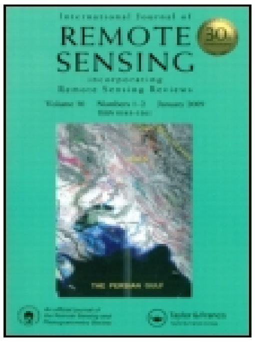

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Satellite imagery and household survey for tracking chickpea adoption in Andhra Pradesh, India

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ABSTRACT

The objective of this study was to map the temporal changes in chickpea cropped area over the last decade in Andhra Pradesh using remote-sensing imagery. Moderate Resolution Imaging Spectroradiometer (MODIS) data composited for every 16 days were used to map the spatial distribution of seasonal crop extent in Andhra Pradesh. MODIS derived 16 day normalized difference vegetation index (NDVI) and maximum value composite (MVC) with seasonal ground survey information for the years 2005–2006 and 2012–2013 were used. A subset of ground survey information was also used to assess the pixel-based accuracies of the MODIS-derived major cropland extent. Chickpea-growing areas were identified and mapped based on their characteristic growing periods during the post-rainy season. Significant growth in the chickpea-growing areas was observed in the four districts of Andhra Pradesh between 2001 and 2012. The area cropped to chickpea almost tripled from 0.22 million ha during 2000–2001 to 0.6 million ha by 2012–2013. Furthermore, survey data were also used to assess the accuracy of the MODIS estimates of chickpea-growing areas. When compared with ground survey, the 10 land-use and land-cover classes derived from the MODIS temporal imagery resulted in overall accuracies of 86% of actual. The accuracy of areas identified as cropped to chickpea was 94%. To complement this remote-sensing study, a state-level representative primary household survey was conducted to elicit information on the socio-economic characteristics of chickpea-growing farmers, the extent of adoption of improved cultivars, costs and returns from chickpea cultivation, competitiveness of chickpea with other post-rainy crops, etc. during 2012–13. The findings revealed that nearly 98% of the chickpea cropped area is now under improved cultivars, with an average increase in yield of 37% over yields achieved with unimproved varieties. The average annual per capita incomes have increased to US$ 1.89 day^{-1} with this silent chickpea revolution across the rain-fed areas of Andhra Pradesh.

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1. Introduction

Legumes are a very important part of the diet in most South Asian countries (Geil and Anderson 1994; Aykroyd, Doughty, and Walker 1982) with Chickpea (*Cicer arietinum* L.) – a major cold season grain legume – grown in many parts of South Asia and especially India (Singh and Singh 1992). Chickpea is the largest pulse crop grown in India and the second largest food legume in the world. It occupies around 15% of the total pulse area globally and is cultivated in almost 52 countries (FAO 2012). South and Southeast Asia alone contribute about 88% and 86% share in global area and production, respectively. Chickpea, similar to other pulse crops, is traditionally grown in several parts of the world, and being a short-duration crop, it can easily find a place in diverse cropping sequences. It is an important source of protein in human food and animal feed and helps in the management of soil fertility through biologically fixed nitrogen (Sharma and Jodha 1982). The long-term macro trends (1980–2010) in India indicate that cropped area increased at 0.25% year^{-1}, but production and productivity have however increased significantly, exhibiting growth rates of 1.3 and 1.04% per annum, respectively (Bantilan et al. 2014). Madhya Pradesh, Rajasthan, Maharashtra, Uttar Pradesh, Karnataka, and Andhra Pradesh states together contribute more than 90% of the area and production of chickpea in India. However, the growth rate during the last four decades (1970–2010) in area, production, and productivity has been distinctly higher in Andhra Pradesh when compared with the other states. The productivity in Andhra Pradesh increased from 0.85 t ha^{-1} during 1996–1997 to 1.3 t ha^{-1} by 2009–2010 due to the widespread adoption of high-yielding short-duration cultivars (Deb 2013). Rainy season (*kharif* season) fallow followed by chickpea is the dominant cropping system prevalent in the four districts (Kurnool, Anantapur, Kadapa, and Prakasam) of Andhra Pradesh. In the post-rainy season, this is the main cropping system, which is found on the vertisol soils, which comprise 60–70% of the cropped areas of the study districts. In Andhra Pradesh, during the last two decades there was five-fold increase in area, two-fold increase in productivity, and a ten-fold increase in production (Bantilan et al. 2014). Remote-sensing imagery analysis will be extremely handy to document such dramatic changes in cropping patterns across large areas (Mundia and Aniya 2005).

Existing national statistical data on agricultural areas provide a coarse view of cropping patterns at the macro level, but is not location specific (Gaur et al. 2008; Gumma et al. 2011c). Remote-sensing imagery studies will assist in the analysis of huge volumes of data and provide an alternative, quick, and independent approach for the estimation of cropping intensity, area, and changes in land use (Badhwar 1984; Lobell et al. 2003; Thiruvengadachari and Sakthivadivel 1997; Thenkabail 2010). Several studies have reported the efficient use of multispectral and multi-temporal data to map irrigated areas, land use, land cover, and crop type across diverse locations (Goetz et al. 2004; Thenkabail, Schull, and Turral 2005; Velpuri et al. 2009; Varlyguin et al. 2001; Knight et al. 2006). The Moderate Resolution Imaging Spectroradiometer (MODIS) normalized difference vegetation index (NDVI) time-series satellite data have been used by numerous researchers to map agricultural areas (Biggs et al. 2006; Gaur et al. 2008; Gumma et al. 2011c) and seasonal changes in crop area (Sakamoto et al. 2005). Monitoring land-use change is extremely important to understanding changes in cropping pattern and crop type and finding solutions for sustainable agriculture development (Coppin et al. 2004; Lu et al. 2004; Singh 1989).

