MAPPING CROPS FROM THEIR TEMPORAL BEHAVIOR BY INTEGRATING SENTINEL-2 SATELLITE AND GROUND DATA

AHSANULLAH[1*] AND SUMAIRA ZAFAR[2]

Department of Remote Sensing and Geo-Information Science Institute of Space Technology, Karachi, Pakistan.
**Corresponding author email: aukhan.geo@gmail.com*

خلاصہ

زراعت کی بہتر پیداواراور تحفظ کے لئے فصل کی نگرانی ضروری ہے. فصلوں کی نگرانی کو سمجھنے کے لئے یہ بھی ضروری ہے کہ موسمیاتی تبدیلی کس طرح فصلوں کے پیٹرن پر اثرانداز ہو رہی ہے.

ریموٹ سینسنگ کی صلاحیت کی بدولت دنیا بھر میں وسیع مقامی گرینولائزیشن فراہم کی گئی جس کی مدد سے بڑےپیمانے پر فصلوں کی اقسام کی نقشہ سازی اورحیاتاتی پیرامیٹرز کے تخمینہ کے لئے مدد ملی.

سینٹنل سیٹلائٹ کاآغاز(کوپرنیکس پروگرام) فصلوں کو منظم طریقے سے ہر5 سے10 دن کی نگرانی کرنے کاایک منفرد موقع فراہم کرتا ہے. فصل کی نگرانی کے لئے استعمال ہونے والے طریقوں کی تخلیق میں ہر فصل کی نوعیت میں عارضی تبدیلیوں کو سمجھنا متفرق خصوصیات میں شامل ہے.اس مطالعہ کا مقصد ڈسٹرکٹ بنوں میں ویجیٹیشن انڈیکس کے تجزیہ کی بنیاد پر مختلف قسم کے فصلوں کی شناخت جس میں موسم سرماکی فصلوں(گندم، سرسوں، گاجراورلوسن) سمیت دوران موسم فصل کی صحت کی شناخت ہے.

اکتوبر2017 سے اپریل2018 تک سینٹنل. دوئمسیٹلائٹکی تصاویر حاصل کی گئی ہیں. ہر فصل کی فینولوجی پروفائلزاین ڈی وی آئی اور فصل کیلنڈر سمیت سبز صحت کے انڈیکس پر مبنی ہیں.

ان فینولوجی پروفائلز کوماحولیاتی حالات کے ساتھ طبعی طور پر تشریح کی گئی اور10 میٹر ریزولشن پر نقشہ کشی کی گئی. حاصل کردہ فصل کے علاقے اوراس کی صحت کے نتائج بہت قابل ہیں اور روایتی فصل کے اعداد و شمار جمع کرنے کے طریقوں کے مقابلے میں تیز رفتار، مؤثرلاگت پذیری اور قابل اعتماداعداد و شمار فراہم کرنے میں منظور شدہ تکنیک کی کارکردگی کو نمایاں کرتی ہے.

Abstract

Monitoring of crop is important for food security and to improve agricultural productivity. Crop monitoring is also important to understand that how changing climate is affecting the cropping pattern. The ability of remote sensing to provide increased spatial granularity across the globe extensively helped in mapping crop types and for the estimation of biophysical parameters. The launch of Sentinel satellite (Copernicus programme) gives a unique opportunity to monitor crops systematically every 5 to 10 days. The development of operational crop monitoring methods involves an understanding of the temporal variations in spectral properties of each crop type. This study aims to analyze the temporal trajectory of vegetation indices for the identification of a variety of crops including winter and summer crops (wheat, mustard, carrot and alfalfa) and their health during the season in Bannu District. Sentinel-2 satellite images have been acquired from October 2017 to April 2018. Phenological profiles of each crop were derived based on the vegetation health index including NDVI and crop calendar. These phenological profiles along with environmental conditions were interpreted physically and mapped at 10-meter resolution. The results of the crop area and its health obtained are much promising and highlight the efficiency of the adopted techniques in delivering quick, cost-effective, traceable and reliable data compared to the conventional crop data collection methods.

