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Assessing the potential of Sentinel-2 imagery and NDVI thresholds for the development of crop phenology: A case study of Sahiwal District

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Crop mapping and its health monitoring are of key importance for a country like Pakistan where a considerable share of the GDP originates from agricultural production. Currently, extensive capital and human resource are utilized to record the crop types and monitor crop health due to variations in crop pattern and intercropping practices being observed in many parts of the country. Satellite Remote Sensing, however, can be utilized very efficiently to identify crop types and estimate acreage by using unique phenological cycles derived from NDVI thresholds. In this research, we proposed a semi-automated, efficient and cost-effective state-of-the-art technique for crop classification using satellite remote sensing datasets and GIS techniques to replace outdated conventional survey-based crop estimations procedures. This research was conducted in Sahiwal district, Pakistan to categorise several crop types using two major inputs: satellite (Sentinel-2, 10m) imagery and local crop calendar. The research adopted a semi-automatic approach to find the main crops of Rabi (winter) and Kharif (summer) using ortho-rectified and atmospherically corrected Level-1C images to extract phenological information based on Normalized Difference Vegetation Index (NDVI). The complete phenological life cycle of crops including sowing, growing, and harvesting stages were deeply analyzed with the help of crop calendar and NDVI profiles. Then this information passed through iterative self-organizing (ISO Data Model) of unsupervised classification technique in the form of temporal stacked images. The NDVI profiles of each crop were synchronized with the crop calendar of the study area to develop the crop categorization procedure. The results were validated with the statistics of the agriculture department Lahore and field samples gave about 85% and 88% accuracy for Rabi and Kharif cropping seasons respectively. It is concluded from the research that the tested methodology is capable of providing a fast, cost-efficient, and reliable solution for crop mapping instead of conventional survey-based crop area assessment techniques (conventional Girdawri) which requires a vast number of resources and time, and it can be replicated in different areas with minor changes.

Keywords: Crop-classification, NDVI, phenology, stack, Sentinel, ISO data model.

INTRODUCTION

Accurate and real-time monitoring and mapping of crops are very important for food security, particularly in the challenging economy of Pakistan. The existing agricultural land area is under high pressure to meet the requirements of the continuously increasing population and climate change scenarios (Azam and Shafique, 2017). Pakistan's economy is much dependent on the agriculture sector which contributes about 19 % of the Gross National Product (Bint Zaman *et al.*, 2021). The 44% of the labour force get employment chances and 62% of the population from the rural area are dependent upon the agriculture sector. Developing countries like Pakistan must capitalise on and use the latest technology to overwhelm agricultural difficulties and in this way can enhance the product's quantity and quality, hence it needs time to produce the correct crop estimations to strengthen the decision-making regarding food security (Jamal eddine *et al.*, 2015). The cropland mapping of large study areas is a challenging task as per most of the relevant literature (Wardlow and Egbert, 2008; Lobell and Asner, 2004). Thus, it is essential to develop agricultural observation abilities to deliver crops updated information on time and approximation of cropped area yield data (Akhtar *et al.*, 2018). A plant goes through different biological changes (its growth throughout the period) under different climatic conditions commonly known as the phenological cycles (Gandhi *et al.*, 2015; Hamel *et al.*, 2009; Hrebei and Sala, 2016). The study of crop phenology is an important indicator to assess crop water requirements, health monitoring and yield modelling whereas the crop calendar described the duration of seeds sowing time, their peak time, and harvesting periods of

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different crops in an area.(Hussain *et al.*, 2008; Jakubauskas *et al.*, 2002; Khalid *et al.*, 2017).

GIS techniques and temporal datasets of satellite remote sensing make it easy and efficient to develop crop maps over a large area by capturing the phenological variations with minimum human and field resources (Tran *et al.*, 2022). Satellite image-based vegetation indices are well known for their application to identify crops and their types and NDVI is the most used and recommended index to assess crop health and its classification (Liu *et al.*, 2018). In 2010, (Heupel *et al.*, 2018) used MODIS's NDVI product along with the local crop calendar to study phenological changes and classify the different crops (Liu *et al.*, 2018) defined the crop calendar based on phenology profiles using the time series MODIS satellite data and cross-checked the results with pre-existed local crop calendar (Jamal eddine *et al.*, 2015) also aimed to map crop types by combining satellite imagery and crop calendar by using Landsat TM images in unsupervised classification and created the image stacks for each crop of its complete growing season. So, in contrast to conventional techniques which acquire survey-based crop data for crop mapping, remote sensing can provide free commercial-based dataset collection and algorithms to develop crop maps and regular monitoring (Rahman *et al.*, 2004). In this research NDVI based phenological curves or profiles were extracted for major crops of two cropping seasons of the study area using the time series Sentinel-2 satellite images. These profiles integrated with local crop calendar information utilized for the crop classification of both cropping seasons i.e., Rabi (October-April) and Kharif (May to October). The sentinel 2A and 2B satellites were launched in June 2015 and March 2017 respectively providing the facility to capture free-of-cost images in the same place for five days at regular intervals. In this research, the phenological pattern of the multiple crops was detected by comparing the time series NDVI data with the local crop calendar. The NDVI datasets were created from the high-resolution Sentinal-2 data which is freely available on the ESA website with five days' revisit time. This revisits time or temporal resolution plays an important role in the detection of the crop growth e.g., one can easily observe the sowing, development, peak and harvesting time of the crop by deriving their NDVI values over time. Remote Sensing practices are taking an edge over conventional ground survey techniques for vegetation mapping and have proved to be successful in a lot of published research.