Although several earlier studies have developed protocols and methods for major crops such as rice, sugarcane, and maize, none of these studies attempted to identify areas sown to chickpea, an important leguminous crop in the semi-arid tropics (SAT) of India. Given the above-mentioned background, this study attempts to map the land use/land cover and expansion of chickpea area during the last decade using 16 day NDVI time-series imagery acquired from the MODIS instrument on board the Terra satellite. Furthermore, the remote-sensing results were compared with ground and secondary data. The household surveys were conducted to identify the major drivers for the rapid expansion of chickpea in the study region.

2. Study coverage

Andhra Pradesh, with a total geographical area of 16 Mha, has nine districts in the coastal region and four districts in the plateau region (see Figure1). The majority of the population depends mainly on agriculture and livestock. Chickpea is one of the major post-rainy season crops grown in the state. Kurnool, Anantapur, and Kadapa districts from Rayalaseema region and Prakasam district (Figure 1) from the coastal region of Andhra Pradesh were selected for the present study because together they constitute the most significant chickpea-growing areas in the state.

3. Data sets

3.1. *Ground survey*

Ground survey information was collected from 449 locations during 14–22 January 2013 and from 216 locations during 13–26 October 2005. At each location, the following data were

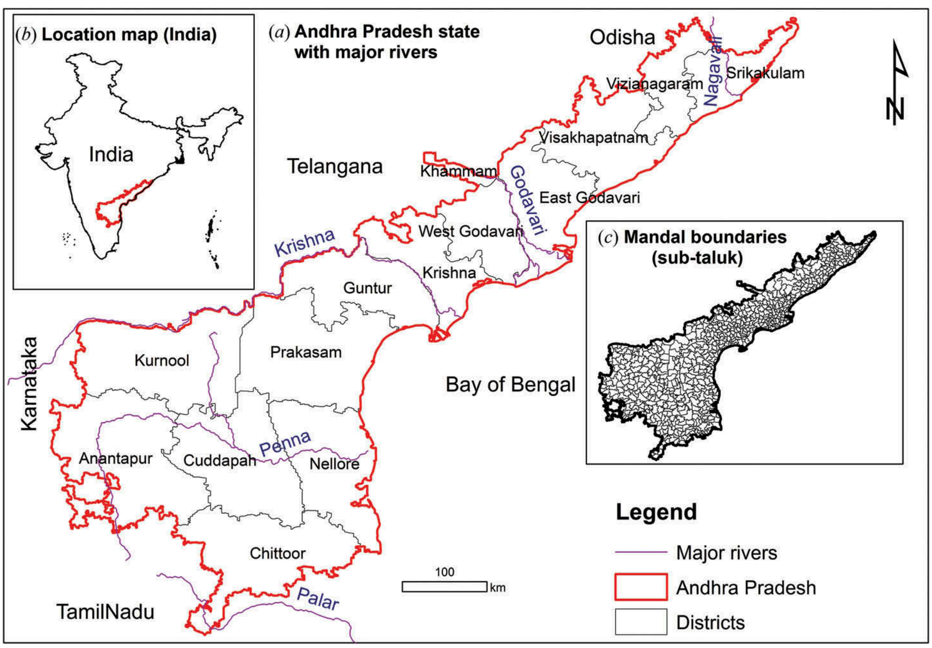

Figure 1. The study area: (a) Andhra Pradesh state with major rivers, (b) location map of the study area, and (c) sub-district boundaries.

collected: (a) geographical coordinates using the global positioning system (GPS), (b) crops grown, (c) cropping intensity (*kharif, rabi,* and summer) based on interviews with agricultural extension officers and farmers, (d) cropping pattern (crop combinations), (e) area scale (small, medium, and large), (f) land-cover categories (including trees, shrubs, grasses, waterbodies, and hills), and (g) capturing the landscape with a digital camera. Source of irrigation and seasonality of irrigation were also recorded at each location. The main purpose of ground survey collection was to identity land-use classes accurately during the classification process and to assess the accuracy of the final map (Congalton 2001; Anderson 1976).

The spatial resolution of a MODIS pixel is 250 m and it requires a minimum sampling unit of 250 m × 250 m for ground data validation. Ground data locations were selected based on the homogeneity in the sampling unit and road access. The emphasis was on the 'representativeness' of the sample location in representing one of the classes to ensure precise geo-location of the pixel. Class labels were assigned in the field using a labelling protocol (Thenkabail, Schull, and Turral 2005; Biggs et al. 2006; Gumma et al. 2011a). The precise locations of the samples were recorded by a hand-held GPS. Additional information such as historical crop information was collected based on interviews with agricultural extension officers and farmers with photographs of the crop type/land use taken (Figure 2).

Out of 665 locations, 152 points were used for classification and ideal spectra generation (Gumma et al. 2011a; Thenkabail et al. 2009; Gumma et al. 2014) and the remaining 513 ground data points were used for accuracy assessment. Details on ground data locations are shown in Figure 2.