Index Terms— Crop Type Mapping, crop monitoring phenology, Sentinel-2

Introduction

The continuous monitoring of crop health and timely information on crop yield is critical to many socio-economic applications. The information about crop yield and health could be an input for the decision-making authorities to make a decision on the issues of food security and extreme weather conditions such as famine or drought. In the developing countries like Pakistan, the crop estimation techniques are usually based on conventional survey methods which question the reliability of crop data being manual in character. Thanks to satellite remote sensing for its coverage and temporal resolution, it is providing uninterrupted land surface information. Medium and coarse spatial resolution satellite data (Landsat and Moderate Resolution Imaging Spectroradiometer - MODIS) is a continual source of valuable information. These data have helped in developing models for crop yield forecasting, health and damage assessment from Global to local scales. This remote sensing data assist in crop growth monitoring, through accurate and timely phenological status information and vegetation development. This information can also provide valuable information on different issues, specifically, if they combined with agro-hydrological models for crop yield (Ferrant *et al*., 2014)(Fieuzal and Baup, 2015) carbon (Veloso *et al*., 2017)(Revill, Sus, Barrett, and Williams, 2013)and water budget (Le Page *et al*., 2014). Most of the vegetation indices have a direct relationship with crop performance.

In view of many scholars, the cropland mapping of large study areas is a challenging task (Lobell & Asner, 2004)(Wardlow & Egbert, 2008). Optical data provide the opportunity to analyze the photosynthetic and optical properties of the plant leaves using a number of vegetation indices. Normalized Difference Vegetation Index (NDVI) is one of the commonly used indices for vegetation health mapping. Optical data also enables us to derive a range of crop added-value products, such as crop area estimates, crop type maps (Wardlow and Egbert, 2008) and estimation of biophysical parameters at various phenological stages (Qureshi and Lu, 2007)(Quramby *et al*. 1993)(Bontemps *et al*., 2015). Vegetation indices such as Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Vegetation Health Index (VHI) and/or biophysical parameters such as Leaf Area Index (LAI), Fraction of Photosynthetically Active Radiation (FPAR) and gross primary products could be used to assess crop yields at district level.

In past monitoring of crop, dynamics was very much hindered by the unavailability of higher spatiotemporal satellite time series data. The launch of Sentinel -2 satellite by the European Space Agency is the start of a new era of optical remote sensing, providing the nonpareil amount of free data for the continuous spatial monitoring needs. Sentinel-2A launched in June 2015 and Sentinel-2B launched in March 2017 are now providing data at a time interval of 05 days. This temporal resolution varies according to the data type and the region of the world. This reduced temporal resolution can help in weekly crop monitoring.

For Sentinel-2 (12 days temporal resolution for Pakistan) and Landsat 8 (16 days temporal resolution) remote sensing satellites, the combined temporal resolution has been reduced up to 06 days, and therefore it is very helpful to study the biophysical parameters of the agriculture. This study aims to investigate the Sentinel-2 remote sensing satellites data for crop mapping and health monitoring. The study involved mapping different types of crops, identifying the shifts in crop periods with respect to the previous crop calendar and to analyze the NDVI profiles for crop water stress conditions. For this study, the previously used approach of using time series NDVI for the cropping season based on the crop calendar was used. This technique allows the mapping of crops based on their phenology (Zafar and Waqar, 2014). Sentinel 2 with the higher temporal resolution availability of data made it easier to analyze the crop phenology on each 6th day and the crop was mapped at the scale of 10-meter resolution.

Study area

The study was conducted in an agriculturally rich area with multi-cropping. Bannu District of Khyber-Pakhtunkhwa was selected for mapping its crop and their health. The study area district Bannu is located in the south of Khyber Pakhtoonkhwa, bordered by Karak, Lakki Marwat and North Waziristan (F.A.T.A.) (Figure 1). Agriculture is the main source of livelihood in Bannu district. Around 92 percent of the total population is involved in agricultural activities, while the rest of the population is based in urban areas of the district. The total cropped area reported in the study area is 32,796 hectors (GoP, 2017). The major crops grown in the study area are wheat, rice, maize, mustard, onion, ginger etc. whereas some of the fruits are grown as cash crops, like guava, sugar cane, banana and palm date. Bannu has warm to hot summer with mean maximum temperature of about 37.4°C (GoP , 2012). Dust storms are very common in early summers especially in the month of May and June. Winters are cool with the mean minimum temperature of around 10.3°C. The mean annual range of temperature is quite high that is 21.8°C. Rainfall is widely distributed throughout the year, roughly 50percent falls in summer (July to September) usually in the form of a thundershower. The winter rain (December to February) contributes around 20 percent of the total rain that impacts positively on kharif crops especially in barani areas of the district.

