distribution of Zaid crop (April to July) in Bihar during 2001–2012

the district was analysed with rainfall, flood and other government reports (DMD 2013, 2014, 2015) it was found that there is an inconsistency in the MODIS LC data. The net sown area from MODIS LC for the Jamui district for the years 2001, 2005 and 2009 is 51, 46 and 64 % respectively, and the results from EVI based analysis is 79.21, 79.46 and 79.60 % respectively. Year 2005 was a bumper year for Kharif and Rabi crops (better than 2001 crop area) but

MODIS LC based net sown area was found to be the lower than our estimates. It was not possible in this study to analyse the exact cause behind the in-accuracy of MODIS LC and GLC products. In Kishanganj and Nawada districts also there was a discrepancy between EVI and MODIS LC results, but GLC results matched with EVI (Fig. 9).

The EVI based net sown area results were cross checked with Government reports (DES 2014) and the comparison

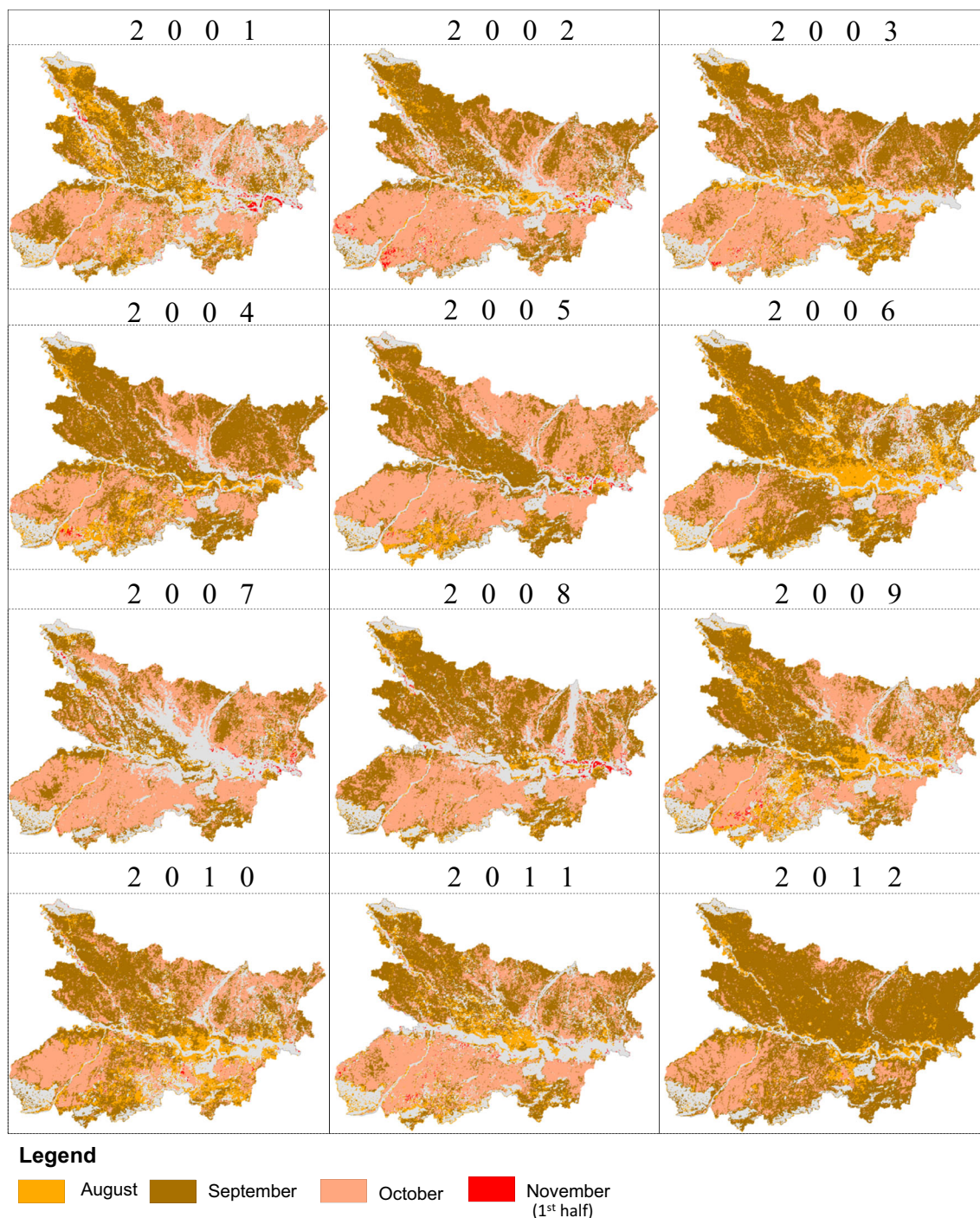


Fig. 8 Spatio-temporal distribution of Kharif crop (August to 1st half of November) in Bihar during 2001–2012

