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QUANTIFICATION OF LAND USE CHANGES IN COMPLEX CROPPING OF IRRIGATED INDUS BASIN, PAKISTAN USING MODIS VEGETATION TIME SERIES DATA

Muhammad Jehanzeb Masud Cheema[1,2*], Mobin ud Din Ahmad[3], Tasneem Khaliq[4], Muhammad Usman Liaqat[5], Muhammad Mohsin Khan[5] and Humera Amin[6]

[1]CAS-AFS, University of Agriculture, Faisalabad, Pakistan; [2]Faculty of Agricultural Engineering and Technology, PMAS-Arid Agriculture University, Rawalpindi, Pakistan; [3]CSIRO Land and Water, Canberra, ACT, Australia; [4]Department of Agronomy, University of Agriculture, Faisalabad, Pakistan; [5]Department of Irrigation and Drainage, University of Agriculture, Faisalabad, Pakistan; [6]Department of Sociology and Criminology, University of Sargodha. Pakistan
[*]Corresponding author's e-mail: mjm.cheema@gmail.com

Quantification of change in area under different crops is vital for conducting macro scale hydrological studies as spatial crop water use depends on type of crops grown. This becomes more challenging in areas with complex cropping systems like irrigated Indus basin of Pakistan. In this study, estimation of cropped area was carried out using Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation time series at six-hectare spatial resolution i.e. Soil Adjusted Vegetation Index (SAVI). Two cropping years i.e. 2002-03 and 2013-14 were selected to quantify cropped area as well as assess how the cropping systems had changed over a time span of eleven years. Each pixel was trained to assign the vegetation, a particular crop cluster. Four and five major crops were discerned for *rabi* (winter) and *kharif* (summer) seasons, respectively. Wheat is dominant *rabi* crop while rice (a high delta crop) and cotton are dominant *kharif* crops. Sugarcane is an annual crop and being grown in different tracts of the basin. A confusion matrix prepared for accuracy test shows an overall accuracy of 79% and 74% for *rabi* and *kharif* seasons, respectively. The *Kappa* coefficient (0.64 and 0.62) expresses moderate agreement between satellite-derived map and on ground situation. Change detection indicates that wheat area has been increased significantly 4.2 mha (38.3%) from 2002 to 2013. Rice and sugarcane have also shown a significant increase of 0.69 mha (26.3%) and 0.29 mha (21.8%), respectively during the time span of eleven years. However, it is highly cautious for water management planners due to higher delta of these crops. This study provides essential information for spatial distribution of major seasonal crops grown in water stressed irrigated Indus basin for efficient agricultural monitoring and water resources management.
Keywords: LULC, irrigated Indus basin, MODIS, SAVI, rabi, kharif, crop phenology, change detection.

INTRODUCTION

Spatial mapping of cropped area is always attractive for researchers working on agricultural water management and policy making (Abbas *et al.,* 2006; Misra and Vethamony, 2015; Waqas *et al.,* 2019).These remote sensing based datasets are used to characterize various surface and subsurface properties such as vegetation cover (for crop mapping, land changes and biodiversity), curve number (for rainfall runoff modeling) rooting depth in order to calculate soil moisture, albedo (for ET), surface roughness (for evapotranspiration), etc (Cheema and Bastiaanssen, 2010).Therefore, developing of water accounting and modeling of water balance (Molden, 1997)needs pixel information on agricultural area, to be known as water use competition within the agricultural land uses governs the water fluxes. Spatial extent of these agricultural land uses (irrigated and rainfed crops), locality and type is critical for estimating crop water requirement that varies from crop to crop (Zheng and Baetz, 1999).

Compilation of crop information is not straightforward and becomes even difficult especially in areas with complex cropping systems. Irrigated Indus basin of Pakistan is one of such examples. Various studies have been carried out during the last decade to discern crops, based on spatio-temporal satellite data on vegetation (Cheema and Bastiaanssen, 2010; Saeed *et al.,* 2017; Rehman and Kazmi, 2018). But all of these are less appropriate to use when large scale hydrological modeling studies are required due to their extent and lacking details on crops. The spatial resolution of freely available satellite datasets (moderate) and their temporal availability (in case of higher spatial resolution) made them less suitable to detect dominant crops in Pakistani farm settings that can result in mixed classes (Portmann *et al.,* 2010). This situation is more vulnerable in mixed cropping system with varying cropping schedule. Crop sowing and harvesting windows are different in different agro-climatic zones in the basin (Gumma *et al.,* 2011; Liping *et al.,* 2018). Moreover, this situation is more challenging in small-irrigated areas average lies between 3-4 acres where different crops are being grown with variable water demand and supply. Therefore, precise crop-based classification is required for carrying out judicial water allocations.

Moreover, a quick shift in cropping patterns is observed in the basin due to changing climate and unreliable market price of the commodities grown. Marketing issues has forced farmers to keep on changing their cropping patterns. Therefore, these modification in cropping patterns due to various climatic and hydrological factors facilitate famers, water managers and policy makers to keep changes cropping area data (Gitelson *et al.,* 2007; Liaqat *et al.,* 2017) for effective planning and crop production (Liang *et al.*, 2014).

Remote sensing data acquired by sensors onboard different satellite platforms have been applied successfully in many land cover classification and land use change detection studies. MODIS is a key instrument aboard or fixed on the Terra called as EOS AM-1) and Aqua (EOS PM-1) satellites. Presently MODIS (Terra and Aqua) are providing images after every sixteen days at 250 m resolution and can therefore provide 8-day time series for analysis of LULC (Hereher *et al.*, 2012).