Materials and Methods

Sentinel-2A/2B Satellite Images

For this study, 21 images of Sentinel 2-A and 2-B were acquired from Copernicus Open Access Hub, respectively. The images were acquired from October 2017 to April 2018 to cover winter crops of Bannu district.

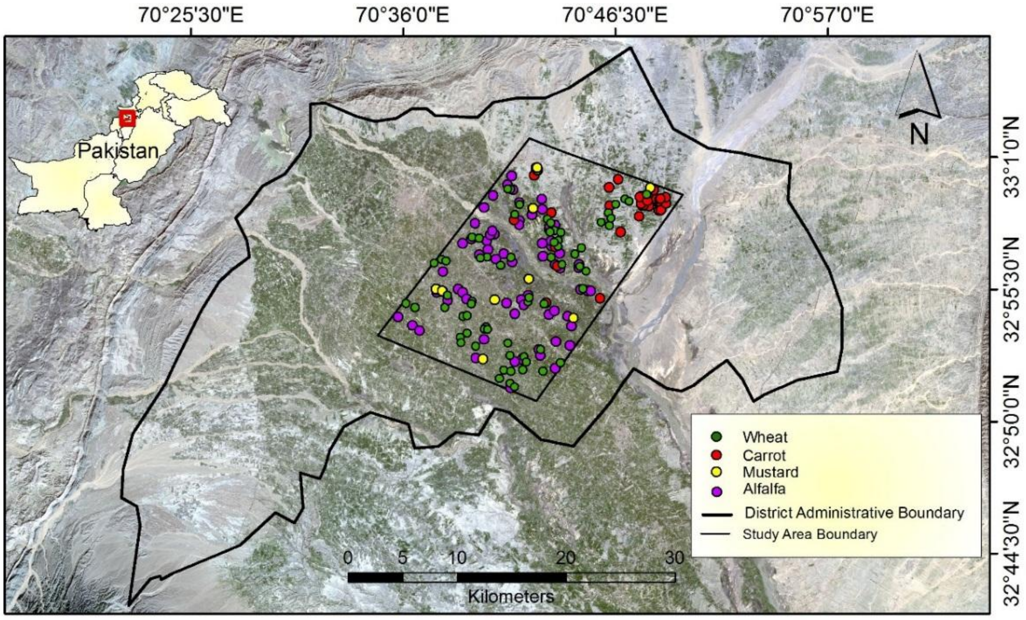

Fig.1. Study Area

Image Preprocessing and Atmospheric Correction

Sentinel 2 Level 1 products were downloaded and atmospherically corrected to convert into level 2 products which were further processed as shown in (Figure2) up to accuracy level. This processing involved the calculation of time series NDVI, applying the ISODATA unsupervised classification to create 100 classes for crops to delineate the crops from there phonological profiles. The map prepared on pehnological base was testified using the ground data (GPS coordinates) collected during the study period.