The primary objective of the research was to develop crop classification of the study area using high-resolution satellite imagery that can be used as an alternative to extensive field surveys to estimate cropped areas. The secondary objective was to develop the crop phenology profile, it's validation with the local crop calendar and the validation of classified crops of the Rabi and Kharif seasons' area with the available resources.

Description of study area: The Sahiwal district (study area) is located between the rivers Ravi and Sutlej. The area is situated from 30°17'- 30°44' N of latitude and 72°27' - 73°15' E. The study area is considered one of the largest districts of Punjab, having a dense population and a wide variety of crops. Sahiwal district was the part of the semi-arid zone before the development of the irrigation system of Lower Bari Doab Canal (LBDC) (ur Rehman *et al.*, 2019). It covers a total area of 3,201 km^2 and has a population of 7.3 million (Rana and Bhatti, 2018). The major crops of the study area are wheat, cotton, sugarcane, maize, and rice, but farmers also cultivate vegetables including potato, tomato, turnip, and onion. This study area is also prominent for grain production and milk supply (Government of the Punjab, 2016).

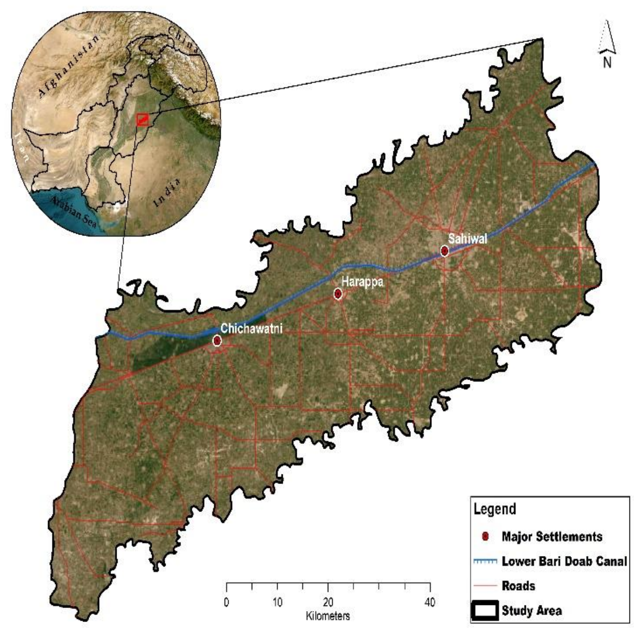

Figure 1. Study area map of district Sahiwal.

MATERIALS AND METHODS

The overall flow procedure of the research is demonstrated in Fig. 2. In this study, multispectral images from Sentinel-2 satellite were used to identify crop types and crop phenology. Three scenes (43RBP, 43RCP, and 43RCQ) of Sentinel-2 satellite were needed to cover the study area in a single instance i.e., a total of 78 images was processed for the whole cropping year from April 2018 to June 2019. All the images were downloaded from Copernicus Open Access Hub's official website (https://scihub.copernicus.eu) provided by the European Space Agency (ESA). The study area experiences the two-cropping season (Rabi and Kharif) within one annual cycle.

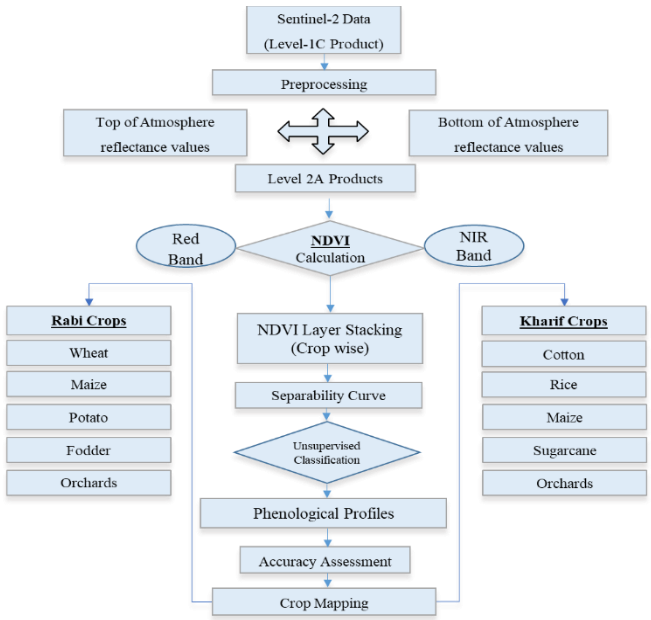

Figure 2. Flow methodology adopted in the research.

The Agriculture Department of Lahore, Punjab provided the crop calendar for the Sahiwal district, which was verified during the data collection phase by consulting the local farmers available in the study area (Fig. 3).

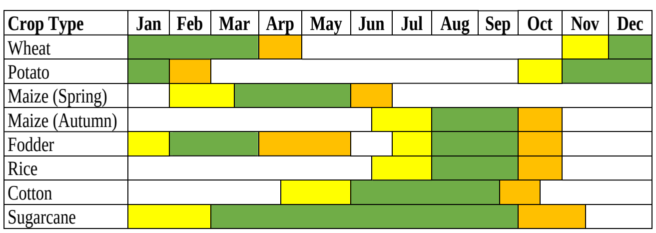

Figure 3. Crop calendar for district Sahiwal.

