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# Distinguishing Growth Stages of Wheat Crop by Remote Sensing Techniques and Time Series Analysis

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**ABSTRACT**

*Remote sensing has attracted the attentions by providing a broad and comprehensive view of the world. The use of remote sensing in various fields such as agriculture is constantly expanding. Spectral bands in visible and infrared ranges can be used to discriminate between phenomena and ground cover by computing various spectral indices. Investigating plant physiology is essential to know the physiological and ecological aspects of plant functions. In this study, images of Sentinel-2 satellite were used to compute spectral indices and correlate them with phenological stages of wheat crop in two agricultural centers in Fars province, Iran. Zadoks scale is one of the most reputed methods to state growth stages of wheat crop. The Zadoks scale uses two-digit codes to demonstrate different phenological processes. In this study, nine growing stages were carefully identified using ground truth method. After calculating two spectral indices of normalized difference vegetation index (NDVI) and soil adjusted vegetation index (SAVI) on satellite images of various dates during the growing season, NDVI and SAVI time series were generated. Each time series image consisted of nine bands, each band being an image obtained from a wheat growing stage. Study the trend between NDVI and SAVI indices and the Zadoks scale showed that the phenological stages of wheat can be identified using remote sensing technology.*

## INTRODUCTION

Watching the Earth from space is crucial to understand the impact of human activities on natural resources and reflects periodic changes in the phenomena of the Earth's surface(Zubair, 2006). With the advent of technology and satellites, aerial photography and satellite imagery have turned into the form of new science called remote sensing (Johnson, 2009). In a more accurate sense, remote sensing (RS) means identifying and measuring the properties of a phenomenon without physical contact with it (Zubair, 2006). In recent years, RS and geographic information systems (GIS) have been widely used to identify and analyze land cover and land use changes in different parts of the world(Zubair, 2006). Surveying and assessing fields in order to find out the type of crop, identifying pests and diseases, detecting water stress, calculating the area under cultivation and estimating crop yield are among the areas of interests for researchers using high resolution imagery. The main drawback of these images is low temporal resolution (Eva and Lambin, 1998). One solution to use satellite imagery to evaluate the gradual changes over the long period of time is to create time series. Based on the data obtained from time series analysis, changes made from the past to the present can be identified and helps to predict future changes accordingly (Decuyper *et al.*, 2022). Spectral indices are mathematical transformations defined by different bands of sensors in multispectral satellites, and are designed to evaluate plants observations (Mao *et al.*, 2013). Many spectral indices have been presented so far, each with its own characteristics, pros and cons (Jawak and Luis, 2013). Vegetation indices (VI) are a mathematical combination of two or more wavelengths reflection selected to represent a particular plant characteristic (Xue and Su, 2017). Two popular and most cited indices include normalized difference vegetation index (NDVI) and soil adjusted vegetation index (SAVI).

The turning point of the remote sensing research in the field of vegetation analysis in multispectral imagery is the introduction of NDVI by Rousse et al. (1973). This index, which is still used as the main index of plant analysis of multispectral images (Nouri *et al.*, 2017). Two popular and most cited indices include normalized difference vegetation index (NDVI) and soil adjusted vegetation index (SAVI).

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main index of plant analysis of multispectral images (Nouri *et al.*, 2017).

Normally the normalized gray level of this index is between -1 and 1, and pixel values that have greater than 0 are discriminated as a vegetation. The non-randomness of this threshold itself is a very important feature that has led to the widespread use of this index in studies related to the extraction of vegetation from multispectral images. These studies include overall plant extraction (Malingreau *et al.*, 1989), crop type prediction and plant growth monitoring (Myneni *et al.*, 1992), land cover classification (Senay and Elliott, 2000), predicting the time of famine and drought (Kogan, 1995) and climate analysis (Bounoua *et al.*, 2000).

Huete (1988) developed the SAVI index, which has increased the accuracy of the NDVI index. This index compensates the effect of soil physical characteristics and their effects on the amount of plant reflection. They stated that saturation problem in the NDVI index (due to the nonlinearity of the index) being the main factor behind the presentation of the SAVI index.