for the years 2008/2009 and 2009/2010 was carried out. The net sown area estimates from Government report is consistently less for both the years. There are two possible reasons. One could be due to coarse spatial resolution of the data used in this study where sub-pixel mixing of land cover like plantations, wasteland along with agriculture area could have contributed for over estimates in our study. Second reason could be due to gap in the government data

collecting mechanism as the procedure adopted by the government is not clearly available to public. Also it was observed that the estimates revealed in the reports from different government departments do not match. For example, report of the state of environment (GOB 2007) published by the government of Bihar is different from Directorate of Economics and Statistics (DES). GOB (2007) revealed the net sown area in Gopalganj, Saran, and

Table 2 Monthly mean peak crop area (in %) extracted using MODIS EVI time series data (2001–2012) over Bihar

Districts	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
W. Champaran	8.85	41.01	0.63	0.20	0.28	1.28	4.76	12.81	55.83	4.95	0.31	0.05
E. Champaran	12.51	78.00	0.96	0.08	0.80	1.37	1.98	6.49	73.54	12.79	0.23	0.08
Sitamarhi	5.17	87.16	0.16	0.05	4.46	8.23	2.94	3.16	56.45	35.58	0.09	0.02
Madhubani	4.28	78.45	0.10	0.10	6.58	13.44	4.45	2.19	46.46	45.13	0.15	0.01
Gopalganj	14.78	73.43	0.80	0.01	0.47	2.90	3.74	7.66	74.26	7.34	0.43	0.01
Sheohar	5.19	86.42	0.11	0.12	3.92	7.48	4.04	2.50	62.64	28.02	0.11	0.01
Araria	6.05	78.09	0.18	1.27	14.34	28.86	14.14	1.81	45.30	36.40	0.03	0.00
Supaul	10.13	67.81	0.03	0.11	16.57	32.21	10.18	1.73	39.91	32.61	0.01	0.01
Kishanganj	6.71	20.90	0.03	2.39	37.75	13.87	3.78	1.82	61.63	27.14	0.05	0.00
Darbhanga	10.26	80.59	0.42	0.51	9.34	16.17	7.32	3.52	39.65	37.38	0.31	0.08
Muzaffarpur	16.38	70.64	0.35	0.05	6.63	6.86	5.10	6.44	60.21	16.19	0.16	0.09
Siwan	10.98	82.11	0.56	0.02	0.31	1.45	1.94	5.63	69.73	18.09	0.15	0.05
Saran	14.05	72.96	0.70	0.01	0.45	3.04	6.31	8.02	52.64	18.09	0.39	0.20
Purnia	8.91	47.03	2.22	5.15	17.61	16.68	14.23	7.23	46.89	24.58	0.65	0.73
Madhepura	4.88	64.87	4.42	2.75	16.07	26.92	9.98	2.79	43.53	35.17	0.50	0.07
Samastipur	25.23	63.62	1.53	0.44	5.08	8.17	8.36	12.82	47.18	11.80	0.18	0.87
Saharsa	3.18	59.78	4.58	1.45	17.99	19.58	8.70	2.70	38.47	38.12	0.63	0.01
Vaishali	29.69	52.27	0.16	0.04	4.19	4.93	6.79	13.40	53.39	9.02	0.20	0.27
Katihar	8.65	32.89	2.11	9.76	13.49	13.90	17.96	10.08	33.25	18.79	4.62	2.36
Begusarai	37.88	46.33	0.12	0.01	0.30	1.64	9.05	35.24	36.94	1.74	0.22	2.24
Buxar	6.44	87.64	0.92	0.00	0.03	0.42	2.83	5.84	29.35	58.22	0.12	0.09
Bhojpur	14.35	77.81	1.27	0.00	0.11	1.18	5.36	6.75	24.43	58.72	0.23	0.10
Patna	20.27	65.24	0.43	0.14	0.66	2.80	6.89	8.09	25.26	41.93	0.42	0.78
Khagaria	20.24	55.20	11.89	2.68	3.52	4.94	14.83	24.51	22.21	10.14	1.02	1.06
Bhagalpur	17.35	51.08	1.97	0.20	1.23	7.10	23.48	18.18	16.13	23.61	5.61	1.70
Munger	12.06	37.40	0.80	0.03	0.63	6.75	10.25	9.29	11.49	28.68	0.63	1.12
Nalanda	10.67	82.99	0.16	0.01	0.66	5.91	8.65	7.15	24.96	55.63	0.12	0.06
Kaimur	1.18	53.59	0.28	0.00	0.01	0.16	1.03	6.01	16.05	42.61	0.42	0.14
Rohtas	0.49	68.27	0.53	0.00	0.03	0.33	1.30	4.35	20.30	51.48	0.08	0.13
Lakhisarai	25.55	47.15	0.88	0.01	0.19	5.53	10.28	15.22	16.66	35.84	0.50	1.13
Jehanabad	2.82	86.93	0.14	0.00	0.00	2.21	10.32	8.12	20.90	62.70	0.09	0.03
Sheikhpura	8.17	80.37	0.08	0.00	0.54	6.51	12.02	10.78	20.80	58.20	0.24	0.07
Jamui	0.52	15.58	0.17	0.00	0.22	2.15	4.69	11.85	41.99	22.39	0.09	0.02
Aurangabad	1.54	64.11	2.35	0.02	0.29	1.15	4.20	9.65	10.06	65.99	2.25	0.72
Banka	0.07	30.78	1.19	0.00	0.62	4.68	4.79	8.75	38.77	40.42	0.05	0.00
Nawada	1.61	63.31	0.09	0.00	0.09	4.43	11.76	6.65	18.46	46.58	0.20	0.02
Gaya	3.09	51.60	0.35	0.00	0.02	0.54	3.87	15.39	28.66	34.19	0.43	0.28
Arwal	1.42	86.25	0.83	0.00	0.09	1.17	4.59	4.32	12.49	74.16	0.50	0.47