The MODIS is being used for crop monitoring and land use land cover classification exhibited reasonable results (Xiao *et al.*,2006; Zhang *et al.*,2008; Gontia and Tiwari, 2011; Badreldin *et al.*,2014; Kundu *et al.*,2016; Miettinen *et al.*,2016; Qiong *et al.*,2017). In this study, a campaign was carried out to map four to five major crops being grown in irrigated areas of the Indus basin for the growing seasons of *rabi* (winter) and *kharif* (summer). The first objective of this study was to discern five crops within the complex cropping system of irrigated Indus basin. eight days' time series of Soil Adjusted Vegetation Index (SAVI) derived from MODIS in combination with ground-based information, agricultural statistics and expert opinion on crop phenology was used to identify each crop grown during the year 2013-14. Secondly, the developed methodology was applied for previous years to identify cropped area in 2002-03 thus providing an opportunity to assess changes in cropping pattern during eleven years' time span.

MATERIALS AND METHODS

Study Area**:** The research was conducted in one of the largest canal network of world in irrigated Indus Basin (IB) which is located between longitudes 67.32°to 74.68°east and 24.14°to 34.52°north. River Indus and its tributaries (Jhelum, Chenab, Ravi, Beas, and Sutlej) are irrigating IB through a network of 48 major canals. Figure 1 shows the locations of canal commands within the basin. Average annual rainfall occurrence is also varied with less than 200 m recorded in the lower areas of the basin while 1000 mm observed in north and northeastern parts. The reference crop evapotranspiration (ET_o) within the basin ranged between 650 mm to 2000 mm calculations based on 30 year average data.

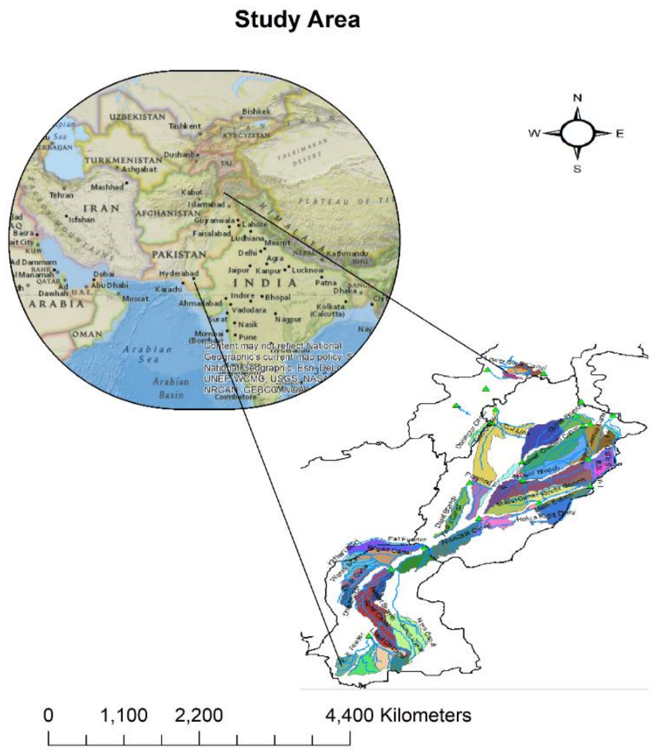


Figure 1. Canal command area of Irrigated Indus basin, Pakistan.

Cropping season**:** Two cropping seasons exist within the basin i.e. *rabi* (November to April) and *kharif* (May to October). Wheat is main crop of *rabi* season whereas rice and cotton are major crops of *kharif* season. These crops contribute 82% value add in major crops (Pakistan Economic Survey, 2017-18). Sugarcane is a yearly crop and being grown in various tracts of the basin alongwith seasonal fodder. Table 1 provides information on growing season of various crops grown in the basin.

Data acquisition

Satellite data**:** The use of high temporal and moderate resolution data with multi spectral bands like MODIS in conjunction with appropriate classification technique are considered being a good base for optimal crop classification results (Qiong *et al.*,2017). MODIS time series data proven reliable to monitor the phenological changes in crops and create discrimination for vegetation types at global and regional scale (Wang *et al.*,2014). In this study, MODIS (MOD13Q1) product sensor on board Aqua and Terra Satellites at 250 m pixel resolution available at eight days intervals was used. SAVI time series data for the years 2002-03 and 2013-14 covering growing season of *kharif* – *rabi* –

Table 1. **Location based cropping calendar for rabi (winter crops) and kharif (Summer Crops) (Adopted from SUPARCO bulletin). In case of sugarcane, two seasons are provided instead of location. Green color represents cultivation time while yellow, harvesting and light blue cultivation & harvesting.**

Crop	Province	Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wheat	Punjab	Upper Punjab												
		Lower Punjab												
	Sindh	Lower Sindh												
		Upper Sindh												
	KPK	Plain												
		Hilly Area												
	B-tan	Plain												
Cotton	Sindh	Hyderabad												
		Badin												
		Upper												
	Punjab	South& Central												
	KPK	DI Khan												
	B-tan	Lasbela												
Sugar-cane	Punjab	Autumn												
		Spring												
	Sindh	Autumn												
		Spring												
	KPK	Peshawar												
Rice	Punjab	North East												
	Sindh	Upper												
		Lower												
	KPK	Plain												
		Hilly												

Cultivation	Harvesting	Cultivation& Harvesting

kharif, thus obtained was used to carry out crop phenology investigation and corresponding land use classification.

***Cropped area information*:** Official cropped area information for each administrative district was obtained from Agricultural Statistics of Pakistan and Provincial Crop Reporting Services (CRS) for the said years. The CRS provides agricultural statistics for all crops by obtaining data from sample villages. For this purpose, a gardawri (survey) of each crop was carried out in each sample village for approximation of total cropped area sown in *rabi* and *kharif* (Dempewolf *et al.*,2014).