Simulation of wheat crop growth stages using RS has the potential to monitor growth and predict crop yield. Many researchers try to use this technology and prediction techniques to estimate crop yield (Guo *et al.*, 2018).

The term growth, refers to the small changes that occur during plant development and can be defined as irreversible changes in the size of the cell, organ, or whole organism (Hunt, 2012). Plant development is defined as a sequence of phenological events controlled by external factors, which determines changes in the shape or function of some organs (Slafer *et al.*, 1996).

Yuping *et al.* (2008) used leaf area index (LAI) and soil adjusted vegetation index (SAVI) to simulate growth stages and estimate winter wheat yield in north China.

The use of remote sensing technology to monitor wheat crop is expanding day by day. Various wheat cultivars with different growth habits follow almost the same developmental pattern, but the occurrence time for each phenological stages depends on different factors such as growth habit, sowing date, climate conditions and geographic location. As an example, phenological processes, occur more rapidly in warm regions than in cold ones or precocious cultivars grow faster than late cultivars (Balla *et al.*, 2019). Different scales have been introduced to identify and record the phenological stages of wheat crop. The most reputed ones in literatures include Zadoks, Haun and Feekes scales (Reynolds *et al.*, 2012).

In this study, the relationship between Zadoks scale and two spectral indices (NDVI and SAVI) using Sentinel-2 satellite imagery in wheat crop in two research centers was studied. To aim this goal, the time series of two above-mentioned indices were used and Zadoks scales were recorded regularly using field scouting annotations

## MATERIALS AND METHODS

### Study Area

The research was conducted in winter 2018 and spring 2019 at Shiraz University agricultural research stations located in Fars province. The first study station was located at school of agriculture Bajgah distirict with 52° 35' E and 29° 43' N and altitude of 1830 meter above the sea level and the second station was Koshkak Agricultural Research Center that located in Dorudzan and Ramjerd district with 52° 35' E and 30° 5' N and altitude of 1620 meter above the sea level.

It is important to select two regions for this study to eliminate the bias due to environmental factors. Figure 1 and 2 show the study regions on the map, respectively.

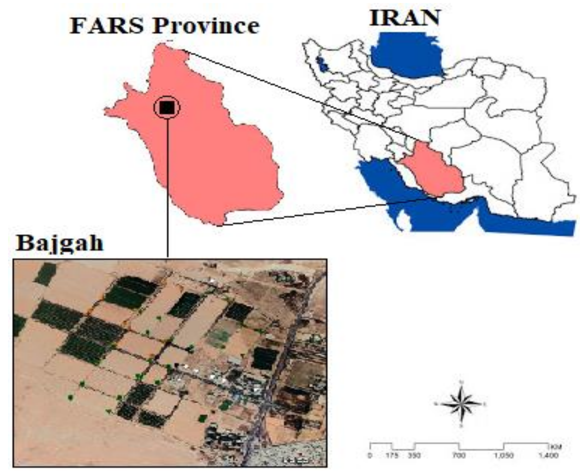


**Fig.1.** Geographical location of the experimental fields in school of agriculture, Shiraz University marked by handheld GPS. Green, yellow and red dots are shown the study field boundaries of various crops (wheat, barley canola and alfalfa) in Bajgah district.