Prepressing: In the first step, raw Sentinel-2 Level-1C images were acquired and processed in open-source software SNAP 7.0 provided by European Space Agency (ESA) to get atmospheric and radiometric corrected Level-2A images. The SNAP 7.0 provides a tool named Sen2core processor which completed the whole image conversion procedure with the following steps as shown in Fig. 4 (Louis *et al.*, 2016).

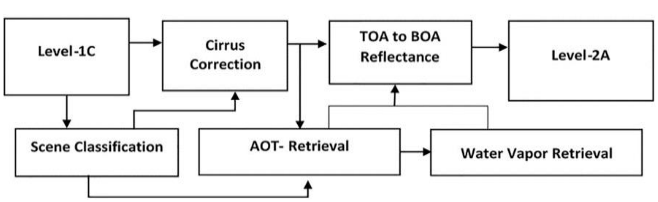

Figure 4. Sen2cor main processing steps in SNAP software.

***Calculation of NDVI and crop-based layer stacking*:** The Normalized Difference Vegetation Index (NDVI) is the most widely used index for crop classification (Wang *et al.*, 2019). The NDVI for each image of the study area was calculated using the Near Infrared (Band-8) and Red (Band-4) spectral bands of Sentinel-2 data shown in the equation below.

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

After calculating temporal NDVI, the images were stacked together as per their phenological cycle and crop stages (i.e., between the sowing and harvesting stages) using the local crop calendar for different individual major crops including wheat, spring maize, rice, tomato, cotton, sugarcane, autumn maize, and orchards. These stacks were visualized in RGB combination to analyse the tonal variation of different crops. A total of nine stacks were produced as per the nine major crops of the study area. The duration of all seasons of the NDVI images is presented in Table 1.

Table 1. Sentinel-2 images with scene index.

RBP	RCP	RCQ
6-Apr-18	6-Apr-18	6-Apr-18
26-Apr-18	26-Apr-18	26-Apr-18
11-May-18	11-May-18	11-May-18
26-May-18	26-May-18	26-May-18
5-Jun-18	5-Jun-18	5-Jun-18
10-Jul-18	10-Jul-18	10-Jul-18
30-Jul-18	30-Jul-18	25-Jul-18
24-Aug-18	24-Aug-18	Cloud Cover
13-Sep-18	13-Sep-18	8-Sep-18
28-Sep-18	28-Sep-18	28-Sep-18
8-Oct-18	8-Oct-18	8-Oct-18
28-Oct-18	18-Oct-18	23-Oct-18
7-Nov-18	7-Nov-18	7-Nov-18
2-Dec-18	2-Dec-18	2-Dec-18
27-Dec-18	22-Dec-18	22-Dec-18
6-Jan-19	6-Jan-19	6-Jan-19
11-Jan-19	16-Jan-19	26-Jan-19
5-Feb-19	5-Feb-19	5-Feb-19
15-Feb-19	15-Feb-19	15-Feb-19
7-Mar-19	7-Mar-19	7-Mar-19
17-Mar-19	17-Mar-19	17-Mar-19
6-Apr-19	6-Apr-19	6-Apr-19
26-Apr-19	21-Apr-19	26-Apr-19
6-May-19	6-May-19	6-May-19
26-May-19	26-May-19	26-May-19
5-Jun-19	5-Jun-19	10-Jun-19
30-Jun-19	30-Jun-19	30-Jun-19

Clustering algorithm based on Iterative Self Organizing Data Analysis Technique (ISODATA): The ISODATA clustering is an unsupervised technique, was used in this study for the clustering of feature data into crop types in ERDAS IMAGINE 2014. The K-means and ISODATA clustering techniques are the most frequently and unpretentiously used algorithms in unsupervised learning. They are simple in technique and widely used in remote sensing (Gumma *et al.*, 2016). ISODATA first determined the mean of distributed classes within the data space and then incorporates the minimum distance rule to iteratively combine the leftover pixel values. In every iteration, the average value was recomputed, and the pixel was again classified according to the new mean. The early clustering number or a number of classes was an essential constraint for the ISODATA classification (Ma *et al.*, 2020). In comparison to an unsupervised K-means classifier, ISODATA provides more customization by adding and splitting the defined end clusters to achieve more suitable results (Abbas *et al.*, 2016).

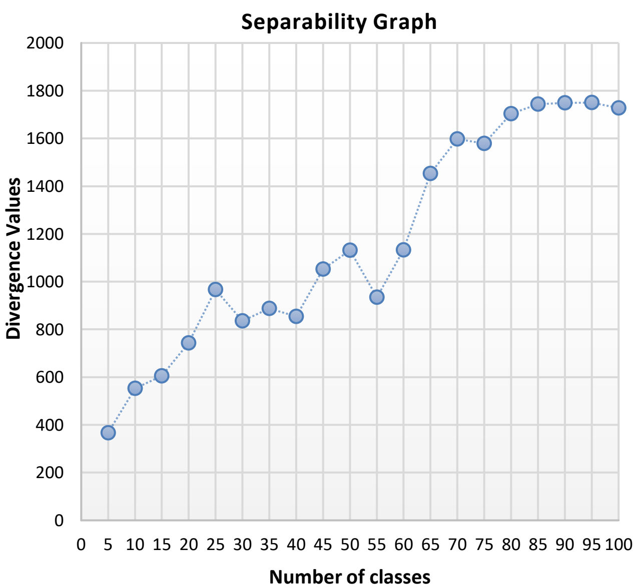

Figure 5. Separability curve for the number of clusters' selection for ISO Data Model.