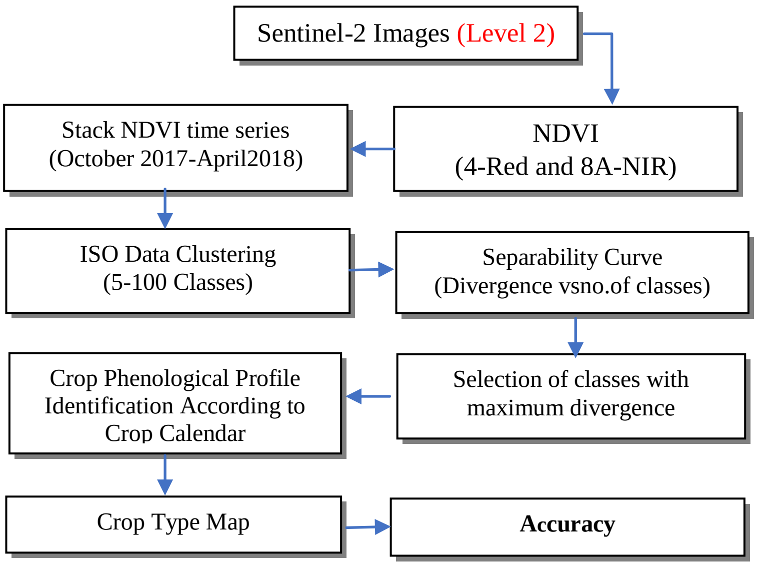

Fig.2. Methodology

Crop Type Mapping and health monitoring

To map the crop type Normalized Vegetation Index (NDVI) was computed for Sentinel-2A scenes using band 8A (NIR) and band 4 (red) (Figure 3). Following formula was used to compute the NDVI;

$$\mathbf{NDVI = (NIR\text{-}Red) / (NIR + Red)}$$

After computing NDVI, all the images were stacked from the starting period of the winter crop (October 2017) to the last scene of the winter crops in April 2018. This period covers the all major growing winter crops of the Bannu District. To map crop type using time series NDVI data, separability of classes were measured using divergence. Divergence measures the separability of a pair of probability distributions based on the degree of overlap of two spectral classes which is defined as the likelihood ratio. In our study, the separability of crops classes was checked by plotting the divergence against a number of crop classes. The unsupervised classification of time series VIs was done using ISODATA clustering, ISODATA clustering was done using a class interval of 05 to 100 classes. Identification of crops based on the phenological profiles extracted through ISODATA clustering of VIs time series.

Accuracy Assessment

To validate the resultant classified map, accuracy assessment has been done with collected GPS points of crops. Overall all accuracy and Kappa coefficient have also been calculated.

Results and Discussion

The study outcomes are divided into four parts; 1) development of separability curves to identify the best number of classes for the data; 2) analysis and identification of phenological profiles of specific crops; 3) crop mapping; 4) accuracy assessment.

1. Separability Curve

Divergence varies with a different number of classes due to the variability in the dataset. In general, the divergence increases with the number of classes but after certain classes, the divergence started to decrease which means that the class with the highest divergence have maximum variability in the data. The classification results of 100 classes with the highest divergence used to identify the crop type in this study.

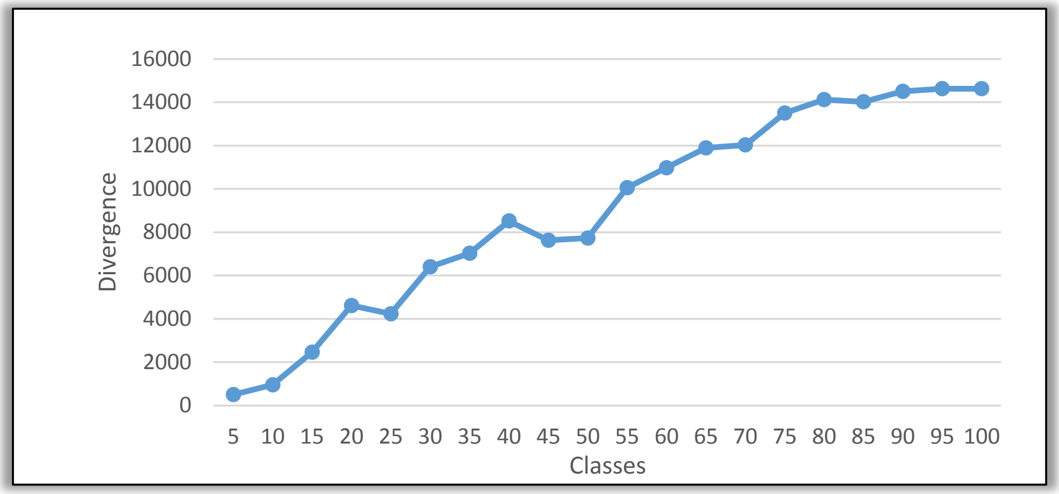

Fig.3. Separability Curve

2. Phenological profile for each Crop

With ISODATA clustering, signature profiles for each class were also generated. These signature profiles show the trend of NDVI from October 2017 to April 2018. For the vegetative cover, it shows the variation of the entire year. All the profiles were plotted and checked against the crop calendar of the study area to identify the crops and major health issues if any. Phenological profiles for all the Crops extracted and mapped the crop type at 10-meter resolution, Sentinel 2 gives us the opportunity to estimate the area more precisely.

a. Wheat

Wheat crop is sown in between months of October to December and harvested in March and April. For the wheat crop, two type of phonological profile has been observed in the study area(Figure 4).The phenological profile (blue) shows that the NDVI value is at the minimum level that means the area is cropless or a fellow land. At the start of the phenological profile (Blue) is increasing slowly but there is a stage where the growth stage stops due the winter season till February. After that, the growth starts rapidly in spring till the peak of maturity to harvesting.