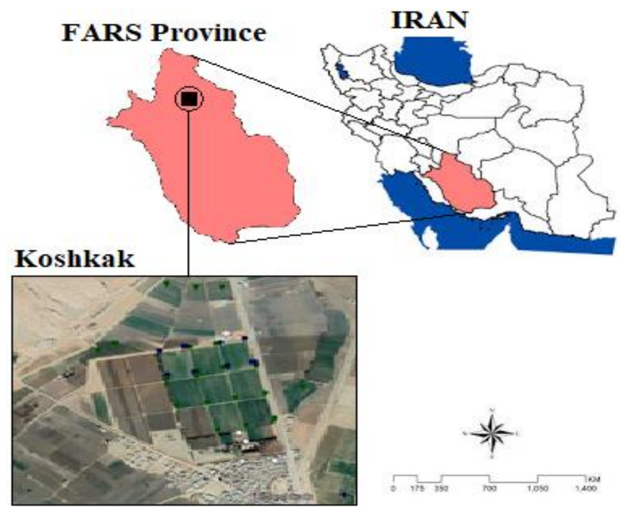


**Fig.2.** Geographical location of the experimental fields in Koshkak research center marked by handheld GPS. Green and blue dots are shown the study field boundaries (wheat and barley) in Dorudzan-Ramjerd district.

### Sentinel-2 Satellite Imagery Data Acquisition

Satellite imagery was the main data used in this research because of its high capability to monitor changes and classifying phenomena. Sentinel-2 satellite has 13 spectral bands in the visible, near and short-wave infrared bands with spatial resolution of 10, 20 and 60 meters (Baillarin *et al.*, 2012). In this study, 18 satellite images were used (9 for each study regions). For the purposes of the current study, near-infrared and infrared bands with a spatial resolution of 10 m and a spectral range of 490 to 850 nm were used as a 4-band dataset. Bands with a spatial resolution of 10 m due to their relatively high accuracy in displaying surface phenomena have high ability to provide quality maps of the study area.

The ENVI software (V5.3, RSI, USA) was used to process data include geometric correction tools, atmospheric correction, terrain analysis and calculate spectral indices (Rahnama *et al.*, 2018). The specifications of the bands used are presented in Table 1.

**Table 1.** Specifies the bands used to create the dataset

| Spectral Band | Wavelength (nm) | Band width (nm) | Spatial resolution(m) |
|---|---|---|---|
| Band 2 (Blue) | 490 | 65 | 10 |
| Band 3 (Green) | 560 | 35 | 10 |
| Band 4 (Red) | 665 | 30 | 10 |
| Band 8(NIR) | 842 | 115 | 10 |

### Field Data

To obtain accurate information about the phenomena in both study areas, both locations were surveyed and the geographical location of wheat fields was recorded using a handheld GPS (Garmin, Map62s, Taiwan). The BaseCamp software (4.3, Garmin, Taiwan) was used to download and prepare vector map of marked points collected in experimental fields. Monitoring and recording the growth physiological stages of wheat crop was also carried out during each satellite revisit dates by consulting expert agronomist. Among the phenological stages listed in Table 1, tillering, stem elongation, booting, spike emergence, flowering, milk development, dough development and physiological maturity were studied.

### Image Acquisition and Processing

The processing level of images that used in this study was L1C. Since at this level of processing usually no major conversions have taken place and the images are unprocessed data in all bands thus, appropriate preprocessing should be done on the image. Geometric, atmospheric and radiometric correction were applied to all images in ENVI software.

The downloaded image frames from the Sentinel-2 satellite comprises a large size of 10980×10980 pixels. To increase the speed of processing and also the processing accuracy, the study regions, were cropped to 540 × 540 pixels frames from the original images.

Fig. 3 and 4 shows the original downloaded image of Bajgah and Koshkak regions with cropped image at right side, respectively. Since there were also other crops in neighbor fields in both regions so, the geographical coordinates of wheat fields were collected and mapped into ArcMap software (10.6, Esri, USA) and matched with satellite imagery. Each experimental field was cropped by ROI using ENVI. ROIs were selected with proper threshold to avoid marginal biases due to variations in crop density and weeds. Finally, 8 experimental fields with a total area of 64.5 hectares in Bajgah region and 6 fields with 34 hectares in Koshkak research center were studied.

