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Monitoring Changes in Rice Cultivation Area Using Multi-Temporal Satellite Images (Case Study: Beiranshahr Region, Iran)

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Abstract

In arid and semi-arid regions, cultivating crops with high water demand can seriously threaten water resources. This research was conducted to investigate the expansion of rice cultivation areas from 2013 to 2021 in this region. For this purpose, using Landsat 8 and Sentinel 1 satellite images, the changes in rice cultivation in this area were determined. After radiometric and atmospheric corrections, the Normalized Difference Vegetation Index (NDVI) was calculated. The vegetation area in hectares was obtained using the pixel size of the images. Finally, the change in vegetation area with time was plotted graphically. For more certainty, the cultivated area in August 2021 was also determined with radar images. After performing the preprocess corrections (thermal noise removal, calibration, terrain flattering, multilink, speckle filter and terrain correction), a suitable RGB image was created. Then sampling was done on different classes of land. The final land cover map was prepared using a random forest algorithm. In order to estimate the trend in the time series of area change, the MannKendall test was used and the nonparametric Sen's method was used to determine the slope of a linear trend. The results showed that the area under rice cultivation has increased from 2,564 hectares in 2013 to 4,771 hectares in 2021. The results of the Mann-Kendall test showed that a positive increasing trend exists in the data series. Investigating the underground water level showed that the depth of the water in some parts of the region has reached 10 meters, while in the past, the depth of the underground water in this region was less than 2 meters. These findings show that increasing rice planting in this region can endanger the region's water resources, and in the long term, the region will face serious challenges. Therefore, it is recommended to limit rice cultivation in the region and cultivate crops with less water demand instead.

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Introduction

Determining the agricultural area is one of the most important stages for monitoring the crop produced in each region. Knowing the type of crops cultivated in each region helps policymakers to make correct decisions regarding the food needs of the population covered by each region (IPBES, 2019; Sadoghi *et al*., 2021). This issue is so important, especially for developing countries, including Iran, since accurate agricultural statistics are important for food security and economic planning (Nicholson *et al*., 2021). On the other hand, rural life and food security depend on agricultural lands, especially in Iran. Optimal land use requires correct and accurate management by national and provincial officials. Policymakers, knowing the level of crops under cultivation, can provide services and equipment according to the existing assets. In addition, this information will determine the real potential of agricultural areas and prevent them from changing their use. The first step in managing and controlling agricultural land is to observe the current situation and examine the trend of land use changes in the last few decades.

Remote sensing technology provides this information with low time and cost to achieve sustainable goals (Weiss *et al*., 2020). In fact, remote sensing is one of the fast and most suitable tools for monitoring the cultivated area. Using this tool, it is possible to determine the expansion or reduction of the cultivated area even for years when data are unavailable without going to the fields and spending time and money (Mousavi *et al*., 2022). Multi-temporal satellite images have the ability to distinguish different types of agricultural crops from each other (Pourgholam and Rahimzadegan, 2017). This method has been applied by researchers in recent years. In Iran, Pourgholam and Rahimzadegan (2017) investigated the area of saffron cultivation in Torbat Heydarieh using this method. These researchers reported that if the normalized difference vegetation index (NDVI) index is used as one of the vegetation survey methods (Renza *et al*., 2017), the cultivated area will only be 5.7% different from the observational data collection. Research conducted by Riahi et al. (2019) also showed the appropriate accuracy of using remote sensing in Iran. Tamela and Hailu (2020) integrated Sentinel-1A Synthetic Aperture Radar (SAR) with Sentinel-2 multispectral sensor (MSI) images to map rice field extent in a tropical area, Fogera Wereda, Ethiopia. These researchers concluded that the VH polarization of Sentinel-1A is suitable for rice field mapping. Mansaray et al. (2017) used optical and Radio Detection and Ranging (RADAR) remote sensing data to map and monitor rice growth.

Rice (Oryza sativa L) is one of the most important food sources in the world. It is the food of half of the world's people, and its consumption is increasing every year (FAO, 2017). The average area under rice production in Iran in the last five years has been about 517 thousand hectares, and the average production has been 1980 thousand tons, which has increased by about 7.5% compared to 2012 (Anonymous, 2018). In Iran, with an average rainfall of 250 mm per year, only two provinces, Mazandaran and Gilan, have a high average rainfall of about 1000 mm per year. Other provinces are facing water shortage problems (Anonymous, 2021). Therefore, about 71% of rice cultivation is in these two abovementioned provinces, and other provinces cover the remaining 29% (Anonymous, 2018). Based on various factors, including high profit and short growing seasons, the desire of farmers in other provinces to cultivate rice has increased in recent years. This subject is noticeable considering Iran's arid and semi-arid climate and the problems caused by water scarcity (Yaghoobzadeh *et al*., 2017a, b). On the other hand, the rainy season in Iran is from mid-Autumn (October) to late winter (April), which does not coincide with the rice-growing season in summer. For this reason, rice cultivation in Iran has always faced various challenges and problems. Lorestan province, in Iran, where rice cultivation has expanded in recent years, faces water scarcity. The average cultivated area in this province is estimated to be around 10 thousand hectares (Anonymous, 2018). However, according to some local data, due to a lack of water, this amount has decreased to less than 7 thousand hectares in 2021. This subject has caused pressure on the water resources of this province. Because there were no accurate statistics on the change in rice cultivation in some areas of this province, including the Beiranshahr region, this research evaluated the change in rice cultivation area using multi-temporal satellite data.