In the orange profile, the NDVI decline is shown before the wheat seeding process which means that the land was not fellow before the seeding process.

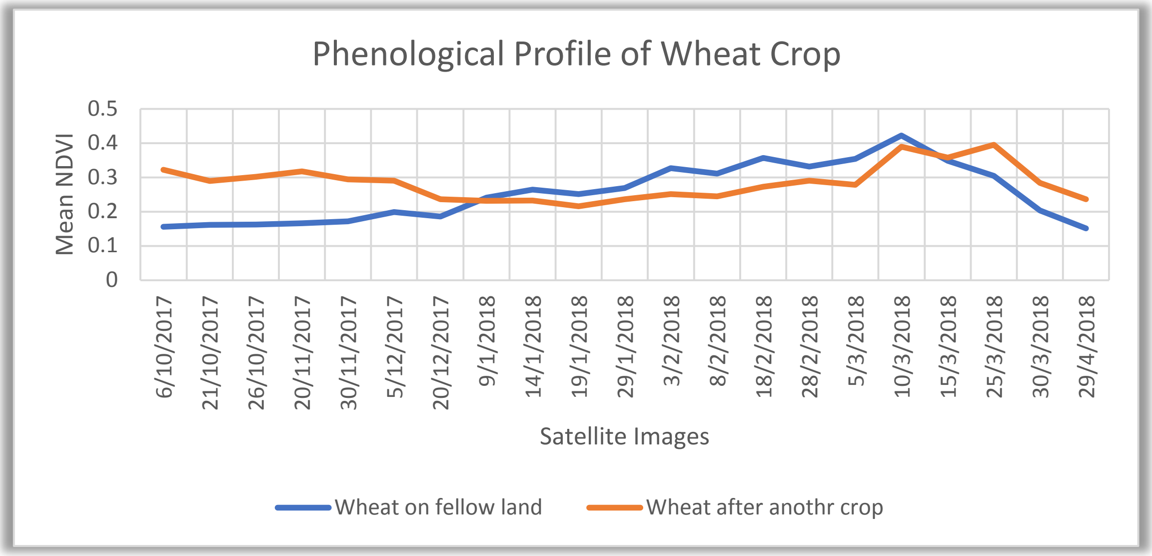

Fig.4. Phenological Profile of Wheat Crop

Mostly farmers grow maize or any other crop before wheat. This makes the seeding process late as well as it decreases the fertility of soil which impact on the growth of the wheat crop. It also makes the difference in phenology of the same crop at a different situation which might affect on crop production also.

Since the fellow lands are specially prepared for the forthcoming crop by using fertilizers as well as other necessary preparation for the crop, the land becomes more fertile. Therefore when crops are grown on these lands their growth is healthier than crops growing in regular rotation on normal fields. Moreover the yields of the crop growing on the fellow land is also higher than the crops growing in the rotation.

b. Carrot

In Bannu district, the root crop (carrot) sown in early October. According to the temporal NDVI (Figure5)values, there are two types of phonological profiles for a carrot. One which shows the seeding to harvesting period of the carrot crop and other profile with higher NDVI peak extended from November to end of January shows that the crop is preparing for inflorescence to get the new seeds for next year crops.