***Field data collection*:** In order to build confidence on the satellite information, ground data were collected in two canal commands. Overall 160 points were collected during the field survey conducted in *rabi* of 2013-14 while 140 during *kharif* 2014.For classification, standard criteria was followed for training and accuracy assessment i.e. 70% of ground data were used in training and classification while remaining 30% data were used for accuracy assessment (Schmedtmann and Campagnolo, 2015).

***Satellite based vegetation indices*:** Near and visible infrared bands of electromagnetic spectrum can be used to estimate canopy maturity, heading stage of crop and leaf chlorophyll architecture as described by Reddersen *et al.* (2014). In our study, crop condition and heading stage were estimated using SAVI. SAVI is hybrid between a perpendicular index and ratio (NDVI, Normalized difference vegetation index). The major advantage of using SAVI is its ability to account parameters of soil background that can miss part of reflectance, if otherwise, as in case of NDVI and EVI (Fu *et al.*, 2014; Liaqat *et al.*,2017). SAVI is estimated using equation:

$$\mathrm{SAVI} = \left(\frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R} + \mathrm{L}}\right) * (1 + \mathrm{L})$$

where, NIR and R are spectral bands in near infrared and red regions, respectively. L is a correction factor which is based on the vegetative cover. For densely vegetative areas its value is zero equal to NDVI while for lower vegetative cover its value is 1.

***Semi Supervised Image Classification*:** The OBIC approach was developed using time series multi-temporal MODIS data with semi-supervised classifier. Initially, layer stack images were classified based on un-supervised classification. Expert knowledge on cropping pattern was then employed to refine the classification as mentioned by Cheema and Bastiaanssen (2010). Figure 2 shows the stepwise methodology used for LULC change analysis.

Features including vegetation index and spectral reflectance of individual crops at different phenological stages were extracted for classification. A SAVI time series profile and feature selection for one and half year representing major crops were developed in order to reduce the influence of seasonal effects. The vegetation scaling factor (0.1-1) and knowledge of crop phenology (Table 1) were used to distinguish crops having specific SAVI temporal profiles. The values of each vegetative index were checked by scaling factor and interpreted in the image. The commencement of a growing season for an individual crop was considered when there was a substantial increase in SAVI.

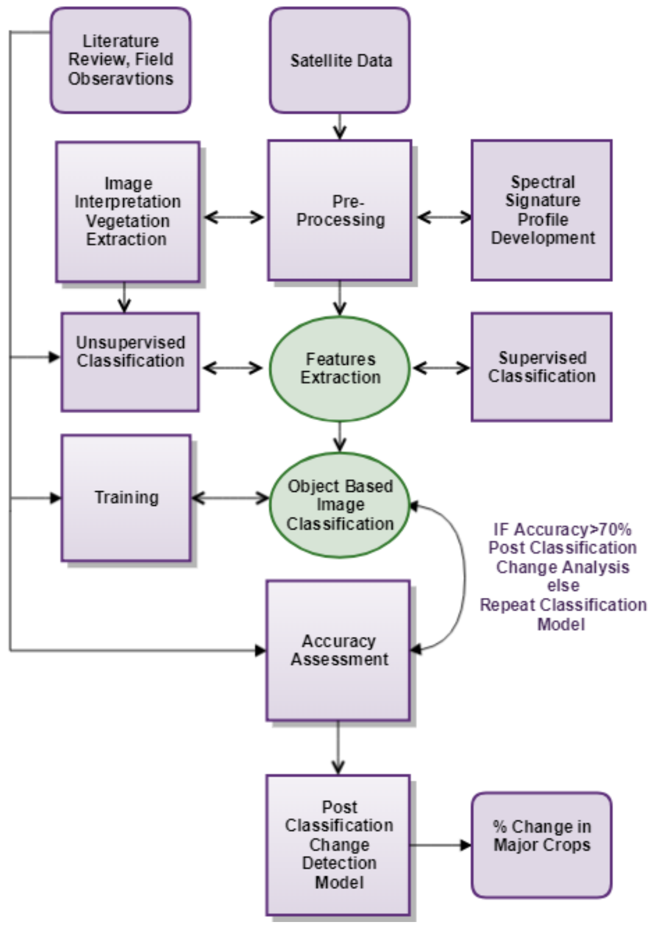


Figure 2. Functional flow of methodology used for LULC changes analysis.

The onset of the SAVI was a result of increased photosynthetic activity. Similarly, a decrease in SAVI expresses the end of growing period. Initially, image was classified into 80 classes using SAVI information for *rabi* 2013 -14, *kharif* 2013 and *kharif* 2014 that were again reclassified and narrowed down to four/five major classes mostly grown in a particular season (Figure 3).

The classification was carried out in two steps: 1) unsupervised classification of cropped area 2) then applying decision tree rule using various cropping features as mentioned above. The sowing period of crops was dissimilar for different agro-climatic zone thus hindering proper classification of a single crop that has similar vegetation value. This problem was solved by developing clusters of three to four classes for every crop using field information, high resolution maps, district wise crop statistics and standard accuracy limit. The methodology was then replicated on images of 2002–03 that resulted in spatial map of crops grown in *rabi* and *kharif* of 2002–03. A post classification method was used, which is one of the most widely used change detection techniques, that differentiates pixel by pixel combination of images from two different intervals. In addition, the technique provides statistics of geographical changes and their extent (Bhatta, 2010).The change in cropped area during the eleven years was assessed by carrying out post classification method on the *rabi* of 2002-03 and 2013-14 and *kharif* of 2003 and 2014.The accuracy of classified maps were checked using accuracy assessment technique as described below.