3.2. *Household primary data*

The extent of area under chickpea cultivation in Andhra Pradesh was 0.61 Mha by the triennium ending 2009–2011(DOES 2011). Four districts of Andhra Pradesh, namely Kurnool, Prakasam, Anantapur, and Kadapa, comprise nearly 77% of the chickpea area in the state. The present study focused on these four rain-fed districts for a thorough understanding of chickpea expansion in Andhra Pradesh (Bantilan et al. 2014). A representative primary household survey was conducted to elicit information on the socio-economic characteristics of chickpea growers, area allocation to chickpea cultivation, extent of adoption of improved cultivars, costs and returns in chickpea cultivation, competitiveness of chickpea with other post-rainy crops, and major constraints in chickpea cultivation during 2012–2013. Around 729 chickpea growers from 81 villages in 27 *mandals* (sub-districts in Andhra Pradesh) of the four districts were interviewed with a structured and pretested questionnaire. A random sampling method with probability proportion to chickpea cropped area was applied in determining the number of sample farmers from each study district.

4. Methods

The present study analysed two sets of data using two different methods: remote sensing and a traditional survey method, complementing information from each other. Methodology flow chart is shown in Figure 3.

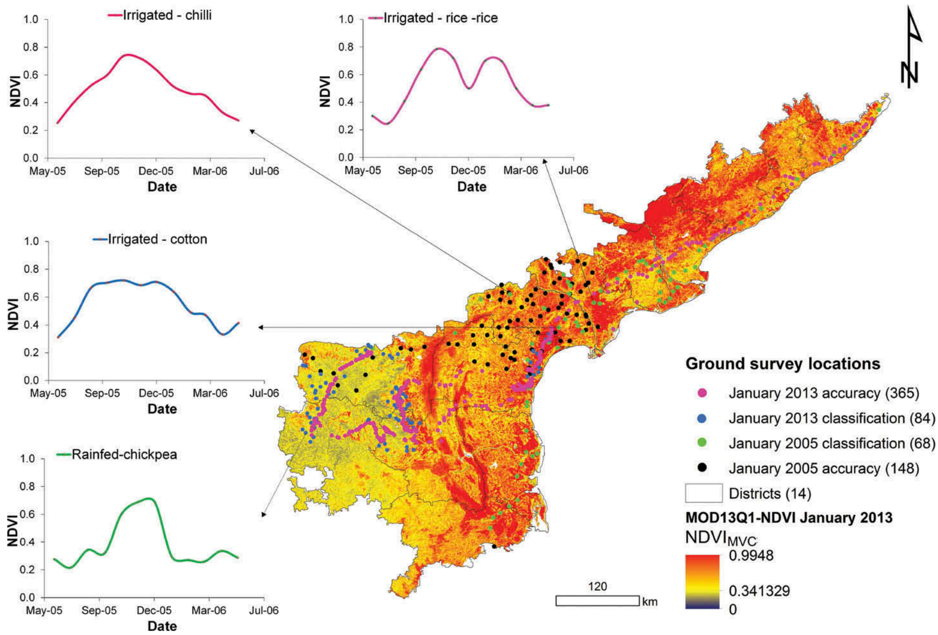

Figure 2. Ground survey point locations in Andhra Pradesh and ideal spectra signatures for major crops.

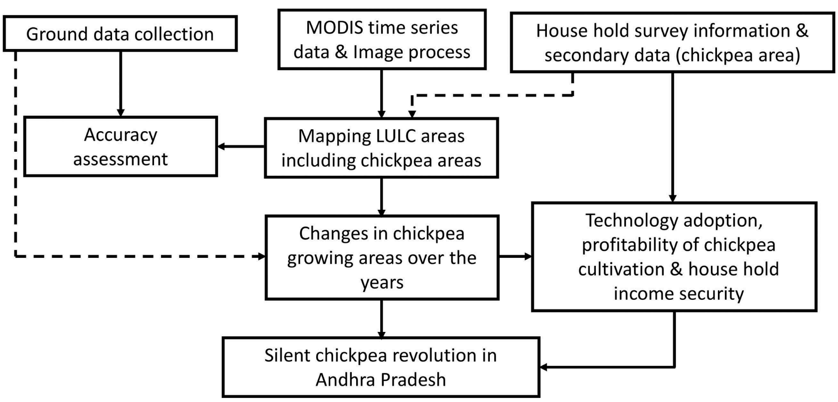

Figure 3. Overview of the methodology for land-use/land-cover mapping, land-use changes, and chickpea area expansion in Andhra Pradesh.

4.1. *Satellite images and process*

The MODIS Terra Vegetation Indices 16-Day L3 Global 250 m SIN Grid V005 (MOD13Q1 product) imagery was downloaded from the Land Processes Distributed Active Archive Center (LP DAAC) (http://e4ftl01.cr.usgs.gov/MOLT/MOD13Q1.005). Sixteen day composites consisting of four-band data for all 23 dates in 2012 were used in this analysis. The spatial resolution of the data is approximately 250 m. Although the data have already undergone atmospheric correction (Vermote and Vermeulen 1999) and cloud screening, each 16 day composite was further processed and cloud contamination was removed (Gumma et al. 2011c; Thenkabail, Schull, and Turral 2005).