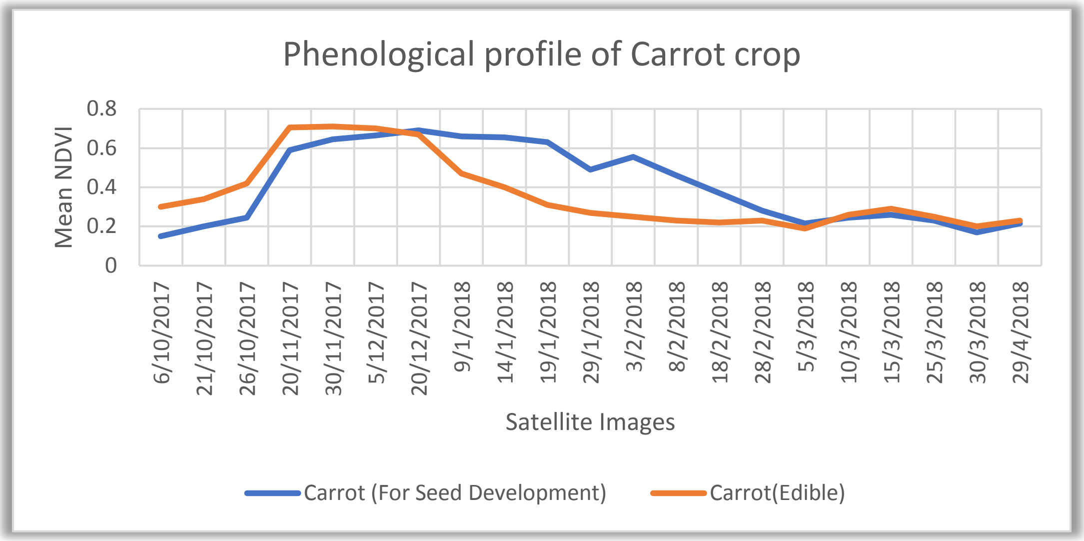

Fig.5. Phenological Profile of Carrot Crop

c. Mustard:

In Bannu district, the Mustard crop is planted on small scale and which has been identified at few places in the study area. Sowing of Mustard mainly starts in the month of October and gets mature at the end of November (Figure 6). As time passes the crop NDVI values slowly start decreasing until crop reaches to develop new seeds. Generally, oil is extracted from these seeds which is used for cooking purpose.

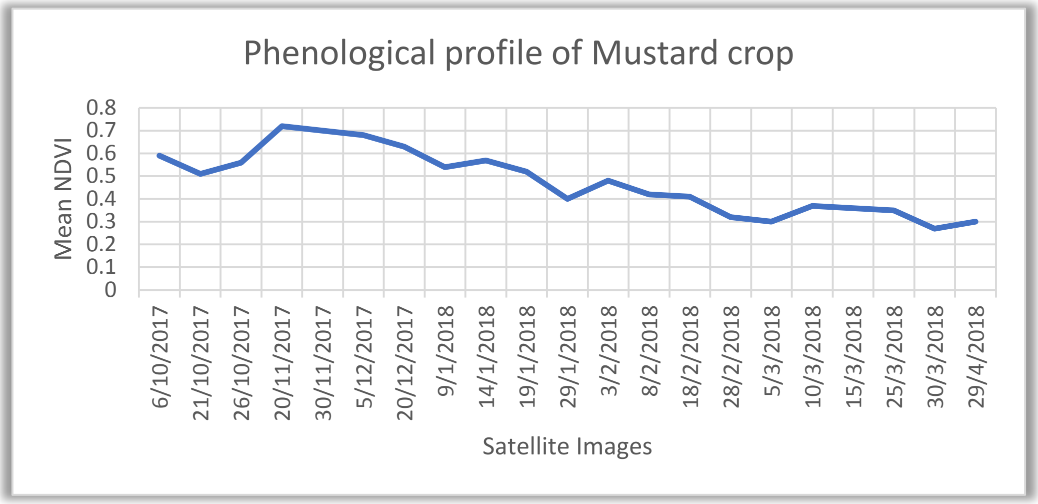

Fig.6. Phenological Profile of Mustard Crop

d. Alfalfa

Alfalfa is also one of the winter crop grown as a fodder for livestock on a large area in the study area. According to alfalfa phonological profile (Figure7), it is sown in December and completed its cycle in May. There are three high spikes in mean NDVI of alfalfa which shows that the crop is reaping thrice in a season from sowing to harvesting period.