**Fig.3.** Original image(Left) and cropped region of interest-Bajgah region (Right)

**Fig.4.** Original image (Left) and cropped area of interest-Koshkak research center (Right)

### Creating Time Series Image

The time series image enables one to monitor the features of a region over a long period of time and detect variations that have occurred during specific time period (Shao *et al*., 2016). To create these images both NDVI and SAVI indices were calculated using equations 1 and 2 in all acquisition dates and were used to generate time series images.

$$NDVI = \frac{\rho NIR - \rho RED}{\rho NIR + \rho RED} \quad (1)$$

In equation 1, ρNIR and ρRED are the reflectance in the near infrared and red spectral bands respectively.

$$SAVI = \frac{\rho NIR - \rho RED}{\rho NIR + \rho RED + L} - (L - 1) \quad (2)$$

In equation 2, L is the soil correction factor. An L value of 0.5 would reduce the variation due to soil brightness and saturation problem in vegetation index (Hu *et al.*, 2021).

Figure 5 shows the procedure of preparing time series images. Each series consists of 9 bands, which corresponds to one of the stages of plant development (Image acquisition date). The specifications of the images used to create the NDVI and SAVI time series for both study areas are presented in Tables 2 and 3.

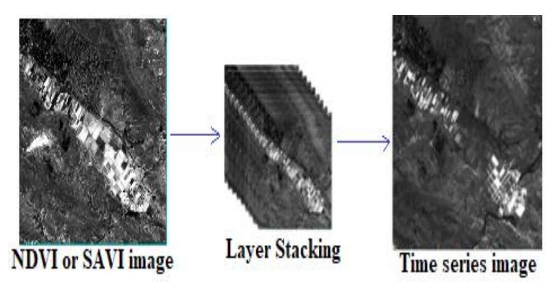


**Fig.5.** Sample of time series dataset

Knowing the cultivation date of each study field is one of the factors influencing the accuracy of the spectral indices. For this purpose, the cultivation dates of all the studied fields in both study areas were accurately recorded. The cultivation dates of the wheat fields are provided separately in Table 4 in Bajgah region. In Koshkak research center all fields were cultivated in almost the same date on 14/11/2018. (All fields were cultivated within two days).

**Table 2.** Images used to create NDVI and SAVI time series-Bajgah

| Phenological stage | Image acquisition date | Calculated spectral index |
|---|---|---|
| Tillering | 21/11/2018 | NDVI, SAVI |
| Stem Elongation | 15/04/2019 | NDVI, SAVI |
| Booting | 30/04/2019 | NDVI, SAVI |
| Heading/Spike Emergence | 15/05/2019 | NDVI, SAVI |
| Flowering/Anthesis | 25/05/2019 | NDVI, SAVI |
| Grain and Milk Development | 04/06/2019 | NDVI, SAVI |
| Dough Development | 14/06/2019 | NDVI, SAVI |
| Dough Development | 19/06/2019 | NDVI, SAVI |
| Physiological Maturity | 29/06/2019 | NDVI, SAVI |

**Table 3.** Images used to create NDVI and SAVI time series- Koshkak research center

| Phenological stage | Image acquisition date | Calculated spectral index |
|---|---|---|
| Tillering | 06/12/2018 | NDVI, SAVI |
| Stem Elongation | 11/03/2019 | NDVI, SAVI |
| Booting | 15/04/2019 | NDVI, SAVI |
| Heading/Spike Emergence | 30/04/2019 | NDVI, SAVI |
| Flowering/Anthesis | 15/05/2019 | NDVI, SAVI |
| Grain and Milk Development | 04/06/2019 | NDVI, SAVI |
| Dough Development | 09/06/2019 | NDVI, SAVI |
| Dough Development | 14/06/2019 | NDVI, SAVI |
| Physiological Maturity | 19/06/2019 | NDVI, SAVI |

## RESULTS AND DISCUSSION

### NDVI and SAVI Indices Calculation

The results of applying the NDVI and SAVI indices for both study regions are presented in Figure 7 and 8 as well as the statistical information for each index in Table 5. In Figure 7 and 8, light-colored regions are distinguishable from other phenomena. These include trees and green areas, wheat, barley and canola fields. Dark colored areas often show bare soil, roads and residential phenomena. The NDVI and SAVI indices are similar in appearance, but studying the statistical parameters of these indices and comparing them helps the interpreter to understand the difference between these indices. Comparison of the minimum and maximum values in both indices show that the values of the SAVI index is generally lower than the NDVI index which is associated to background soil effect cancelling of SAVI index by correction factor (L).