MODIS imagery was used to map the spatial extent of land use/land cover for the years 2000–2001, 2005–2006, and 2012–2013. The process begins with rescaling 16 day NDVI images and later stacking into a single data composite for each cropping year (Dheeravath et al. 2010; Gumma et al. 2015, 2011a; Thenkabail, Schull, and Turral 2005).

MODIS 16 day composites were converted to NDVI monthly maximum value composites (MVCs) (NDVI MVC) using Equation (1), where MVC_i is the monthly MVC of the ith month and $i_1$and i_2 are every 16 day data in a month:

$$\mathrm{NDVI}_{\mathrm{MVC_i}} = \max\left(\mathrm{NDVI}_{i1,}, \mathrm{NDVI}_{i2,}\right). \tag{1}$$

In the present study, monthly NDVI MVC was used for classification and an NDVI 16 day data set was used for identifying and labelling land-use/land-cover classes including chickpea areas.

4.2. *Mapping land use/land cover and chickpea areas*

Each cropped year data set was classified using unsupervised ISOCLASS cluster k-means classification to generate NDVI time-series signatures for each class. Unsupervised classification was performed with a convergence threshold of 0.99 and 100 iterations, yielding 100 classes followed by successive generalization. Unsupervised classification was used instead of supervised classification in order to capture the range of variability in phenology over the image, particularly in such a large data set (state level) as this kind where the NDVI signatures of all potential land-use classes were unknown. For class identification and labelling, we compared each class spectra with ideal spectra (Figure 2.). The ideal spectra are generated using time-series imagery for each ground truth point of the same type of homogeneous land use at spatially distributed locations. Similar class spectra are grouped to reduce the 100 classes using spectral similarity values. The lower the spectral similarity value, the higher the similarity between the two classes and they are merged to a single class (Thenkabail et al. 2007, 2009; Gumma et al. 2011a, 2011c; Biradar et al. 2009). Land-use/land-cover class identification and labelling were performed using the above-mentioned procedure, but also additionally using information from very high-resolution images available on Google Earth® application. When a study area contains several distinct land-cover classes over a large spatial extent, there is a risk that some of the classes from the unsupervised classification may contain several mixed classes. These mixed classes were resolved by extracting them from the composite data set, reclassifying them, and applying the above methodology on these new classes.

Ground survey points were used to assess the accuracy of the classification results, based on a theoretical description (Congalton and Green 1999, 2008; Jensen 1996), to generate an error matrix and accuracy measures for each land-use/land-cover map. Error matrices and 'Cohen's kappa coefficient (κ)' are commonly used for accuracy assessment. For example, these are useful when building models that predict discrete classes or classifying imagery. κ can be used as a measure of agreement between model predictions and reality (Congalton 1991) or to determine whether the values contained in an error matrix represent a result significantly better than random (Jensen 1996). κ is computed as

$$\kappa = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}, \quad (2)$$

where N is the total number of sites in the matrix, r is the number of rows in the matrix, xii is the number in row i and column i, x_{+i} is the total for row i, and x_{i+} is the total for column i (Jensen 1996).

4.3. *Land-use changes and chickpea expansion using NDVI signatures*

NDVI is a ratio of red and near-infrared bands (Rouse et al. 1973; Tucker 1979) and is used extensively to differentiate vegetation conditions, including vigour and density (Teillet, Staenz, and William 1997). NDVI values vary from −1 to +1, where +1 indicates high vegetation vigour and −1 low. Changes in irrigated area were mapped using NDVI time-series plots, which also indicate cropping intensity, health, and vigour (Gumma et al. 2011a; Thenkabail, Schull, and Turral 2005).

A comparison was made between the land-use change and ideal spectral signatures (Figure 2) using spectral matching techniques and ground data (Gumma et al. 2011b, 2011a, 2011c; Thenkabail et al. 2007). Since chickpea is a winter season crop, its growing period in those periods acts as a window for identifying the crop in the imagery based on its phenology. In 2012 chickpea areas were identified by taking into consideration the duration, magnitude, and peak of the NDVI curve with ground data. A higher value of NDVI has been noticed during the *rabi* season (with the peak of NDVI observed during December/January) when compared with the *kharif* season. In Andhra Pradesh, the highest value of maximum mean NDVI was 0.65 during the *kharif* season in 2000–2001 (which was rain-fed sunflower); however, the value of NDVI was never above 0.3 in any of the *kharif* months on years with land-use change during 2012–2013.

4.4. *Technology adoption and profitability of chickpea cultivation*

A representative primary household survey was also conducted to track the adoption of chickpea-improved cultivars from sample farmers in the study area. The per unit costs and returns from chickpea cultivation vis-à-vis other competing crops were collected from respondent farmers. Furthermore, the data were validated and analysed for an in-depth understanding on the economics of chickpea cultivation. Simple tabular average analysis was performed for comparing the profitability across crops.

5. Results

5.1. *MODIS-derived land-use/land-cover maps and extent*

Altogether, 10 land-use/land-cover classes were identified (Figure 4) using MODIS time-series data, temporal signatures, and intensive ground data (Dheeravath et al. 2010; Gumma et al. 2015, 2011a; Thenkabail, Schull, and Turral 2005; Biggs et al. 2006; Gumma et al. 2011c, 2014). Classification procedures successfully distinguished canal-irrigation, supplementalrain-fed, rain-fed agricultural land, rain-fed-chickpea-growing land as well as other land-cover classes in the study area using spectral matching techniques (Thenkabail et al. 2007; Gumma et al. 2014). For each land use/land cover, area was estimated from the imagery (Table 1). Irrigated areas (class 7) are mainly located under major irrigation projects (Godavari, Krishna, Penna, and Nagavali) that are spatially spread out in the districts of Guntur, Krishna, East and West Godavari, Nellore, and Vizianagaram (Figure 1). Rain-fed agriculture is spread across the Anantapur, Kadapa, Kurnool, and Prakasam districts.