The ISODATA clustering algorithm was used in ERDAS IMAGINE 2014 for the initial input. The separability curve was generated to select the number of classes for unsupervised classification through the plotting of the divergence value vs. the number of classes, as the divergence varies due to the variability in the image. The number of classes was defined for the classification by simply increment of five classes per stacked image. Generally, with an increase in the number of classes, the divergence increases, but after a certain number, it starts to decrease, which depicts the maximum divergence at that point. As a result, a total of one hundred classes were chosen for which the separability curve began to decrease (Fig. 5). After obtaining this plot, the hundred most divergent classes were used for this classification. To assign the names of crops to all classes, the classified data was compared with the ground-surveyed referenced data. The spectral signatures were also incorporated and compared with the local crop calendar provided by the Agricultural Department Lahore (Fig. 3).

Analysis and phenological NDVI profile: After processing the classification results for all major crops of the study area, the most significant phase of classification was achieved by deriving the NDVI curve from the stacked image by using the spectral profile tool available in ERDAS IMAGINE (2014). In this study, NDVI multiple phenological profiles were generated for each crop which was created on some random sites and then added this NDVI curve along with the dates of images from which NDVI was computed.

RESULTS

The flow diagram in Fig. 2 clearly demonstrated that the separability curve can be used to identify the number of land cover classes and identify the crop types based on phenological profiles through an unsupervised ISO data image classification algorithm. The spatial distribution of crop samples, which were collected to distinguish the unique phenological pattern as well as to perform accuracy, can be seen in (Fig. 6).

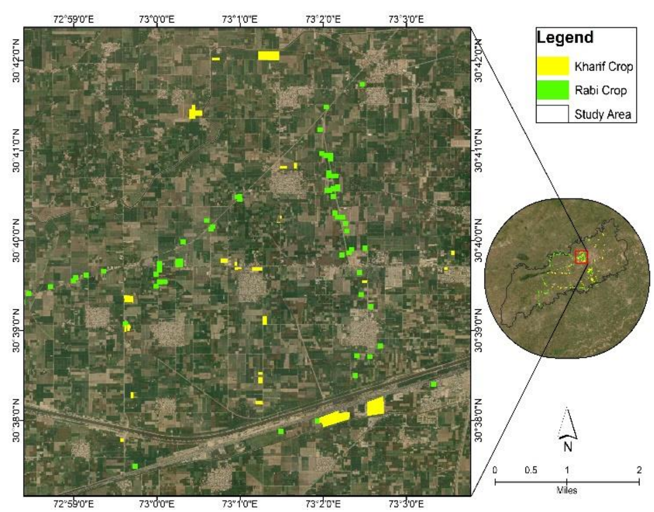

Figure 6. Spatial distribution of training and validation samples in the study area.

The process of assigning the crop names to each cluster number was performed in multiple steps to enhance the confidence and ultimately the accuracy of the outcomes. Firstly, the ground survey data overlapped on the clusters and clusters were labelled. Secondly, we analysed the NDVI-based phenological pattern of each identified crop cluster and cross-matched it with crop calendar information. This process was repeated for each major crop of the study area. The spectral profiles for wheat, autumn maize, cotton, rice, potato, spring maize, fodder and sugarcane are shown in Fig. 7 and classified crop maps are shown in Fig. 8.

