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# Area estimation of saffron cultivation using satellite images and time difference method (case study: Fazl Village in Nishabur County of Iran)

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## Abstract
Estimating crop area is a key factor for crop monitoring and agricultural management. Having annual information on crop acreage and production change is necessary for agricultural decision-makers and planners. In recent years, the cultivation of saffron in Nishabur has received more attention by farmers due to low water requirements and its good income. Planning for the marketing of this strategic product and the provision of agricultural inputs for saffron requires that the information of the area under its cultivation be estimated accurately. The aim of this study was to monitor changes in cultivated areas and to estimate the saffron area using satellite imagery with different spatial resolutions and time series normalized different vegetation indexes (NDVITs). Using Landsat 8 satellite images and time difference methods based on plant phenology estimate the areas under cultivation of saffron was estimated in Fazl Village of Nishabur County. A satellite image of June 17, 2016, related to the plant's dormant phase and another on January 11, 2017, for the vegetative growth stage of saffron was prepared. Using different vegetation indices, saffron cultivation was distinguished from other agricultural products and estimated at 497 hectares with an overall accuracy of 72% and a kappa value of 71%. Also, the results indicated that the accuracy of this method depended on the patch area of agricultural lands, such that in areas less than 2000 square meters, the user's accuracy was 44 percent, in lands with an area between 2000 and 5000 square meters, the accuracy was 66 percent, while in farms between half to one-hectare, the accuracy reached 80% and in lands more than one hectare, the accuracy was 89%. The results of this research indicated that the use method is suitable for estimating the area under the cultivation of saffron and we suggest its examination in other parts of the country.

***Keywords:*** Landsat, NDVI, Phenology, Vegetation index, Remote sensing

## Introduction
In countries with a well-organized agricultural system, post-harvest estimates are still the common method of acquiring the amount of agricultural products. This approach depends on using ground-based data collection which is costly, time-consuming, and labor-intensive. Having reliable statistics attached to a spatial distribution of crop area per month/s before harvest is a major challenge in agricultural remote sensing. Crop-yield prediction using remotely sensed data recently represents a wide field of research and application (Salazar et al., 2007; Parasad et al., 2006; Manjunath et al., 2002).

Saffron has a special status in the agricultural development of Iran from a historical point of view. This product has a close relationship with the social, economic, cultural, and environmental values of agricultural societies, and has long shaped the production, processing, trade, and consumption of this valuable spice in the form of indigenous knowledge of these communities (Koocheki, 2013). For many people, the Iranian saffron is a valuable heritage of ancestors and of strategic importance with its cultivation taught and maintained through generations

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(Khozeymehnezhad et al., 2016). Products such as saffron can cause social change and rural mobility and provide a good source of income for poor rural populations (Bouzarjmehri et al., 2016).

Nearly 94 percent of the world's saffron is produced in Iran, of which around 82 percent is exported (Masi et al., 2016). Despite the adaptability of saffron plants to climatic and soil conditions in large parts of the country, most of this valuable agricultural product is cultivated in areas of central and south Khorasan with low rainfall, due to proper climatic and indigenous knowledge (Koocheki, 2013). The knowledge of native saffron cultivation of the people of Khorasan which has accrued through the centuries of experience and in the face of the challenges of cultivating this product is a valuable heritage.

The short-term growth period of saffron and the low need for water has led farmers in the low-yielding lands to cultivate this product (Yaghoubi et al., 2016; Mohtashami et al., 2016). Planting and producing saffron in arid and semi-arid regions, from May to December, and as the plant's water requirement is zero, is very ideal, and various studies have shown that the economic efficiency of saffron water consumption is superior to other products in these areas (Bashiri and Salari, 2016). The growing trend of the export share of saffron from the country's total non-oil exports, significant remittance, income generation and job creation for rural communities, and higher economic efficiency than other plants in the cultivation pattern are features of this product currently seen in the country (Aghaei and Rezagholizadeh, 2011). The need to pay attention to increasing the sustainable production of this plant has been noticed earlier.

Agricultural planning and management from local to national levels require knowledge of the distribution and level of cultivation of agricultural products. Estimation of the crops' cultivation area has always been an issue for experts so that it can feed the policies and strategies needed to enhance food security and international marketing. The informal estimates provided through questionnaires talks with experts are generally inadequate. The use of satellite data as a new solution not only reduces human-caused shortcomings but also fosters better agricultural planning (Alipour et al., 2014).