A comparison between MODIS-derived chickpea areas and national statistics revealed good agreement. MODIS-derived chickpea area estimates and the published secondary statistics at the district level indicated 93% reliability and accuracy, although some district estimates were above or below the published sources (Figure 5). The MODIS estimates are probably more accurate than the national statistics because remote-sensing techniques are of more scientifically valid measures (Gumma et al. 2015).

5.2. *Accuracy assessment*

Quantitative accuracy assessment was performed through an error matrix to examine whether a known land use/land cover is identified as the same land use/land cover or not. Based on the error matrix (Table 2), it was observed that 365 ground data points

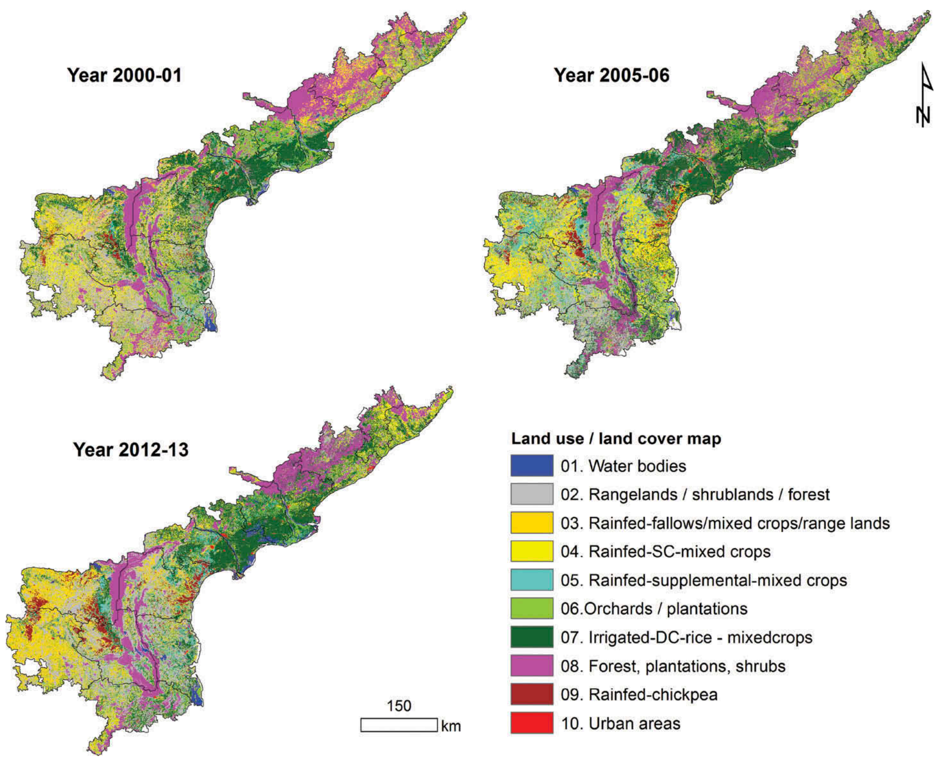

Figure 4. Spatial distribution of land-use/land-cover in Andhra Pradesh and major chickpea-growing areas.

Table 1. Land-use/land-cover statistics derived from MODIS imagery in Andhra Pradesh.

Land-use/land-cover classes	Area in ha (×1000)		
	Year 2000–2001	Year 2005–2006	Year 2012–2013
Waterbodies	125,496	71,602	367,107
Rangelands/shrub lands/forest	2,976,876	2,185,873	2,977,463
Rain-fed-fallows/mixed crops/range lands	1,307,756	1,189,483	2,983,125
Rain-fed-SC-mixed crops	2,338,287	2,420,686	1,227,402
Rain-fed-supplemental-mixed crops	855,715	1639,172	1,389,903
Orchards/plantations	1,805,252	1424,560	354,183
Irrigated-DC-rice, mixed crops	2,997,405	3,616,101	3,402,204
Forest, plantations, shrubs	3,080,283	2,738,113	2,399,119
Rain-fed – chickpea	229,274	416,915	600,267
Urban areas	92,577	124,995	125,006

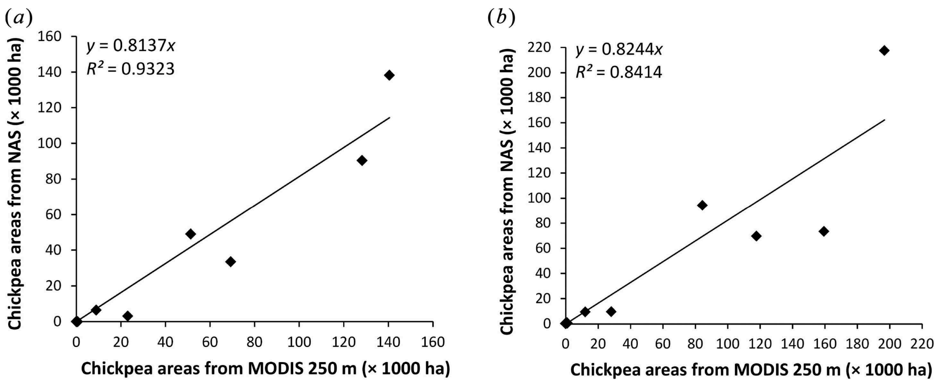

Figure 5. District chickpea areas from MODIS classification compared with national statistics for (a) crop year 2005–2006, and (b) crop year 2012–2013.