Siwan as 98 %, in Sitamarhi, Seohar, Muzaffarpur and Vaishali districts as 95 %, in Darbhanga, Madhubani, and Samastipur as 87 %, and in Aurangabad, Gaya, and Jehanabad as 86.7 % and in East and West Champaran as 84 %. These statistics matched closely with our MODIS EVI based results (Table S1). The uniform extraction approach followed in this study would help in deriving consistent crop area estimates. Through this approach

timing and intensity of agriculture growth at every pixel at a monthly and annual scale could be extracted in a consistent manner.

Finally, district-wise comparative statistics with respect to high spatial resolution satellite (IRS LISS III) derived net sown area (NRSC 2014) of Bihar was carried out for the year 2011/2012. The LISS-III based land cover statistics was downloaded from the Bhuvan website of National

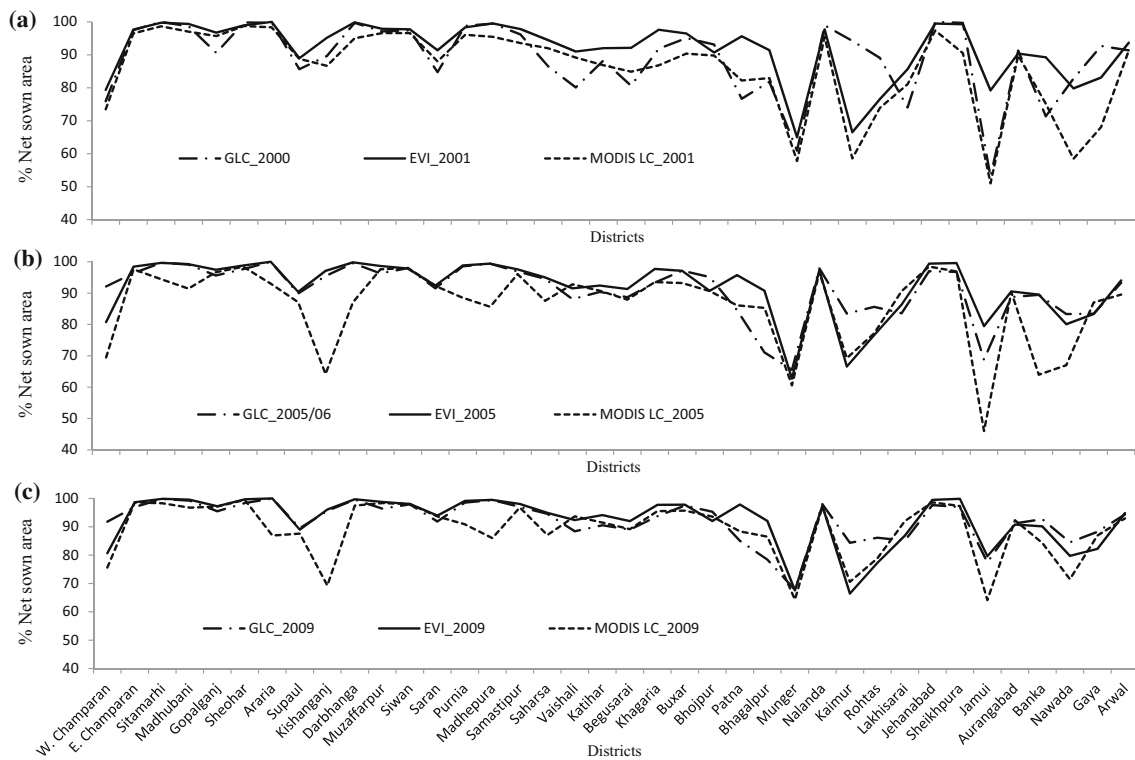


Fig. 9 Inter-comparison of net sown area extracted from GLC (1 km (GLC 2000) and 300 m), MODIS LC (500 m) and MODIS EVI (1 km) at different temporal periods. **a** during 2000/2001 **b** during 2005/2006 and **c** during 2009

Remote Sensing Centre (Bhuvan.nrsc.gov.in). The LISS III data of the month October/November (Kharif season) of year 2011, January/February/March (Rabi season) of the year 2012 and April/May (Zaid season) of the year 2012 was used in their study. The sub class plantation was considered as net sown area and the results were closely matching with results of this study. The difference may be due to three possibilities. First possibility is that spatial resolution of LISS III is 23.5 m and EVI data was at 1 km. Second possibility could be due to the difference in the interpretation methods and the third possibility due to consideration of timing of data. NRSC's statistics was based on visual interpretation where few snapshot images were used for different seasons and exact date/months of satellite images used for their interpretation was not revealed in their report. This has implications in our results as every district has multiple timings for peak growth (Table 2). For example, in Table S2, both the LISS III and EVI results for district E. Champaran would have matched if January month data was not considered in the EVI based approach. Similarly district Kishanganj results would not have matched if the September data was not considered. The comparison with LISS III addressed an importance of using time-series data in revealing sensitivity of the timing of data acquisition in the crop area estimates. Table S2 provided different combination of results considering various possibilities of omission/commission of 1 month data.

The total agriculture area estimated from NRSC was 70.89 % and the closest match from EVI was 74.65 % (without October). Overall, the months October and February has strong influence over the net sown area in MODIS EVI data. Especially when a pixel has 3 cropping cycles then much care is required for date of acquisition in the high spatial resolution data for crop area interpretation.