Satellite remote sensing technology is now providing accurate statistical and spatial information for yield and production forecasts. However, crop classification as an essential step for yield monitoring and mapping is still problematic. Traditional methods such as area sampling, list sampling, point sampling with or without a grid have proven to be successful (Pickup et al., 1993). Moderate to high spatial resolution images have been used frequently for crop monitoring and to identify cropland areas (Epiphanio et al., 2010).

Timely and continuous monitoring in large areas saves time, reduces costs, and updates the database of cultivations (Abaszadeh et al., 2012). In this paper satellite technology is evaluated for estimating the area under the saffron cultivation.

## Materials and methods

### *Study area*

In recent years, we have seen the ever-increasing cultivation of saffron in the area of Nishabur plain (Alavizade et al., 2016). Saffron of Nishabur is often cultivated in three central parts, Zabarkhan and Mianjolge.

The study area is located at 58 °, 48 ' to 58 °, 58' eastern longitudes, and 36 ° 6 ' to 36 ° 12', northern latitudes (Fig.1). The sharp drop in the groundwater table in the critical Nishabur plain and the subsidence of this vast plain, inevitably necessitate a change in the pattern of cultivation and the use of limited aquatic plants.

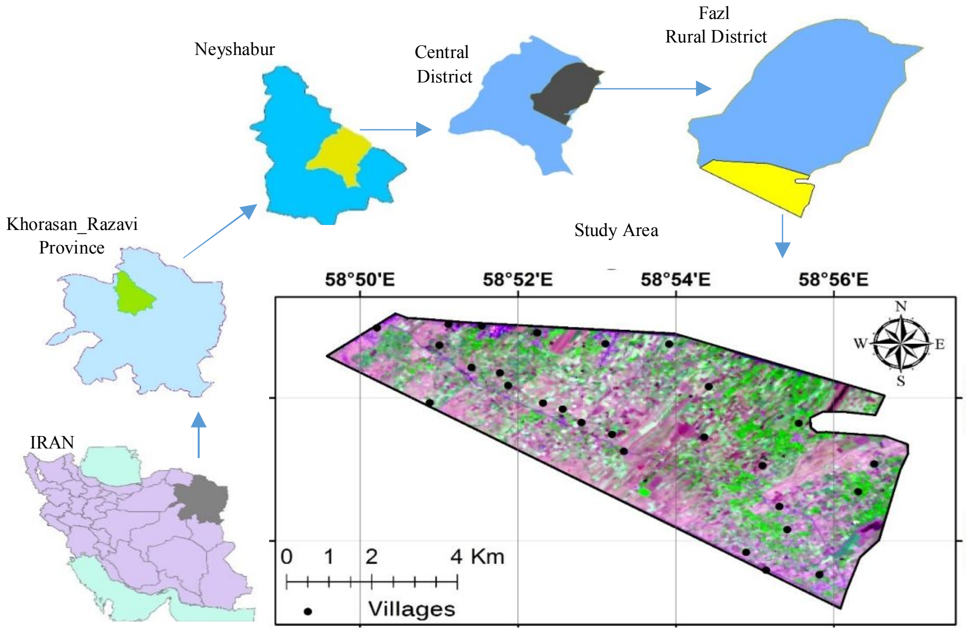


**Figure 1.** Geographic location of the study area

***Phenology of Saffron***

Phenology is the study of vegetative events during a plant's life cycle (You et al., 2013). Earlier, researchers have used much time-series satellite imagery to recognize the plants' phenological stages (Atkinson et al., 2012; Kandasamy and Fernandes, 2015, Cao et al., 2015). To better understand the measurement method, growth conditions of saffron should be considered over a year. Saffron is a perennial herb and has triploid geophyte which can be cultivated successfully benefiting from the weather conditions of the region. Saffron continues to produce flowers until the age of 8 to 14 years (Koocheki and Seyyedi, 2015).