contributed to the accuracy of the nine classes. For the *rain-fed-chickpea* (class 9) ground data points (n = 165), 155 matched with the same class on the ground, with the unmatched points incorrectly indicating rain-fed-mixed crops (class 4). For the *irrigated-rice-mixed crops* (class 7), all ground data points (n = 59) matched perfectly. For rangelands/shrub lands (class 2), from the ground data points (n = 19), nine matched with the correct class, nine matched with rain-fed-fallows/mixed crops/rangelands (class 3), and one class matched with rain-fed-SC-mixed crops.

Similarly, other land-use/land-cover class accuracies were also calculated. The overall accuracy (Table 2) for the year 2012–2013 was found to be high (85.8%) and the estimated κ statistic was 0.8068.

5.3. *Spatio-temporal distribution of chickpea*

The spatial analysis produced chickpea crop extent maps for Andhra Pradesh along with other land use/land cover. These maps were tested for accuracy using ground data collected by the research team and national statistical data obtained from government agencies. Large expansion of the chickpea area was observed in the four districts of Andhra Pradesh during 2000–2001, 2005–2006, and 2012–2013 (Table 3, Figure 6).

Table 2. Accuracy assessment using field-plot data.

	Reference data (field-plot data)														
Classified data	01. Water bodies	02. Rangelands/ shrub lands	03. Rainfed-fallows/mixed crops/ rangelands	04. Rainfed-SC-mixed crops	05. Rainfed-supplemental-mixed crops	06. Orchards/ plantations	07. Irrigated-DC-rice, other	08. Forest, plantations, shrubs	09. Rainfed-chickpea	Row Total	Reference totals	Classified totals	Number correct	Producer's accuracy (%)	Users accuracy (%)
Waterbodies	8	0	0	0	0	0	0	0	0	8	8	8	8	100	100
Rangelands/ shrub lands	0	9	3	0	0	0	1	0	1	14	19	13	9	47	69
Rain-fed-fallows/ mixed crops/ rangelands	0	9	34	9	1	0	4	0	6	63	41	63	34	83	54
Rain-fed-SC-mixed crops	0	1	3	16	0	0	2	0	0	22	32	22	16	50	73
Rain-fed-supplemental-mixed crops	0	0	1	0	21	0	1	0	0	23	24	23	21	88	91
Orchards/ plantations	0	0	0	0	0	2	0	0	0	2	2	2	2	100	100
Irrigated-DC-rice, other crops	0	0	0	0	0	0	59	0	0	59	68	59	59	87	100
Forest, plantations, shrubs	0	0	0	0	0	0	0	9	0	9	9	9	9	100	100
Rain-fed-chickpea	0	0	0	7	2	0	1	0	155	165	162	165	155	96	94
Column Total	8	19	41	32	24	2	68	9	162	365	365	365	313		

Overall classification accuracy = 85.75%
Overall kappa coefficient (κ) = 0.8068

Total chickpea cropped area was 168,362 ha during 2000–2001 and grown mostly in rain-fed-black cotton soils. The cropped area was expanded to 389,361 ha by 2005–2006 and to 558,713 ha during 2012–2013 (Table 1). Major expansion was seen in the districts of Anantapur and Prakasam from 2005–2006 to 2012–2013. Between these periods, there was an estimated >65% increase in chickpea planted area (Figure 6 and Table 3). However, the cropped area in 2012–2013 has been increased to 232% compared with the base year, i.e. 2000–2001.

5.4. *Extent of chickpea technology adoption*

Desi and *Kabuli* are the prevalent chickpea types for cultivation in major districts of Andhra Pradesh (Table 4). Nearly 85% of chickpea crop in the state is under *desi* varieties (JG 11 and JAKI 9218), whereas the remaining area is occupied by *Kabuli* varieties (KAK 2 and Vihar). Except for Prakasam district, all of the other three study districts are dominated by JG 11 (*desi* variety). Only around 10–15% of chickpea cropped area in

Table 3. Major expansion of chickpea areas across Andhra Pradesh derived from MODIS 250 m.

	Area (ha)		
Districts	MODIS-2000	MODIS-2005	Modis-2012
Anantapur	34,777	51,304	84,493
Kadapa	30,343	69,258	117,903
Kurnool	68,113	140,511	196,793
Prakasam	35,129	128,288	159,524