**Table 4**. Date of cultivation of wheat fields – Bajgah

| Experimental Field ID | Planting date |
|---|---|
| 4<br>7<br>13<br>24 | 18/11/2018 |
| 8<br>14<br>26<br>28 | 01/11/2018 |

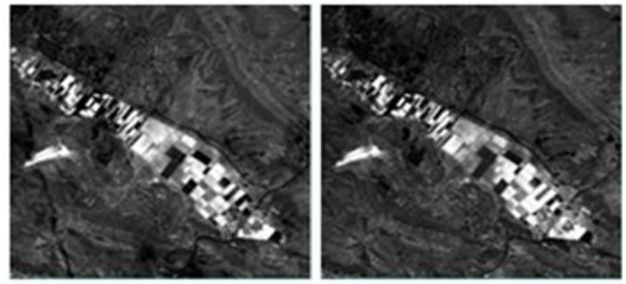

**Fig.7.** Result of calculating spectral indices of Bajgah region- Left: SAVI, Right: NDVI

**Fig.8.** Result of calculating spectral indices of Koshkak research center- Left: SAVI, Right: NDVI

**Table 5**- Statistical information for spectral indices in both regions

| Study Area | Spectral index | Min | Max | Mean | Standard deviation |
|---|---|---|---|---|---|
| Bajgah | NDVI | -0.12 | 0.94 | 0.32 | 0.12 |
| | SAVI | -0.04 | 0.60 | 0.19 | 0.06 |
| Koshkak | NDVI | 0.06 | 0.89 | 0.43 | 0.20 |
| | SAVI | 0.03 | 0.51 | 0.21 | 0.09 |

### The Result of the Relationship Between the Zadoks Scale the NDVI and SAVI Indices

Since wheat fields of Bajgah region were sown on two different dates as mentioned earlier in table 5. NDVI and SAVI indices were calculated for each field individually then values of fields with same cultivation date were averaged. Regular field scouts were conducted to identify and record the developmental stage of the wheat and assign the two-digit Zadoks code by agronomists. Table 6 shows the sub-codes of the Zadoks scale along with detailed growth stage of the wheat plant at each scouting dates as mentioned in table 2 and 3.

**Table 6.** Wheat developmental stages based on Zadoks scale

| Step Description | Zadoks scale | Developmental stage |
|---|---|---|
| Tillering | 24 | Main stem and four claws |
| Stem Elongation | 31 | The first node is visible |
| Booting | 49 | Visibility of the first shells |
| Spike Emergence | 55 | Half spike emergence |
| Flowering/Anthesis | 69 | Complete spike pollination |
| Milk Development | 75 | Mid-milking |
| Dough Development | 83 | Early dough |
| Dough Development | 87 | Dough hard |
| Physiological Maturity | 91 | Grain hardening |

The variation of the NDVI index and its relation to the Zadoks developmental scale for both cultivation dates are shown in Fig. 9 in Bajgah region.