The Saffron flowering period is from late October to late November. Vegetative growth continues until late April. From late April to mid-October, saffron becomes dormant and its leaves dry (Amirshekari et al., 2007). The physiological changes in saffron mainly occur below ground. Therefore, studying the phenological stages of the plant based on the formation and development of underground organs can provide a more precise concept of plant growth changes during the growing season. However, considering that satellite images can only receive reflections from the surface of the earth, this research focuses on the growth of the aerial parts of the plant. The phenological stages of the saffron includes generative, vegetative and dormant stages (Fig. 2) (Kumar et al., 2009; Chemura et al., 2017). Comparing June and January, the green spectrum in January will be more than from June. Few plants cultivated by farmers in this region, such as wheat and barley, have similar phenological conditions.

Alipour et al. (2014), in their research to estimate the crop area, pointed to the plant vegetative period and suggested the best time for the selection of satellite images, which is the peak of greenness.

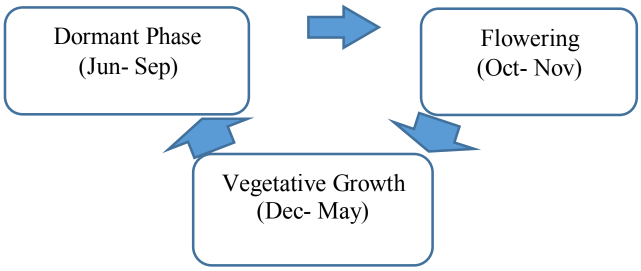


**Figure 2.** Growth stages of saffron

In this research, two images of Nishabur (row-path: 35-159) from Landsat 8 series and OLI sensors (Table 1) were taken at two different times. The first image dated June 17, 2016 (plant dormancy), and the second image dated January 11, 2017 (vegetative period). The reason for choosing these two times was based on the plant's phenology and its difference with other crops. While the greenness of the saffron plant in January is more than June, this is the opposite in other crop and garden plants. Normalized vegetation difference index (NDVI), which uses near-red and near-infrared bands, is sensitive to chlorophyll in plant's leaf and, therefore, can be used to identify the green leafy saffron. Where the greenness is higher and vegetation is denser, the index tends to one, and in the low vegetation and in bare soil, the index tends to be negative. Equation 1 shows how to calculate NDVI from the Landsat 8 image.

$$NDVI= (\rho_5 - \rho_4)/(\rho_5 + \rho_4) \quad (1)$$

**Table 1.** Characteristic of L8 Spectral Bands

| Sensor Name | Band Name | Band number | Resolution(m) | Wavelength(µm) |
|---|---|---|---|---|
| OLI | Coastal-Aerosol | 1 | 30 | 0.435-0.451 |
| | Blue | 2 | 30 | 0.452-0.512 |
| | Green | 3 | 30 | 0.533-0.590 |
| | Red | 4 | 30 | 0.636-0.673 |
| | NIR | 5 | 30 | 0.851-0.879 |
| | SWIR1 | 6 | 30 | 1.566-1.651 |
| | SWIR2 | 7 | 30 | 2.107-2.294 |
| | Pan | 8 | 15 | 0.503-0.676 |
| | Cirrus | 9 | 30 | 1.363-1.384 |
| TIRS | TIR1 | 10 | 100 | 10.6-11.19 |
| | TIR2 | 11 | 100 | 11.5-12.51 |

The values of $\rho_5$ and $\rho_4$ are the surface reflectance of band 5 (NIR) and band 4 (RED), respectively. The surface reflectivity is defined as the ratio of reflected spectral flux to the fluctuation spectroscopy. In order to measure the surface reflectivity in each Landsat band, Equation 2 is used:

$$\rho=[\pi\times(L_\lambda - L_p)\times d^2]/(ESUN_\lambda \times \cos\theta_s) \quad (2)$$

Lλ is the thermal radiance and is calculated using Equation 3:

$$L\lambda=M_L\times DN+A_L \quad (3)$$

$M_L$ and $A_L$ are calibrated constants of the Landsat sensor, and DN is pixels gray degree. In Equation 2, Lp is the path radius or atmospheric radiance, which is calculated as Equation 4 (Tewari et al., 2003, Rahimzadegan et al., 2017).

$$L_p=M_L\times DN_{min}+A_L-0.01\times ESUN_\lambda\times\cos\theta_s/(\pi d^2) \quad (4)$$