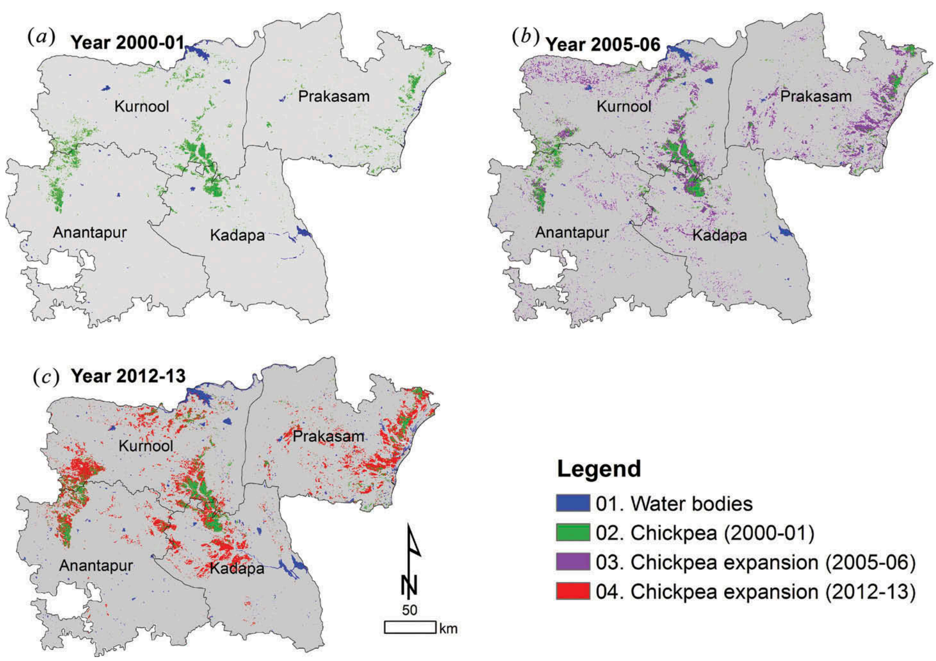

Figure 6. Spatial distribution of chickpea and expansion of chickpea cropped area from 2000–2001 to 2012–2013.

Table 4. District-wise chickpea area under different cultivars (% area), 2011–2012.

District	Anantapur	Kadapa	Kurnool	Prakasam	Pooled *
Desi variety					
Annigeri	0	0	0.1	0	1.2
JAKI 9218	1.9	0.4	0	0	0.4
JG 11	97.5	79.4	87.7	33.9	81.9
JG 130	0.6	0	0	0	0.1
Kabuli variety					
KAK 2	0	0.8	0.6	58	6.6
Vihar	0	19.4	11.6	2.2	9.1
Dollar (BOLD)	0	0	0	5.9	0.6
Total	100	100	100	100	100

* Pooled information estimated at the state level.

these districts cultivated the *Kabuli* varieties. In case of Prakasam, nearly 60–70% of chickpea area was under *Kabuli* varieties because of their price premium than the desi types. The development of improved short-duration cultivars has replaced the earlier single dominant variety, i.e. Annigeri, in the state within a span of eight years. The major sources of information for the rapid spread of the new cultivars were fellow farmers and government extension agency. Quick multiplication of seeds and subsidy on it encouraged farmers for quick diffusion.

5.5. *Profitability in chickpea cultivation*

Chickpea is found to be more profitable than other major competing crops grown in the study districts. On average, the crop yields have increased from 1475 to 2017 kg ha^{-1} with the adoption of improved chickpea cultivars, with the gross return increasing from US$ 805 to 1210 ha^{-1}. The net returns after deducting the total variable costs per ha were estimated at US$ 610, representing a significant income source for such to rain-fed farmers (Bantilan et al. 2014). The relative benefit-cost calculated for chickpea is much higher than other competing crops such as sorghum, sunflower, maize, and tobacco (Table 5). This may be one reason why chickpea has replaced other crops in these study districts over time. Remunerative output prices and high suitability to mechanized cultivation of chickpea enhanced the quick adoption of improved cultivars in the state. Its less-labour-intensive nature and the relatively low investments per ha in chickpea replaced other competing crops in the study districts. The household data analysis also revealed that the returns to scale in chickpea are much higher than other crops.

5.6. *Income and livelihood security*

Fallow chickpea is the dominant cropping system observed across study districts and sample households. Nearly 60–70% of post-rainy season cropped area alone was occupied by chickpea. Owing to their high dependency on chickpea cultivation, the total household earnings from agriculture are significantly influenced by this crop. The high net profitability per ha in chickpea cultivation has increased remarkably the average agricultural incomes per household. The average income per household per annum was the highest in the case of Prakasam district, followed by Kadapa, Kurnool, and Anantapur districts (Table 6). Except in Anantapur, the sample households from all of the remaining

Table 5. Competitiveness of chickpea vis-à-vis other competing crops (\$ ha^{-1}).

District	Crop	Net returns over TC	BCR
Prakasam	Chickpea	458.7	1.36
	Maize	−427.2	0.66
	Tobacco	397.5	1.16
Kurnool	Chickpea	345.3	1.42
	Sorghum	326.3	1.38
	Sunflower	−21.6	0.97
	Coriander	71.8	1.38
Anantapur	Chickpea	235.8	1.37
	Sorghum	−13	0.98
	Sunflower	−291.9	0.54
Kadapa	Chickpea	331.9	1.41
	Black gram	105.3	1.15
	Sorghum	−69.8	0.93
	Sunflower	−198.5	0.66

US\$ 1 = Rs 55; TC, total cost per hectare; BCR, benefit-cost ratio.

three districts obtain more than 50% of the total income from agriculture, especially from chickpea cultivation. All other sources of income were together contributing to the rest of the share in total income. This clearly reveals the income security of households growing chickpea in the study districts of Andhra Pradesh. Owing to all of these factors, the chickpea cropped area has increased tremendously and led to a silent chickpea revolution in the state. The average earning per capita per annum was estimated at US\$ 1.89, which is quite higher than the World Bank poverty line income of US\$ 1.25 day^{-1}.