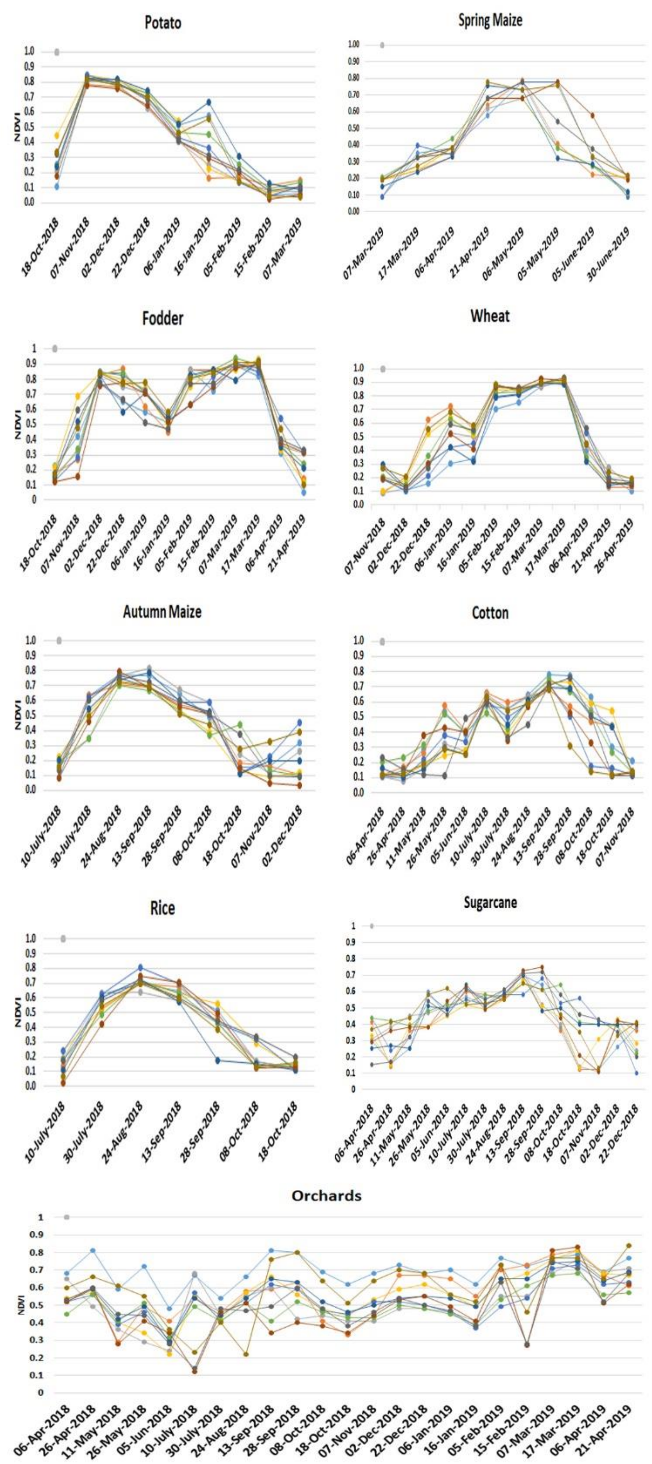

Figure 7. Phenological profiles of the classified crops.

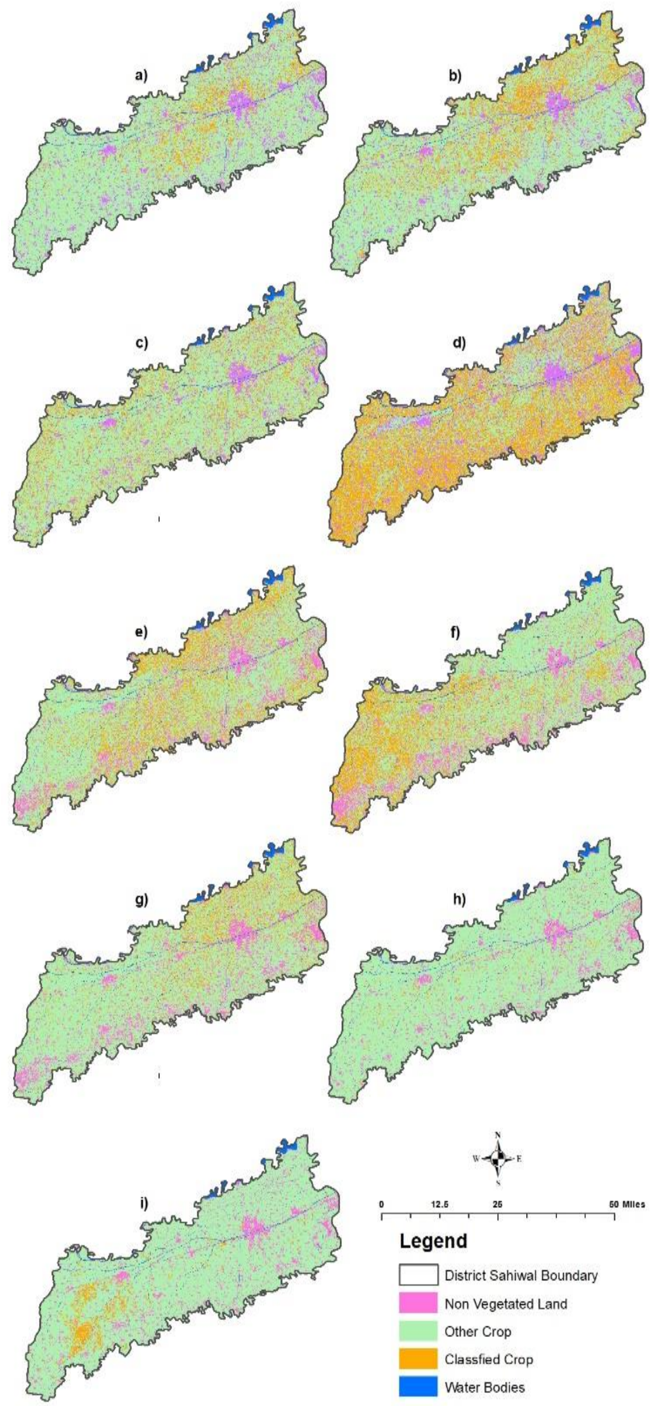

Figure 8. Crop classification maps using phenological profiles a) Potato, b) Spring maize, c) Fodder, d) Wheat, e) Autumn maize, f) Cotton, g) Rice, h) Sugarcane, i) Orchards.