ML and AL are calibrated constants that are found in metadata. θs is the sun's zenith angle, and it is obtained from Equation 5:

$$\theta_{ze} = 90° - \theta_{se} \quad (5)$$

$\theta_{se}$ is the angle of the sun's height in the center of the image, and its numerical value is available in the metadata, while d is the distance between the sun and earth in astronomical units and is available in metadata. $ESUN_\lambda$ is the average of the incident solar radiation at the top of the atmosphere for each band expressed as w/m2/µm. Equation 6 has been proposed for calculating $ESUN_\lambda$ in Landsat (NASA, 2011).

$$SUN_\lambda=((\pi\times d^2)RADIANCE_{MAX}) / REFLECTANCE_{MAX} \quad (6)$$

The numeric values of $RADIANCE_{MAX}$ and $REFLECTANCE_{MAX}$ and d, can be found in the metadata. After calculating the reflectivity in each band, the atmospheric correction was performed using the FLASH method. For this purpose, ENVI software was used. Finally, the vegetation index was produced for the dormancy (Fig. 3) and the vegetative growth periods of saffron (Fig. 4). In order to remove the grass species from the final results, spectral sampling method, and their differentiation using the maximum probability method were used, then the results from the final map were deleted.

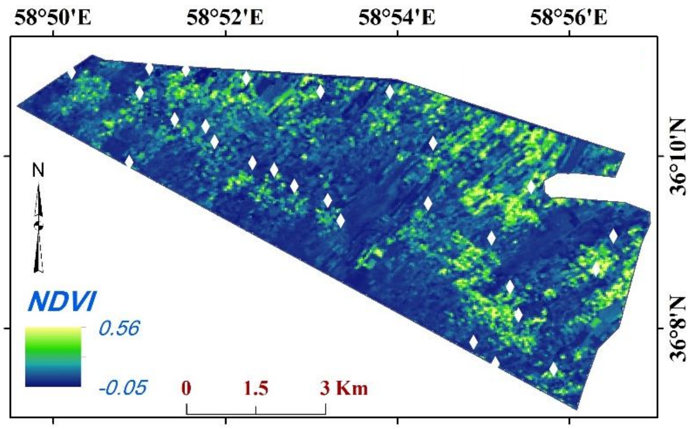


**Figure 3.** NDVI index of the study area in dormant phase of saffron (2016/06/17)

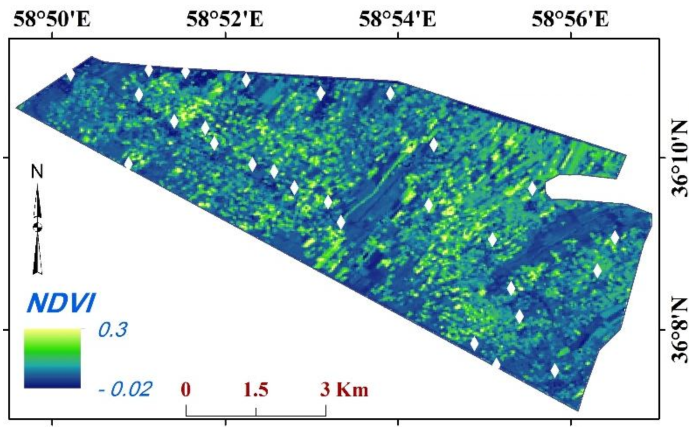


**Figure 4.** NDVI index of the study area in vegetative growth phase of saffron (2017/01/17)

## Results and Discussion

The purpose of the present study was to determine the accuracy of the time difference method based on vegetation indices for identifying the cultivation area of saffron. In this study, Landsat 8 data was available as one of the most reliable satellite data. According to the results (Fig. 5), the area under cultivation of saffron was estimated as 497 hectares.