Accuracy assessment and validation: The accuracy assessment of the classified images is a process to examine the match between the real physical situation and classified images (Campbell, 2011). The confusion matrix was prepared to assess the correctness of the classified maps. The standard criteria for training and accuracy assessment of classified image were followed using ground values i.e. 70% of ground data were used for image classification and remaining 30% for assessing accuracy. The confusion matrix and Kappa statistics between ground and mapped points were used to assess the classified maps' accuracy for *rabi* and *kharif* of

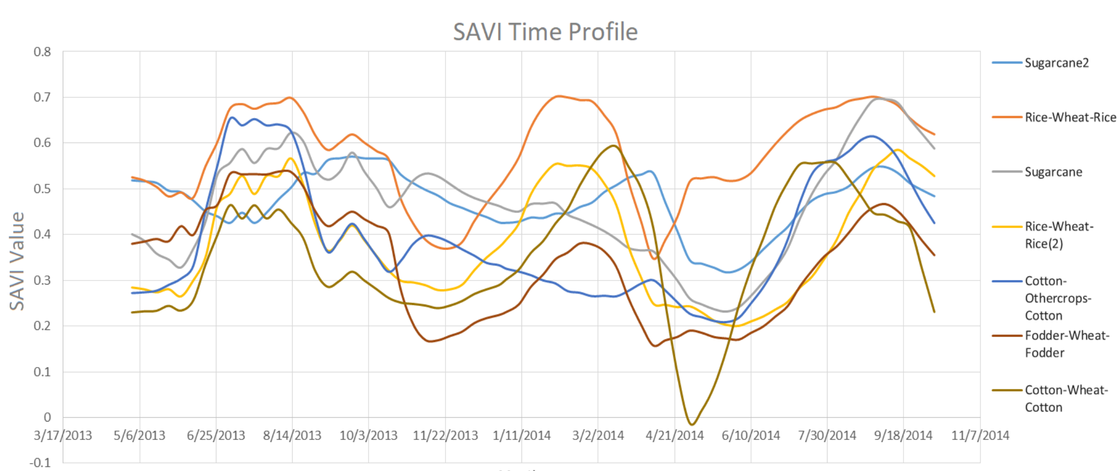


Figure 3. SAVI time series for the year 2013 -14 used in multi-crop identification

year 2013–14. Moreover, co-efficient of determination (R^2), Percent bias (*PBias*) and Nash and Sutcliffe Efficiency (*NSE*) were also used to check the relationship between observed and estimated cropped area for wheat, sugarcane, rice and cotton.

RESULTS AND DISCUSSION

The semi supervised classification and decision tree rules exhibited spatial distribution of major crops for *rabi* and *kharif* season. The cropped area of major crops grown in *rabi* and *kharif* seasons was initially apportioned into 80 classes using unsupervised classification. This initial classification provided a base to further refine the classified map using supervised classification. Crops sown in different agro-climatic zones of the basin exhibits distinct phenological cycle that is also depicted in the Figure 3. Visual inspection of SAVI temporal trends for a complete *kharif – rabi – kharif* crop phenological cycle and expert knowledge helped to identify crops. As sowing and harvesting window for each crop is distinct for each agro-climatic zone, therefore three to four classes with similar phenology were identified foreach crop. Agricultural statistics data on cropped area for each district were used to tweak and merge the classes into a single crop class (Figure 4).

Cropped area statistics for wheat, rice, cotton and sugarcane for the year 2013-14 in different administrative districts are provided in Figure 4. Wheat crop is major staple food crop being grown in *rabi* season throughout the basin. Strong relationship was observed between areas reported in Agricultural Statistics (here mentioned as Observed Area) and estimated through satellite imagery (estimated area). On an