All these individual crop layers were combined into a single composite separately for Rabi and Kharif seasons and then topological correctness was applied to remove the overlapped area of two crops within a cropping season. For example, some pockets of the wheat crop were overlapped with potato crops, as both crops are grown during the same cropping season. To remove this spatial ambiguity, we analysed these chunks repeatedly and assured that the final crop map is accurate based on the distinguished phenological profiles as well as field samples. The final crop type maps and corresponding phenological profile are shown in Fig. 9 and 10.

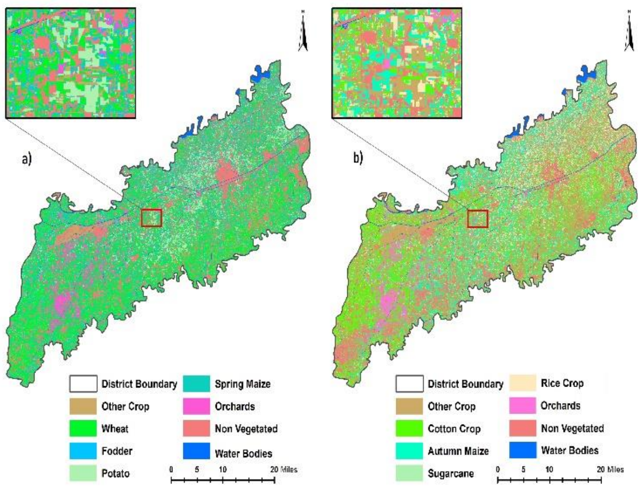

Figure 9. a) Rabi crops combined map b): Kharif crops combined map.

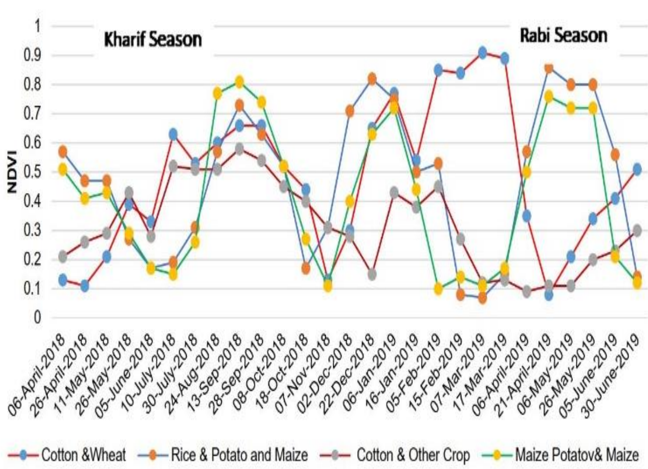

Figure 10. Annual phenological (NDVI based) profiles for of Rabi and Kharif Season.

Land cover area statistics for the Rabi and Kharif season maps (2018-19) are presented in Fig. 11 and 12. Results revealed that wheat, spring maize, fodder and potato covered about 39%, 15.88%, 15.69%, and 8% of the total area respectively during the Rabi season. While in the Kharif season, cotton, autumn maize, rice, and sugarcane contributed 19.79%, 18.86%, 10.88% and 2.70% of the total area respectively. The wheat crop from the Rabi season and the cotton crop from the Kharif season was identified as the dominating crops of the respective seasons.

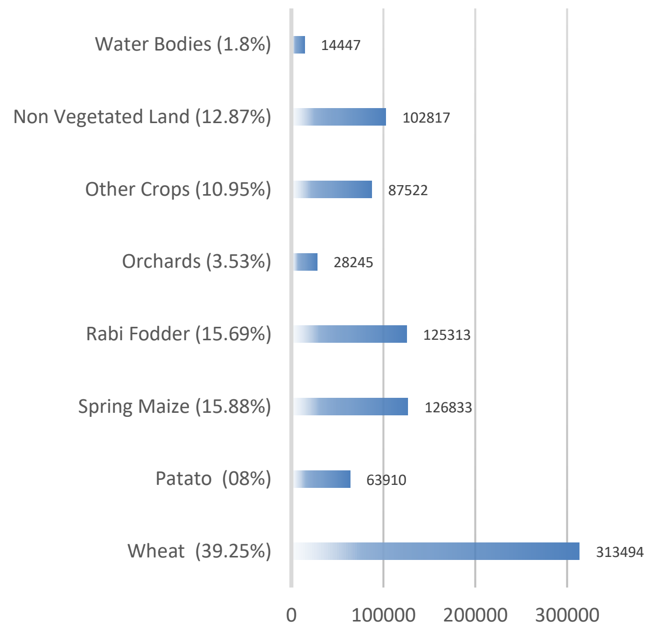

Figure 11. Land cover area statistics of district Sahiwal 2018-19 (Kharif season).

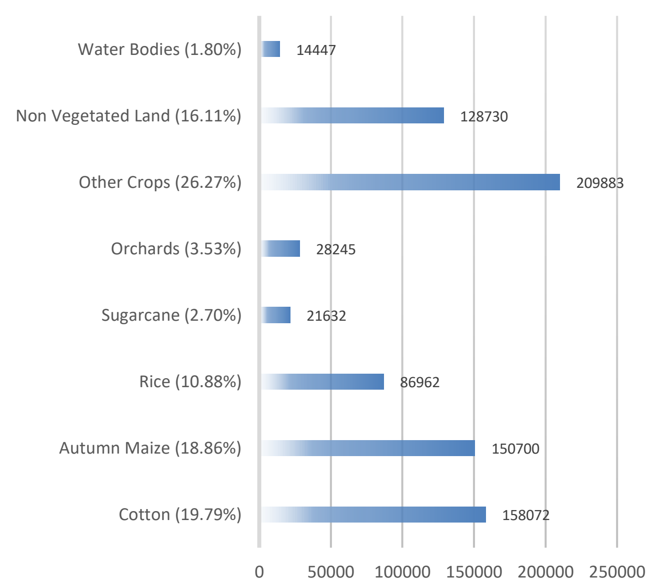

Figure 12. Land cover area statistics of district Sahiwal 2018-19 (Kharif season).