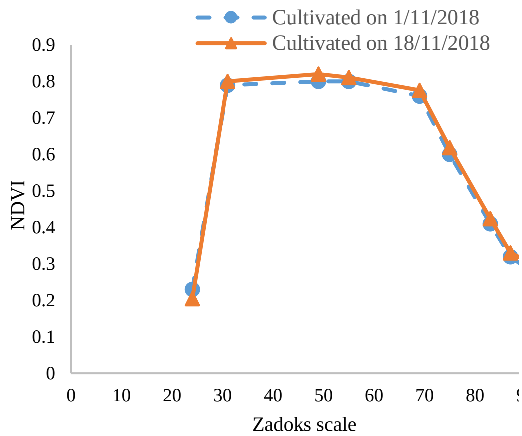


**Fig.9.** NDVI index variation based on the Zadoks developmental stages for wheat fields - Bajgah region

As shown in Figure 9, the lowest numerical value of the NDVI index is related to the tillering stage. At this stage, due to the low crop density in the field, the vegetation reflectance is negligible. Therefore, the numerical values of the NDVI index are the lowest among the other growth stages. Gradually, plant growth causes the vegetation to become denser in the field surface. Hence, the vegetation was the most predominant phenomenon in the field surface, the energy reflected to the sensor was actually obtained from the wheat plants. The maximum values of the NDVI index were taken place in three stages of stem elongation, heading and spike emergence. When the plant started the reproductive phase, the leaf chlorophyll levels gradually decrease. This causes the spectral reflectance of the crop to be reduced and thus decreased the numerical value of the NDVI index.

Figure 10 shows the variations of SAVI over the growing season in Bajgah region. The SAVI index has lower numerical values than the NDVI index since the effect of background soil was eliminated. Results shows that there is no distinguishable difference between both indices values versus same Zadoks codes in different cultivation dates. Although the sowing date potentially can affect the growth and development of the wheat crop, Dong *et al.*, 2019 studied the effect sowing date on winter wheat growth and found that there was no significant difference between the growth stage of crops that were sown in various dates in late-October through mid-November which is in consistent with the results of our study.

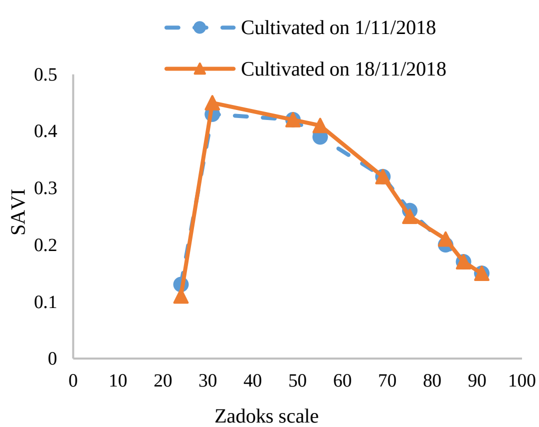


**Fig.10.** SAVI index variation based on the Zadoks developmental stages for wheat fields - Bajgah region

Considering the mean values of the SAVI index shows that this index also follows the same behavioral pattern as the NDVI index. These results were in agreement with previous studies. In both studies, researchers compare several vegetation indices and found that NDVI and SAVI followed the same trend during the growing season and SAVI index had generally lower values than NDVI values in response to soil cancelling factor coefficient (Farg *et al.*, 2012; Hu *et al.*, 2021).

The curves of the NDVI and SAVI for the Koshkak research center are also presented in Figure 11 and 12, respectively. Growth and densification of vegetation at the field level increased the numerical value of the SAVI index and the entry of the plant into the reproductive phase decreased the value of the SAVI index.