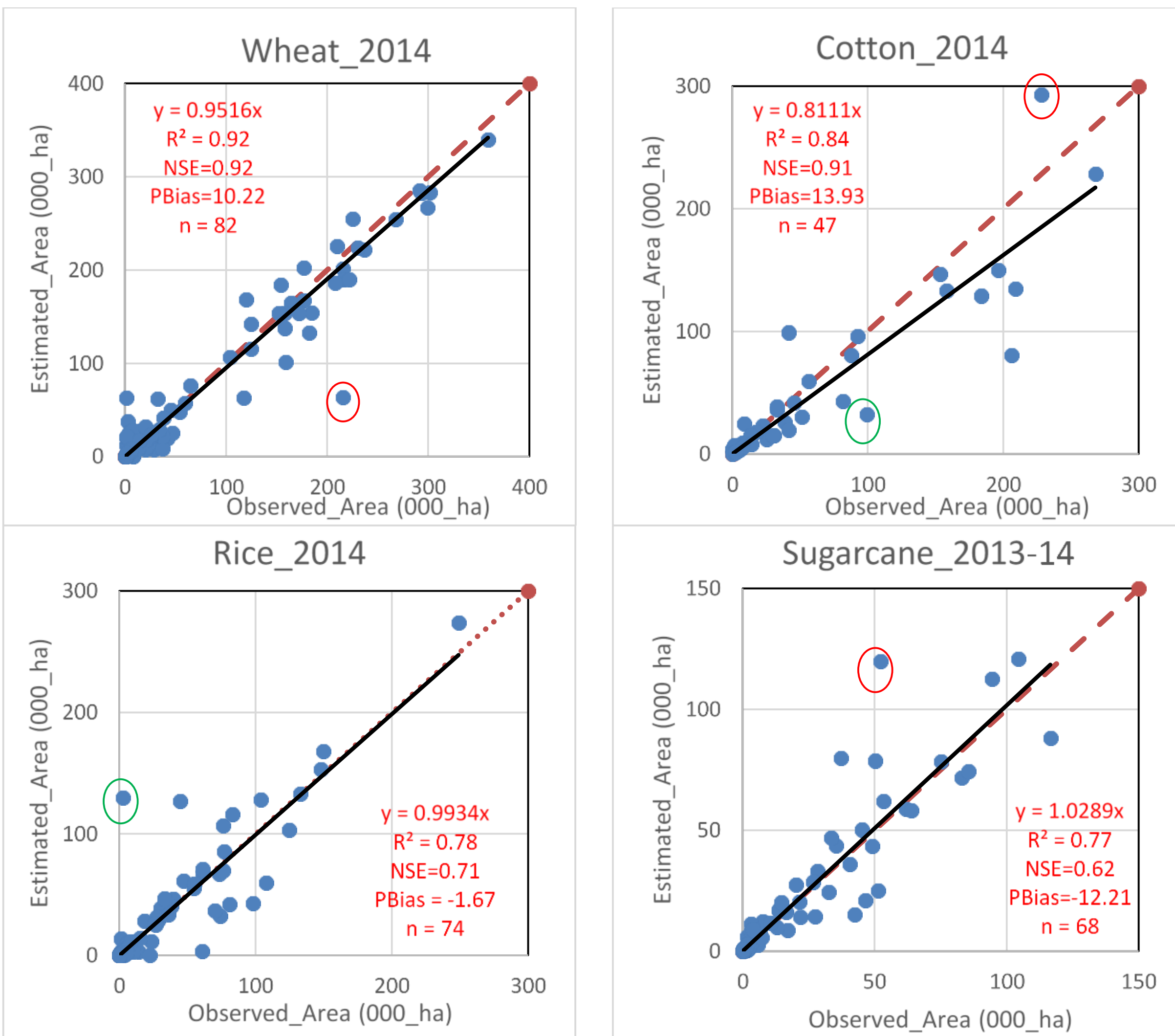


Figure 4. District wise cropped area statistics (estimated/observed) for wheat, rice, cotton and sugarcane grown during the year 2013-14.

average, area estimated by satellite data was 5% lower than the agricultural statistics with R^2 and *NSE* estimated at 0.92 (both) with *PBias* of 10.2. The reason of this higher accuracy with 250 m (6 hectares) pixel resolution is the fact that wheat covers more than 60% of irrigated area of the basin. Such large area can easily be picked up by the moderate resolution satellite sensors. However, there is one point (encircled red) that shows large variability, is Jhelum district of Punjab province that mostly has rain fed wheat that is not picked up well by the satellite.

Similarly, statistics for major *kharif* crops i.e. cotton and rice cropped area are also reasonable with R^2, *NSE* and *PBias* estimated at 0.84, 0.91, 13.9 and 0.75, 0.68, –2.65, respectively. Cotton area was 19% underestimated due to mixed cropping during *kharif* season. One district (Rajanpur, encircled green) has shown significant bias in case of cotton and rice. Mixed signatures of cotton and rice with fodder and tobacco seem plausible cause of this bias. Additionally, large area of tobacco, maize, millet, groundnut and sorghum had also been cultivated during *kharif*. It is also difficult to quantify area of these crops due to similarity in the spectral signature and growing season. Although, these are some drawbacks of using coarse resolution for estimating cropping area in mixed cropping system, present study provide a reliable sketch that is in agreement with the cropping pattern of main crops. Sugarcane cropped area was also fairly mapped with R^2, *NSE* and *Pbias* estimated at 0.77, 0.62 and –12.21, respectively.

The spatial maps for *rabi* and *kharif* 2013 – 14 are shown in Figure 5 depict that wheat was major crop of *rabi* season cultivated on a large area (10.95mha) along with small crops such as berseem and mustard cover an area of 1.60 mha while sugarcane (1.22 mha) was also grown in tracts. It is quite difficult to develop demarcation for *rabi* fodders with wheat crop due to similar in growing and heading stage as well as spectral signature. Hence, SAVI derived similar spectral values for both fodder and wheat. Moreover, cultivated area information for discrete fodder was also not accessible easily to confirm high accuracy in classification. As a result, the fodder classes had to be reclassified and merged into one class. Hence, *rabi* comprised of four classes namely wheat, fodder, sugarcane and other crops.

Spatial map of *kharif* 2014 (Fig. 5-b) indicates that rice was major crop grown in upper Punjab and Sindh provinces of