The crop maps of both seasons reflect that approximately 82.36% (657795 acres) of the study area was estimated as cropland during Rabi, while 58% (445611 acres) was estimated as agricultural land use during Kharif. The total cultivation area for Rabi crops was found approximately 26% more than the Kharif cultivation due to the dominance of wheat crops in the Rabi season which requires relatively less water and less maintenance cost. But on the other hand, rice and cotton as the dominant crops during Kharif season collectively didn't make as much as wheat cultivated during Rabi, probably due to high water demand, seeds cost and soil salinity.

Table 2. Classified crops areas for 2019-20 (Kharif season).

Kharif Crops	Area 2019 (Acre)	Percentage (%)
Cotton	158072	19.79
Rice	86962	10.89
Sugarcane	21632	2.71
Autumn Maize	150700	18.87
Orchards	28245	3.54
Other crops	209883	26.27
Water bodies	14447	1.80
Non-vegetated land	128730	16.11

Table 3. Classified crops areas for 2019-20 (Rabi season).

Rabi Crops	Area 2018-19 (acre)	Percentage (%)
Wheat	313494	39.25
Potato	63910	8.00
Spring Maize	126833	15.88
Fodder	125313	15.69
Orchards	28245	3.54
Other crops	87522	10.95
Water bodies	14447	1.80
Non-vegetated land	102817	12.87

In Punjab-Pakistan, the Crop Reporting Services (CRS) of the Punjab Agriculture Department performs the task of crop area estimation and it mainly relies on conventional sampling survey techniques. The sampling survey-based technique to assess the area of each crop, particularly for the huge Punjab Province is far more time taking and needs a lot of financial and human resources and is not fully reliable, particularly for the remote areas. However, satellites cover every inch of the land and provide more frequent snapshots. In this study, the focus is on crop mapping using advanced remote sensing techniques which can return a high level of accuracy in a short time and can be applied repeatedly. Therefore, a comparison of the outcomes of our study has been made with the average statistics of three years published by the CRS department to cross-check the accuracy of our results (Table 4) and (Fig. 13, 14).

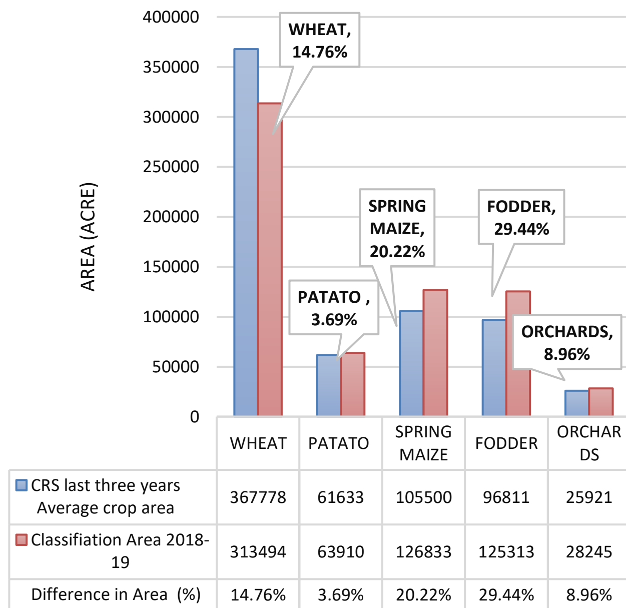

Figure 13. Data validation with Crop Reporting Services (CRS) for three years (2015-2018) of the Rabi season.

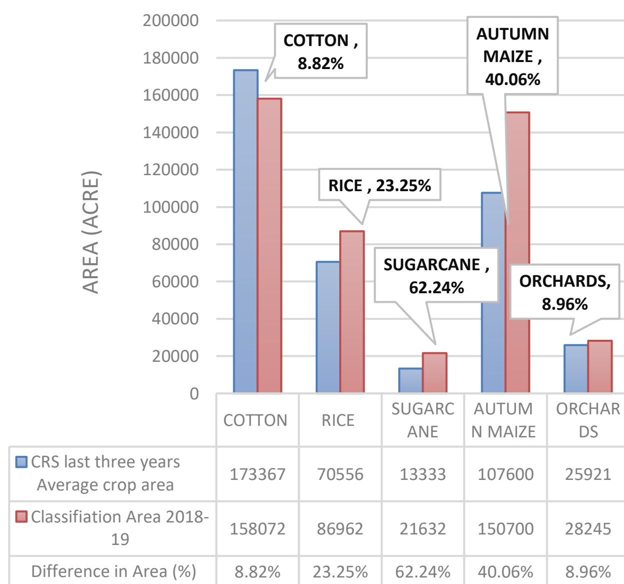

Figure 14. Data validation with Crop Reporting Services (CRS) for three years (2015-2018) of the Kharif Season.