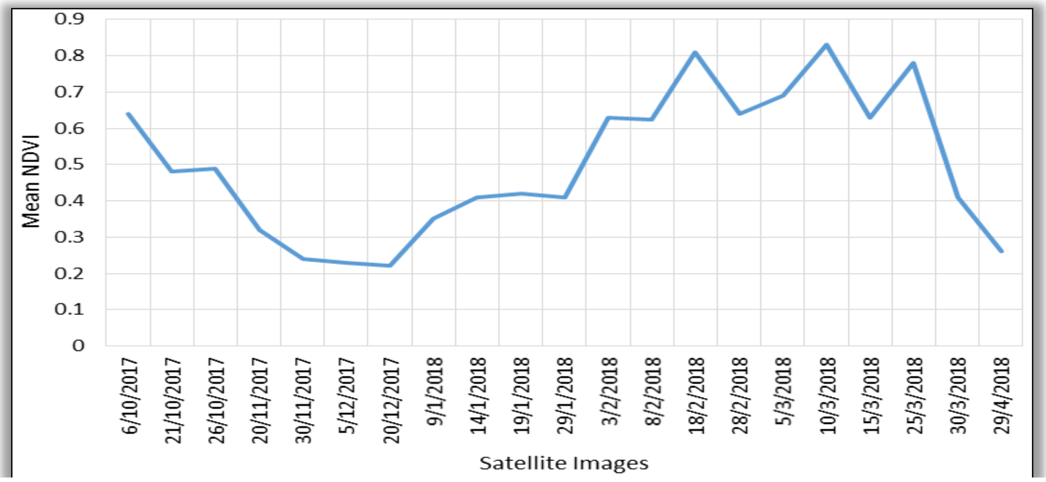

Fig.7. Phenological Profile of Alfalfa Crop

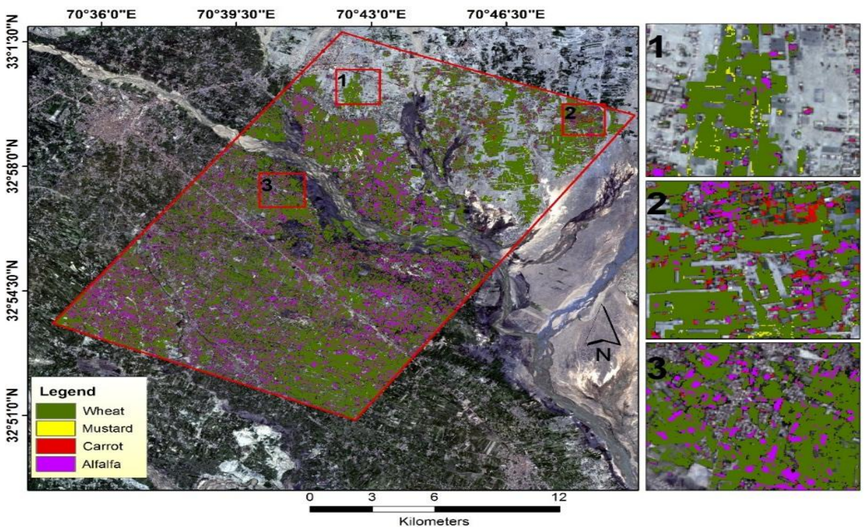

Fig.8. Phenological Based Classified Map of Crop Types

3. Crop Map

With respect to the phenological profiles, all the major crops were mapped. Figure 8 shows the map of all crops identified based on the phenological profile. Wheat and Alfalfa are dominant crops in the area. Wheat is represented with dark green and Alfalfa with light green colors. Mustard and carrot are not cultivated on a large area and we have identified them in patches, showed as yellow and red colors respectively.

4. Accuracy assessment

To check the accuracy of crop identification, ground data (GPS coordinates) were used. The overall accuracy for the crop mapping is 90% and Kappa is also 90%.

Class	Alfalfa	Wheat	Mustard	Carrot	Total	User Accuracy
Alfalfa	40	3	0	0	43	0.930
Wheat	3	28	0	0	31	0.903
Mustard	1	2	24	0	27	0.888
Carrot	0	2	0	12	14	0.857
Total	44	35	24	12	**115**	
Producer Accuracy	0.909	0.8	1	1		
Overall Accuracy	0.904348					
Kappa	0.904324					

Conclusion

Crop mapping was performed on the basis of the temporal behavior of crops by using Sentinel 2 data along with the ground information. Identification of crops was done by deriving phenological profiles of the crops through ISODATA clustering of time series NDVI data. The results of some crops showing multiple phonological patterns throughout the season due to the presence of other crops. Ground sample point of each crop helped in identification of pure phenological profile of each crop. Multiple cropping is a common practice in Pakistan. Moreover, the study also underlined the spatial behaviors of crop phenology, impacts of sowing times/agronomic practices on crop behavior and the temporal shifts. It can be concluded that mapping crops through remote sensing data by exploring phenological patterns is an efficient, reliable and traceable technique compared to other methods.