6. Discussion

6.1. *Remote-sensing analysis*

This study is another demonstration of the usefulness of new science tools such as remote sensing, GPS, and GIS in accurately mapping and quantifying the specific cropped area. Chickpea is a major pulse crop in India, which has increased the income and nutritional security of poor and marginal rain-fed farmers in the SAT. MODIS imagery plays an important role in this type of study where time-series (composites of every 16 days) imagery not only helps in identifying a land-use type by crop, based on its specific growing season, but also monitors the dynamics of such land use over time and space. The compositing of daily data to 16 day imagery has the advantage of

Table 6. Average household income (US\$ × 1000 per household per annum).

Source of Income	ANA	KAD	KUR	PRM	Pooled *
Agriculture	0.29	3.26	1.27	4.18	2.03
Farm work	0.28	0.28	0.31	0.31	0.28
Non-farm work	0.16	0.09	0.26	0.11	0.18
Livestock	0.28	0.18	0.29	0.42	0.27
Caste occupations	0.02	0.01	0.01	0.01	0.01
Business	0.17	0.19	0.2	0.31	0.17
Migration	0	0.03	0.04	0.01	0.02
Remittances	0.09	0.13	0.04	0.09	0.07
Govt. programs	0.12	0.12	0.17	0.09	0.14
Others	0.22	0.54	0.37	0.51	0.29
Total	1.63	4.83	2.96	6.05	3.45

*Pooled information estimated at the state level.

minimal cloud contamination since the best of 16 days imagery is retained for analysis (MVC). Spectral matching technique used in this study is an extremely useful method to identify a specific land use where the spectral profile follows the phenology (Thenkabail et al. 2007).

6.2. *Household analysis*

The household survey confirms the rapid expansion of short-duration chickpea cultivars adoption in the state. The representative study sample farmers allocated a significant portion of the post-rainy season cropped area to chickpea cultivation by replacing other crops. The salient chickpea revolution in the state has taken place in two ways: (a) substitution of old cultivars with new short-duration cultivars, and (b) rapid expansion of chickpea area through replacement of other crops. Owing to this double effect, the production in the state reached tenfold within a short span of time. The new improved cultivars (JG 11, KAK 2, and Vihar) have significantly replaced the old dominated cultivar 'Annigeri', which existed in the study area. Higher yield, wilt resistance, bold and uniform size, attractive colour, good market price, etc. were some of the traits in the new improved cultivars preferred by chickpea growers. Chickpea has clearly demonstrated its competitiveness (high benefit-cost ratio) compared with other crops such as sorghum, sunflower, tobacco, and maize. The short-duration improved cultivators gave yields about 37% higher than previous cultivars available in the study area. The translated unit cost reduction was estimated at US$ 144 tonne^{-1} (Bantilan et al. 2014). Higher demand for chickpea, which is less labour-intensive, and high suitability for mechanical cultivation were the other drivers for the rapid expansion of chickpea cropped area. The profitability analysis clearly showed the attractiveness of chickpea compared with other post-*kharif* season crops in the study districts. Overall, the study has documented the income and nutritional security of the sample farmers in the state.

7. Conclusions

Remote-sensing-based information on agricultural land use has become inevitable in every aspect of developmental planning and decision-making. Technology targeting, impact assessment, and adaptation studies to climate change scenarios – all need spatial information. Numerous satellite platforms of different spatial, temporal, and spectral resolutions are available and many of them in the public domain for a variety of users. These can help produce useful information in a precise manner without much additional research investments. Specific crop-type mapping is the need of the hour, which is useful for research prioritization and better targeting and also for the identification of intensification strategies in the given area. This study, which mapped land use/land cover, revealed that chickpea is expanding its foothold several times across the study districts of Andhra Pradesh.

Mapping chickpea areas is the first step in characterizing important chickpea-growing domains for sustainable livelihood development. Precise up-to-date chickpea research domains and crop statistics are important inputs for assessing the impact of livelihoods (income and intensity in a changing climate scenario). Time-series MODIS NDVI phenological signatures were ideal for the identification of irrigated-mixed crops, rain-fed-supplemental-mixed crops, and rain-fed-chickpea areas. These methods and protocols can be used for mapping chickpea in other regions and further for mapping other crops as well using time-series satellite imagery at better resolutions. The present research makes a broad contribution to the methods and products of the Group on Earth Observations (GEO) for monitoring agriculture areas, the GEO Global Agricultural Monitoring Initiative (GEO GLAM), the global cropland area database using Earth observation data, and studies pertaining to global croplands, their water use, and food security in the twenty-first century (https://powellcenter.usgs.gov/globalcroplandwater/). Most importantly, the study revealed areas where major chickpea expansion happened during the selected years, the extent of technology adoption, and profitability and income security in chickpea cultivation.

The primary household analysis has also complemented the remote-sensing findings in successfully documenting the chickpea silent revolution in the state. The study also observed huge scope for further spread of chickpea short-duration cultivar technology beyond the study boundaries because of its strong applicability and spillover effects to neighbouring districts and states. The spread of these cultivars has already been observed in the neighbouring states of Karnataka and Maharashtra.

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