The field survey data was also used to validate the classification results. In this study, the overall accuracy for the Rabi and Kharif crops was assessed around 85.60% and 88.51% and Kappa was around 0.82 and 0.85, respectively as Table 5 and 6.

Table 4. CRS Annual published Report of main crops during 2018-2019 in district Sahiwal.

Crop Types	CRS Crops Report 2015-16	CRS Crops Report 2016-17	CRS Crops Report 2017-18	Average Area 2015 to 2018
Wheat	387000	352000	364333	367778
Potato	61800	61200	61900	61633
Spring Maize	103000	108000	105500	105500
Fodder	98700	95000	96733	96811
Cotton	212000	138000	170100	173367
Rice	70000	70000	71667	70556
Sugarcane	14000	13000	13000	13333
Autumn Maize	99100	117000	106700	107600
Orchards	29923	22917	24924	25921

Table 5. Accuracy assessment for Kharif crops map.

Classified Data	Cotton	Autumn Maize	Rice	Orchards	Sugarcane	Row Total	Number Correct	Producer Accuracy	User Accuracy
Cotton	43	2	0	0	4	49	43	86.00%	87.76%
Maize	1	44	5	0	0	50	44	86.27%	88.00%
Rice	0	4	46	1	0	51	46	90.20%	90.20%
Orchards	3	2	0	43	0	48	43	95.56%	89.58%
Sugarcane	3	1	0	1	32	37	32	88.89%	86.49%
Column Total	50	53	51	45	36	235	208	Overall classification accuracy 88.51% overall Kappa statistics 0.856	

Table 6. Accuracy assessment for Rabi crops map.

Classified Data	Cotton	Autumn Maize	Rice	Orchards	Sugarcane	Row Total	Number Correct	Producer Accuracy	User Accuracy
Cotton	45	3	0	0	2	50	45	91.84%	90.00%
Maize	3	42	1	4	0	50	42	85.71%	84.00%
Rice	0	1	44	5	0	50	44	97.78%	88.00%
Orchards	0	5	0	42	3	50	42	76.36%	84.00%
Sugarcane	1	4	0	4	41	50	41	89.13%	82.00%
Column Total	49	55	45	55	46	250	214	Overall classification accuracy 88.51% overall Kappa statistics 0.856	

DISSCUSION

Satellite remote sensing can be used to identify crop types efficiently over a particular season and is suited for continuous monitoring of agricultural land with limited resources. It gives us a reliable solution as compared to the conventional methods for crop type assessment which consumes bigger resources and time. The challenge observed during this study was intercropping i.e., two crops are sown (e.g., autumn maize and fodder) at the same time in a field; in such cases, it becomes very difficult to discriminate crops even using high-resolution imagery. This problem was addressed to get better results by incorporating field sample data. A similar situation was observed for orchards where land was utilized for intercropping, by growing wheat or fodder inside orchard fields. Such cases were handled by taking field samples and carefully developing signatures of these crops. The unavailability of vegetable calendars was another obstacle because many pockets were identified as vegetable fields, and it was also confirmed during the field surveys that farmers don’t follow the specific calendar for vegetables. So, discrimination between vegetables and agronomic crops needs more attention which will be addressed in the follow-up study and a comparison will be made with CRS-reported data. However, for fodder crops, there has been a significant underestimation in data reported by Crop Reporting Services compared to the statistics generated through crop classification.

***Conclusion*:** Remote sensing methods are capable of being an instrumental help in decision support for the agriculture sector. In this work, the proposed approach provides cost-effective ways for monitoring crop health and assessment of crop acreage. NDVI-based unique phenological patterns of each crop provide a scientific rationale to rely on remote sensing methods which can generate accurate results with very limited constraints in data availability. Crop calendar information was also synchronized to cross-check the unique NDVI pattern as per their development stages and chlorophyll content. It can also be extended to identify any dip in the health of growing crops and can help to safeguard reduction in yield. Similarly, with minimum changes, this approach can be utilized to make decisions about the upcoming production and storage strategy for crops being grown in the application area. By applying the ISODATA unsupervised categorization methods the result of some specific crops demonstrated varying phenological patterns all over the seasons because of the inter-cropping, and difference in crop calendar in different parts of the study area. Hence, this study recommends a semi-automatic approach for crop classification by integrating the information extracted from unique NDVI patterns representing phenological cycles, local crop calendar and field samples data. Moreover, differentiating vegetables from agronomical crops using the current approach is a bit limited and probably needs more testing; however, it can be improved by developing local vegetable calendars by dividing the study area into further smaller units. In the end, it is concluded that the research approach can be very beneficial to be used by the agriculture sector, especially the crop reporting service (CRS), which can apply and test this model to strengthen and improve their crop reporting statistics by covering the whole province on a near real-time basis. The irrigation department can also adopt this model to identify crops being grown in their canal command areas and allocate water based on crop needs.

***Conflict of Interest*:** The authors reported no potential conflict of interest.

***Authors' Contribution Statement*:** The analysis and data collection performed by MS, WY and WKA supervised for all the analysis and write-up working whereas SR conceived the idea and supervised the work.

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