References

Bontemps, S., Arias, M., Cara, C., Dedieu, G., Guzzonato, E., Hagolle, O., … Defourny, P. (2015). Building a Data Set over 12 Globally Distributed Sites to Support the Development of Agriculture Monitoring Applications with Sentinel-2. *Remote Sensing*, *7*(12), 16062–16090. https://doi.org/10.3390/rs71215815

Ferrant, S., Gascoin, S., Veloso, A., Salmon-Monviola, J., Claverie, M., Rivalland, V., … Bustillo, V. (2014). Agro-hydrology and multi-temporal high-resolution remote sensing: toward an explicit spatial processes calibration. *Hydrology and Earth System Sciences Discussions*, *11*(7), 7689–7732. https://doi.org/10.5194/hessd-11-7689-201

Fieuzal, R., and Baup, F. (2015). Estimation of sunflower yield using multi-spectral satellite data (optical or radar) in a simplified agro-meteorological model. In *2015 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)* (pp. 4001–4004). IEEE. https://doi.org/10.1109/IGARSS.2015.7326702

GoP, 2012 Climatic Normals of Pakistan, 1961-2010, Pakistan Meteorological Deparment, Government of Pakistan, Karachi.

Gop,2017 Development Statistics of Khyber Pakhtunkhwa 2017, Government of Pakistan Islamabad.

Le Page, M., Toumi, J., Khabba, S., Hagolle, O., Tavernier, A., Kharrou, M., … Jarlan, L. (2014). A Life-Size and Near-Real-Time Test of Irrigation Scheduling with a Sentinel-2 Like Time Series (SPOT4-Take5) in Morocco. *Remote Sensing*, *6*(11), 11182–11203. https://doi.org/10.3390/rs61111182

Lobell, D. B., and Asner, G. P. (2004). Cropland distributions from temporal unmixing of MODIS data. *Remote Sensing of Environment*, *93*(3), 412–422. https://doi.org/10.1016/J.RSE.2004.08.002

Quarmby, N. A., Milnes, M., Hindle, T. L., and Silleos, N. (1993). The use of multi-temporal NDVI measurements from AVHRR data for crop yield estimation and prediction. *International Journal of Remote Sensing*, *14*(2), 199–210. https://doi.org/10.1080/01431169308904332

Qureshi, I. A., and Lu, H. (2007). Urban transport and sustainable transport strategies: A case study of Karachi, Pakistan. *Tsinghua Science and Technology*, *12*(3), 309–317. https://doi.org/10.1016/S1007-0214(07)70046-9

Revill, A., Sus, O., Barrett, B., and Williams, M. (2013). Carbon cycling of European croplands: A framework for the assimilation of optical and microwave Earth observation data. *Remote Sensing of Environment*, *137*, 84–93. https://doi.org/10.1016/J.RSE.2013.06.002

Veloso, A., Mermoz, S., Bouvet, A., Le Toan, T., Planells, M., Dejoux, J.-F., and Ceschia, E. (2017). Understanding the temporal behavior of crops using Sentinel-1 and Sentinel-2-like data for agricultural applications. *Remote Sensing of Environment*, *199*, 415–426. https://doi.org/10.1016/j.rse.2017.07.015

Wardlow, B. D., and Egbert, S. L. (2008). Large-area crop mapping using time-series MODIS 250 m NDVI data: An assessment for the U.S. Central Great Plains. *Remote Sensing of Environment*, *112*(3), 1096–1116. https://doi.org/10.1016/J.RSE.2007.07.019

Zafar, S., and Waqar, M. M. (2014). Crop type mapping by integrating satellite data and crop calender over Okara district, Punjab, Pakistan. *Journal of Space Technology*, *4*(1), 3–7.