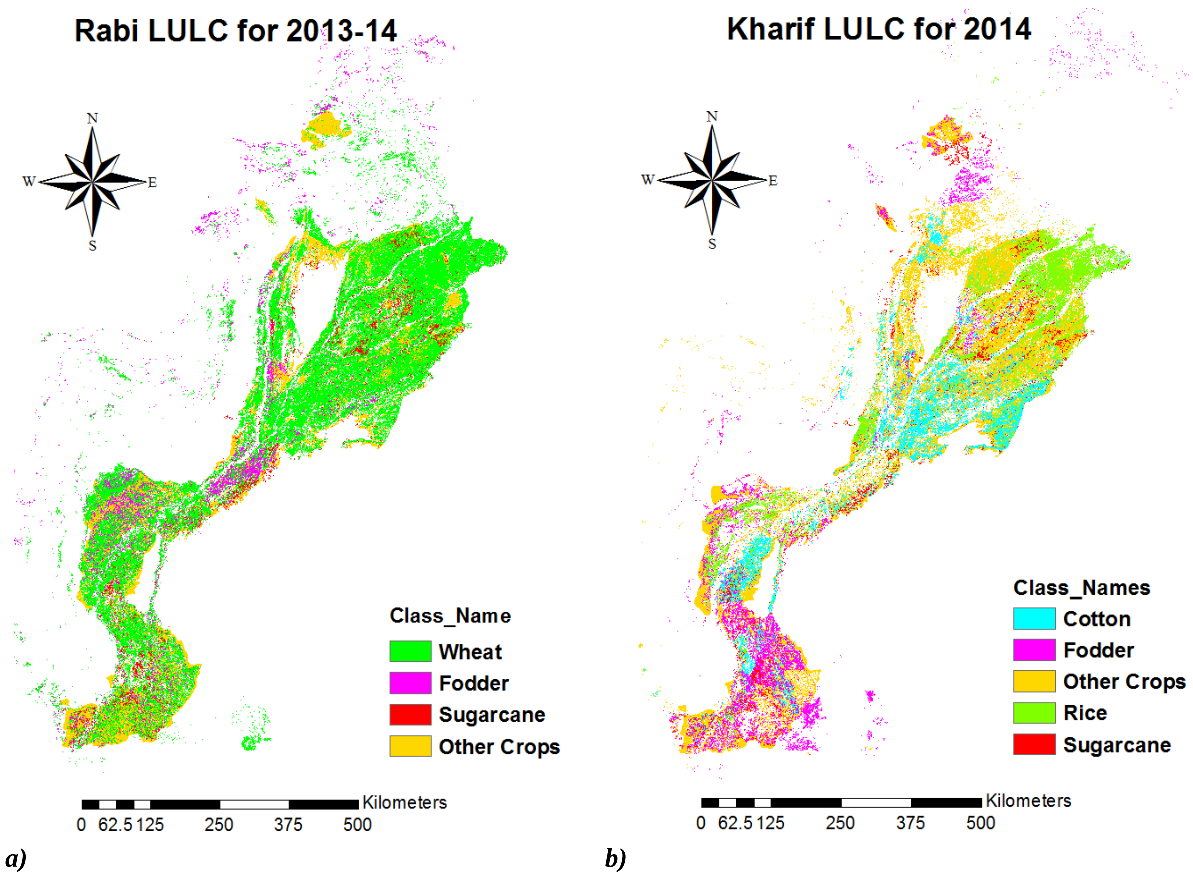


Figure 5. Spatial maps of major crops grown in the Irrigated Indus basin during a) *rabi* 2013-14 and b) *kharif* 2014.

Pakistan with total area estimated at 2.62 mha. Cotton was second major crop covering 2.96 mha area of the irrigated Indus basin. Sugarcane was estimated at 1.33 mha, which is 0.11 mha more than *rabi* statistics. The possible reason is the cultivation of sugarcane in various parts of the basin during February that is captured during *kharif*, thus increasing total sown area.

The confusion matrix calculated with the validation samples obtained at various locations within the irrigated IB is shown in Table 2provides classification accuracy for the crop types. Overall classification accuracy and Kappa coefficient for *rabi* were 79% and 0.64, while for *kharif*, it was estimated at 74% and 0.62, respectively. The producer's and user's accuracy had found much greater for wheat and rice crops as compared to others. The plausible reason of this higher accuracy is because of the fact that these crops are being grown on large tracts. In these tracts, mixed cropping was not in practice. The results were also compared with some other studies in this area (Cheema and Bastiaanssen, 2010; Dempewolf *et al.*,2014; Liaqat *et al.*,2017; Mumtaz *et al.*,2017) found good agreement with previous studies.

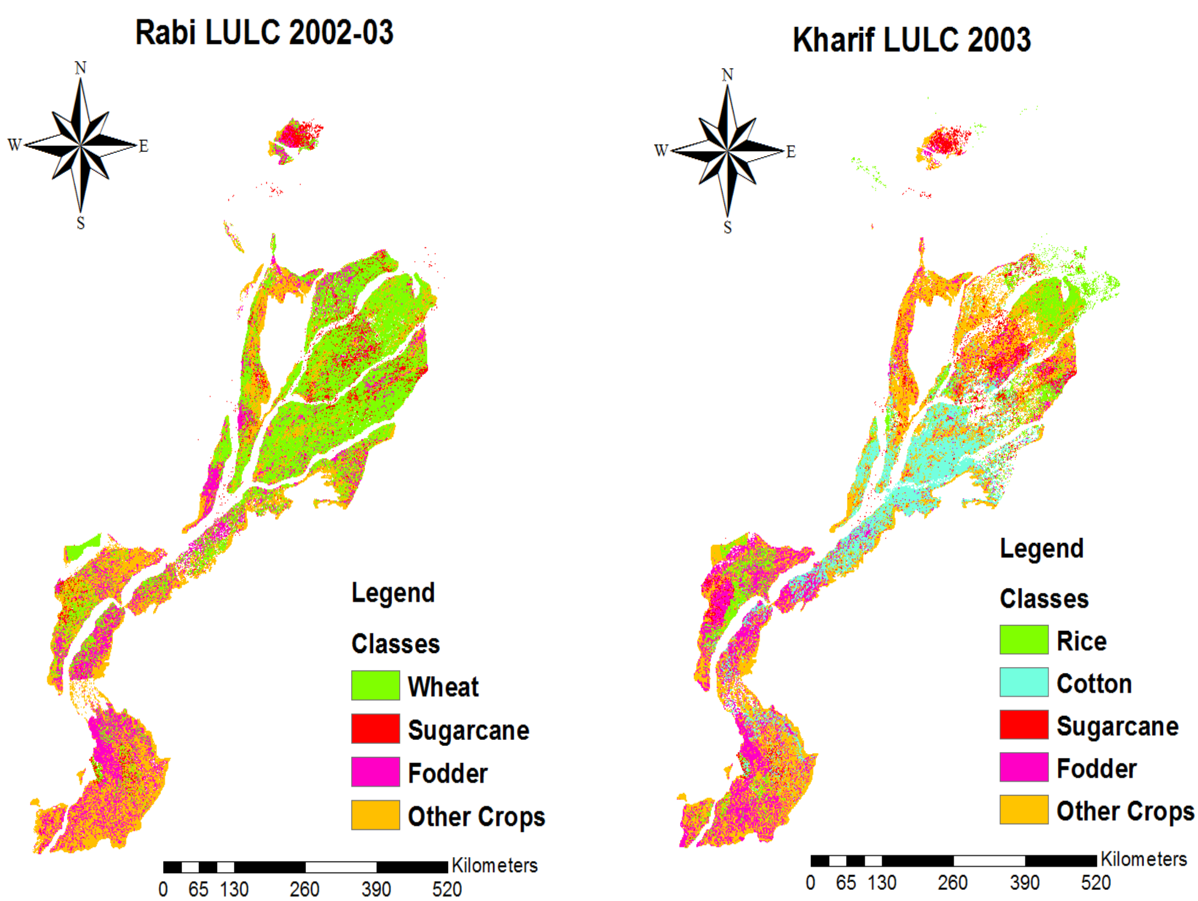
Table 2. Classification accuracies for the crops grown during rabi and kharif (2013 -14).