One important limitation in this study is the spatial resolution of the time-series EVI data. It is possible that overestimates in agriculture area due to settlement and other non-agri feature could be avoided using finer spatial resolution data (Forkuor and Cofie 2011). However processing such data is time-consuming and costly, and did not result in significant difference in the area statistics (refer Table S2). Due to the coarseness of the data, some of the fertile districts (e.g., Sheohar, Araria and Sheikhpura) were found to possess 100 % net sown area (refer Table S1) which is mainly due to lower density levels of settlements and non-agriculture features such as barren land, river and water bodies.

Conclusions

The study used various satellite derived data and products like time-series MODIS vegetation index (EVI; MOD13A2, 1 km, 16 day, 2001–2012), MODIS annual

Land Cover product (MCD12Q1, 500 m, 2001–2012) and Global Land Cover map (Scasia_V4, 1 km, 2000; Globcover_V2.2, 300 m, 2005/06 and V2.3, 2009, 300 m), and extracted horizontal (i.e., area change) and vertical (i.e., cropping intensification) agriculture change pattern. The results were inter-compared, and cross checked with government reports as well as with high spatial resolution data (IRS-LISS III 23.5 m). This study revealed the importance of time series satellite data analysis for extracting seasonal crop condition, extent and timing. It has extracted and quantified single, double and triple cropping cycles at monthly and annual scales. The average area (2001–2012) cropped under (a) single, double and triple cropping pattern is 19.90, 62.04 and 9.11 %, respectively; (b) under Rabi (winter), Zaid (summer) and Kharif (monsoon) season is 66.34, 19.68 and 79.74 %, respectively; and (c) during 12 different months (January to December) is 9.87, 60.12, 1.25, 0.82, 10.30, 7.20, 7.27, 9.04, 39.07, 30.73, 0.64, 0.40 % respectively. The effect of coarseness of the spatial resolution on the area estimate will be taken up in the future studies. Areal extent and spatio-temporal variations of impact on the cropping pattern due to flood and drought was spatially well revealed in this study, and results were synchronous in reflecting the effect of climatic extremes such as drought and flood. The average net sown area is 91.28 % in Bihar during 2001–2012 with 0.04 % positive growth rate. Considering the population growth the agriculture growth rate is very less and the government need to put emphasis on the vertical intensification of the cropping in the region as the area is already cropped to its maximum horizontal extent. There is a huge potential to increase the Zaid and Rabi cropping cycles in the study region.

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