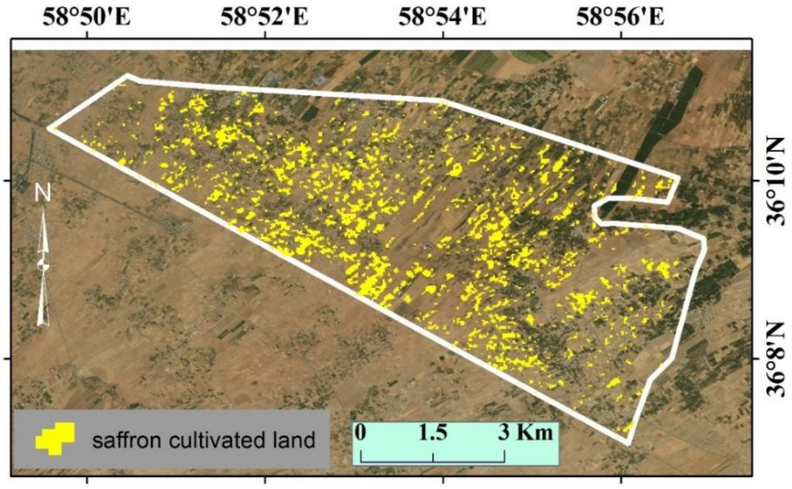


**Figure 5.** The final map of saffron cultivation

In order to evaluate the accuracy of the time difference method, an error matrix or ambiguity matrix was used. In the ambiguity matrix, a comparison is made between categorized pixels and ground reality. In the ambiguity matrix, the overall accuracy shows the ratio of pixels classified to the total known pixels and is calculated using Equation 7:

$$O.A. = \frac{\sum_{i=1}^{c} E_{ii}}{N} \quad (7)$$

In Equation7, C is the number of classes, N is the total number of pixels, Eii, is the diameter values of the ambiguity matrix and O.A. represents the overall accuracy of the classification. Using field studies, the cultivated areas of saffron were calculated using GPS and field methods in the study area. The cultivated area of saffron in the studied area was 497 hectares with an overall accuracy of 72% and a kappa value of 71%. To investigate the relationship between the classification accuracy and farm sizes, the cultivated areas of saffron were categorized into those below 2,000 square meters, between 2000 and 5000 square meters, 5,000 square meters to 1 hectare and farms larger than 1 hectare. It should be noted that in this method, the user's accuracy shows the classification accuracy of each of the above four classes.

Earlier, Ramezankhani et al., (2017) stated that classification algorithms based on the use of multi-time images, performed better than single-time methods. Dehghani Bidgoli et al., (2018), determined the area under saffron cultivation in Darbeghazi Village in Nishabur using different methods. They estimated the overall accuracy of this method as 95% consistent with other studies (Koocheki, 2013, and Bouzarjomehri et al., 2016).

The user's accuracy indicates the probability of classifying a particular class in accordance with ground reality. Therefore, the user's accuracy was used to compare the accuracy of the method in each of the four categories. The results of the research show that the user's accuracy increases with increasing size of the saffron farms (Table 2). The reason for this should be the pixel size of the Landsat images, which is 30 by 30 meters. Therefore, in small agricultural farms, due to the mixing of the reflecting sun's spectrum with the adjacent areas, higher percentage of error occurs.

**Table 2.** User's accuracy in different farm areas

| Area (ha) | User's Accuracy% | Patch area (ha) |
|---|---|---|
| 51 | 44 | ≤ 0.2 |
| 73 | 66 | 0.2-0.5 |
| 90 | 80 | 0.5-1 |
| 283 | 89 | ≥1 |

## Conclusion

Monitoring crop proportion using time difference method and remote sensing curbs charges, while providing an effective utility to maintain the monitoring accuracy. In this study, the estimation of land area under cultivation of saffron in part of Fazl Village was carried out in the central part of Nishabur using time difference method and satellite imagery. The results were compared with field observations. One of the challenges in this study was to select a cloudless image at appropriate times. Due to the 16-day Landsat satellite passing through a specific area over the ground, there should be two high-quality images without clouds, one on saffron dormant period and one on its vegetative period.

Another important challenge in implementing this method is the elimination of Poaceae species from the final results. Due to the synergy of saffron phenotypes and Poaceae species such as wheat and barley, it is necessary to use spatially efficient methods and increase precision. In the present study, the maximum probability method was used for the removal of Poaceae species. Due to the expansion of saffron cultivation in different provinces of the country, the importance of accurate, timely and a low cost method of acquiring information is needed more than ever. We suggest that this approach is tested to prepare surface mapping in other parts of the country.

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