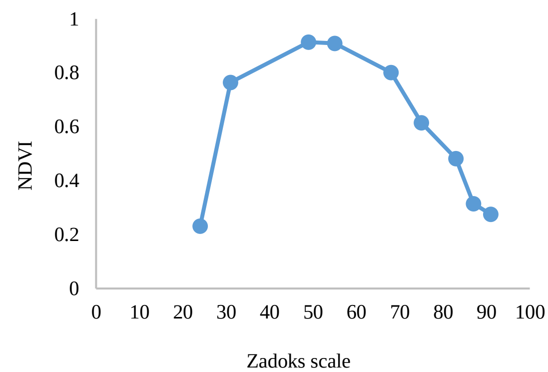


**Fig.11.** NDVI index curve based on the Zadoks developmental stages of wheat fields- Koshkak research center

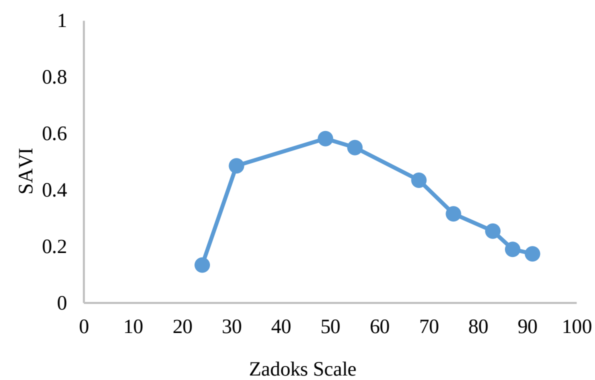


**Fig.12.** SAVI index curve based on the Zadoks developmental stages of wheat fields- Koshkak research field

The two-digit code of the Zadoks scale recorded in field visits were evaluated with numerical values of both NDVI and SAVI indices and the result showed good agreement between the numerical values of the spectral indices and the Zadoks scale in Koshkak research fields. As mentioned in Bajgah region and also results of similar studies, comparison between the graphs of the NDVI and SAVI indices revealed that the same trends and likewise values of the SAVI index are lower than the numerical values of the NDVI index because of soil modifying factor. Although both indices follow almost the same trends, there were slight differences between the values of both indices in both study regions (Koshkak and Bajgah) as shown in figure 13. These variations could be taken place due to differences in climatic characteristics of the two regions or field management practices (Farg *et al.*, 2012; Hu *et al.*, 2021).

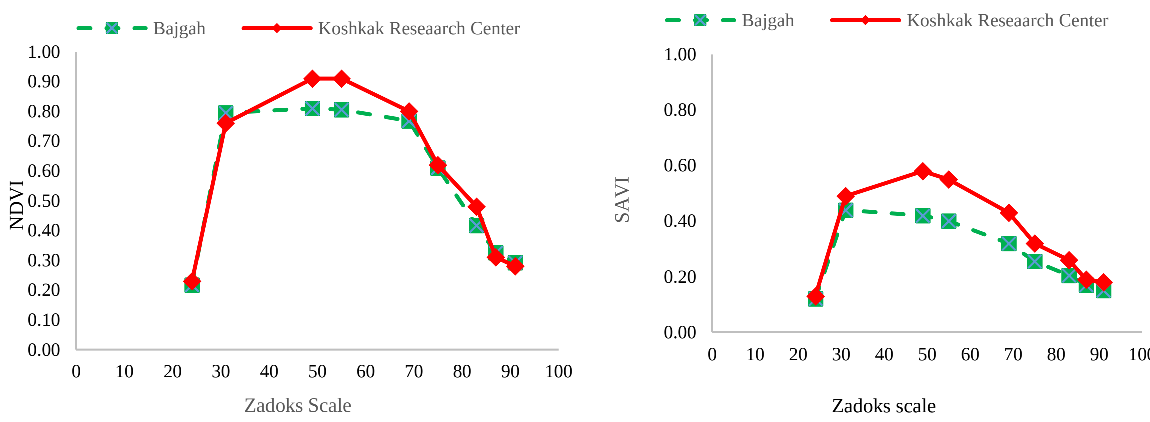


**Fig.13.** Comparing NDVI (Left) and SAVI (Right) indices in both study regions

## CONCLUSIONS

In this study, Zadoks scale was used to explore the relationship between spectral indices and plant developmental stages. The NDVI and SAVI spectral indices were used to reveal the developmental stage of wheat plant. The results of comparing the numerical values for spectral indices and their relation to the Zadoks scale in all fields in both study areas indicated that the phenological stages of wheat can be identified using remote sensing technology in most of the growth stages. This method can help growers and agronomist to have better understanding of growth without the need of intensive field scouting and have better and optimized fertilizer application based on growth stages but still needs to be validated for each region to become practical for growers. More rigorous studies on field management practices and the effect of environmental parameters may reveal the differences between indices values in different regions.

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