Kharif

Crop	User's Accuracy	Producer's Accuracy	Overall Accuracy
Rice	83%	86%	
Cotton	80%	73%	74%
Sugarcane	74%	70%	
Fodder	76%	65%	
Other Crops	58%	69%	
Kappa Coefficient		0.62	

Rabi

Crop	User's Accuracy	Producer's Accuracy	Overall Accuracy
Wheat	86%	90%	
Sugarcane	72%	77%	79%
Fodder	71%	67%	
Other Crops	75%	65%	
Kappa Coefficient		0.64	



a) *b)*

Figure 6. Spatial maps of major crops grown in the Irrigated Indus basin during a) *rabi* 2002 – 03 and b) *kharif* 2003.

After gaining confidence on adopted methodology, same approach was applied for mapping *rabi* and *kharif* crops of the year 2002–03 and the resultant maps are provided in the Figure 6.
The spatial maps for *rabi* and *kharif* 2002 – 03 are given in Figure 6. Wheat being the major staple crop of *rabi*, was grown on a 6.75 mha that was 15% less than Agricultural Statistics estimates. While area under rice and cotton was 1.93 and 2.88 mha, respectively. Sugarcane was grown on 1.04 mha. The values were lower from the reported values. The reason of this variation is based on the fact that the remote sensing estimates are from irrigated area while agricultural statistics provide information for both irrigated and non-irrigated areas. This issue was further investigated by comparing district statistics as provided in Figure 7.
On an average, wheat area estimated by satellite data shows reasonable accuracy with R^2 and *NSE* estimated at 0.87 and 0.78 while *PBias* of – 13.62. Similarly, statistics for cotton, rice and sugarcane were also reasonable thus developing confidence on developed maps.
***Change Detection*: **These maps were further used to detect change in cropping area. Two distinct years are required for such type of analysis (Siebert *et al.*,2010; Lu *et al.*,2014). The percent change in area under major crops for the *rabi* and *kharif* seasons is shown in Figure 8. Results indicate that during *rabi*, wheat area had been increased by 38% while corresponding decrease in *rabi* fodder was observed during the span of eleven years.
This is mainly due the fact that wheat is main staple food in the country, and food security is directly related with flour availability. Government announces support price well before sowing of wheat and farmers try to grow more wheat crop.
For *kharif* season, rice exhibited rise in cropped area that had been increased by 26% however, cotton had shown only 2.7%

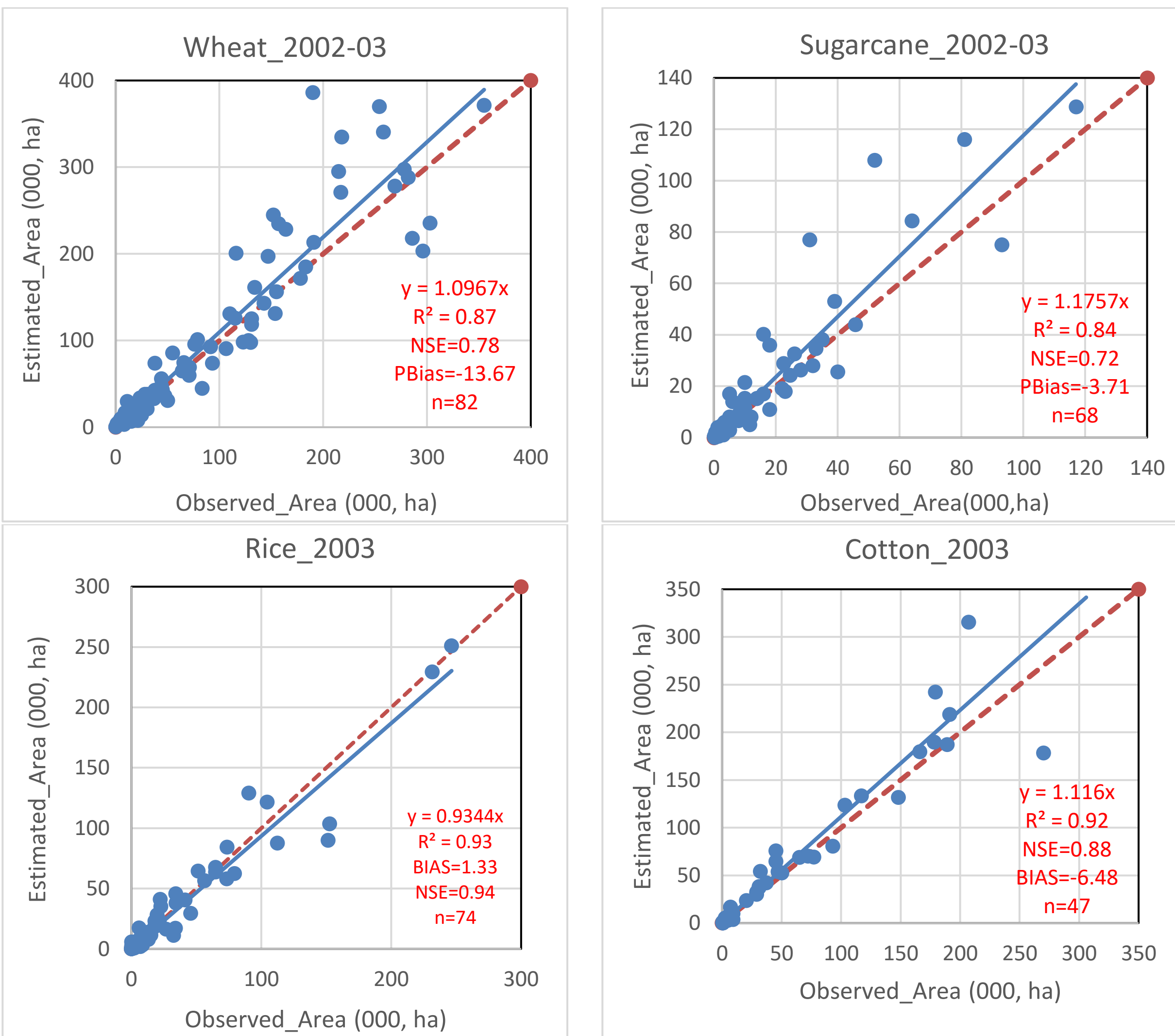


Figure7.District wise cropped area statistics for wheat, rice, cotton and sugarcane grown during the year 2002- 03.

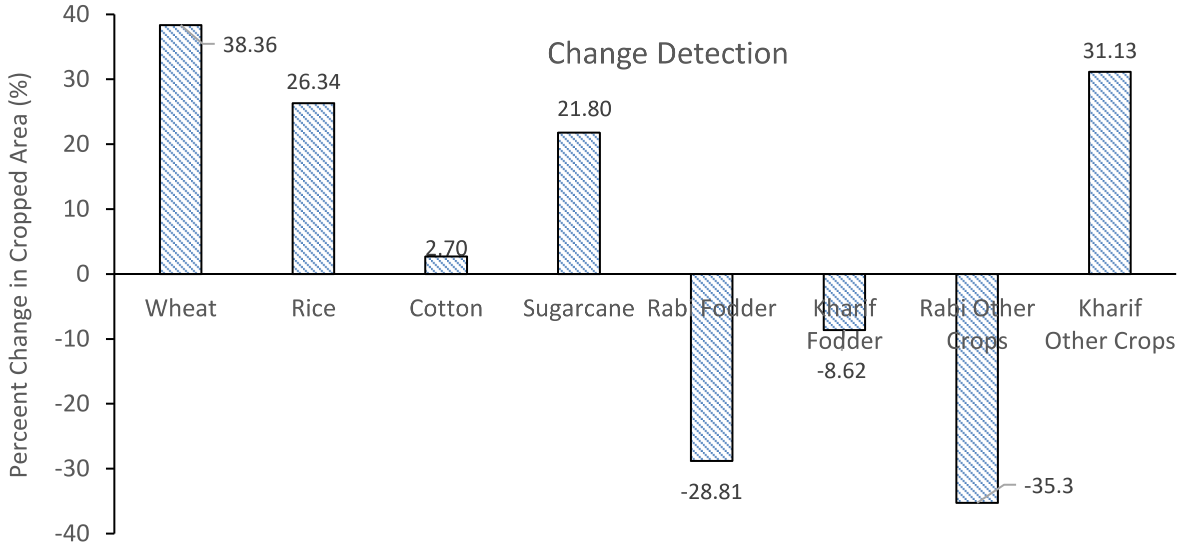


Figure 8. Percent Change in major crops between year 2002-03 and 2013-04.

increase due to the large fluctuations in the market prices of cotton and lack of support prices by the government. Agricultural Outlook Forum (2012) observed 14% rise in cropped area under cotton in Pakistan as compared with that of the year 2011 but in 2014 the trend changed, and farmers opted rice instead of cotton. It is evidence that climate change and changed rainfall patterns along with less resistant cotton varieties also forced farmers to go for rice instead of cotton.

Other *Kharif* crops also illustrates declining trend with positive trend in recent year where sugarcane exhibited a rising trend of about 22%. The analysis thus provided a quantitative estimate of change in the cropped area during last decade within the irrigated IB.

***Conclusions*:** Spatial maps of five major crops grown in the irrigated Indus basin Pakistan were prepared for the years 2002-03 and 2013-14 using 8-days' time series of SAVI derived from MODIS in combination with ground-based information, agricultural statistics and expert opinion on crop phenology. Three season time series (*kharif – rabi – kharif*) of SAVI obtained from MODIS sensor onboard Aqua and Terra satellite proved reasonably good to capture spatial variability of crops grown in the complex cropping system of the basin. The overall accuracy for *rabi* 2013-14 and *kharif* 2014 was 79% and 74%, with Kappa Coefficient of 0.64 and 0.62, respectively. Change detection indicates that wheat acreage has been increased significantly 4.2 mha (38.3%) from 2002 to 2013. Rice and sugarcane have also shown a significant increase of 0.69 mha (26.3%) and 0.29 mha (21.8%), respectively during the time span of eleven years. It indicates that Government is encouraging growing staple foods to ensure food security. But rice being high water use crop, has created lowering of groundwater in the rice growing areas as observed by Cheema *et al.*(2014). *Rabi* and *kharif* fodders are significantly reduced thus posing threat to livestock and dairy development.

It is recommended to conduct such studies on regular basis for continuous monitoring of crop growing area. Identification of areas with high delta crops will help to conduct basin scale water management plans for efficient utilization of scarce water resource.

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