Material and Methods

Study Area

Beiranshahr region is located in the north of Khorramabad city in Lorestan province, western Iran, at latitude 48° 33′ 42.31″ N and longitude 33° 38′ 1.31″ E (Figure 1). Beiranshahr has a mountainous climate with cold and snowy winters and mild summers. The occupation of its people is mostly agriculture and animal husbandry. Soil moisture and thermal regimes are Xeric and Mesic, respectively. There is no evidence to suggest that the area lacks the necessary background conditions for rice cultivation. However, rice cultivation suddenly started on a large scale in this area in 2013. Therefore, we used Landsat 8 satellite images and Sentinel-1 radar images to monitor changes in the rice cultivation area. We first used Landsat 8 images to determine changes in the total crop cover in the area. We used the high accuracy of radar images to confirm the cultivated area in August 2021. Since the highest canopy cover for summer crops is in August, the images in this month were compared in different years.

Landsat 8 satellite images

Suitable images without a cloud cover of the Landsat 8 satellite were downloaded from the https://earthexplorer/usgs/gov website. The images from 2013 to 2021 belong to August. The characteristics of the images used in the research are shown in Table 1. In order to obtain multitemporal and multispectral reflection data on farmland and also to derive the time series of vegetation indices, which are calculated as a function of the red, green, blue, and infrared spectral bands, these satellite sensors can be used (Zhao *et al*., 2021).

Images preprocessing

After downloading the images, a subset of images was taken according to the region boundary. Then the geometrical and georeferencing conditions of the images were checked. In this case, Landsat 8 images are reference images for geometric correction of other images and maps. For this reason, these images did not require geometric correction. A radiometric correction was used to reduce or eliminate two major types of atmospheric and sensor errors. Quick atmospheric correction (QAC) was used for atmospheric correction because its application speed is high compared to other atmospheric correction methods, and its absolute results are normal. It does not require the presence of other special bands for water absorption and aerosol dispersion.

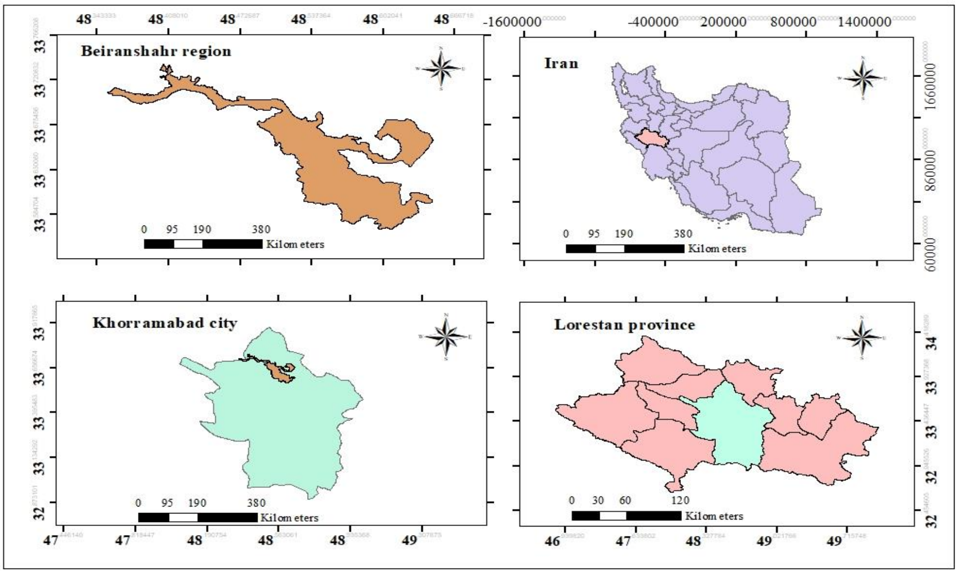


Fig 1. Location of study area

Table 1. The characteristics of the images used in the research

Row	Path	Date	Satellite	Sensor	Spatial resolution (m)	Number of bands
37	166	20130829	Landsat 8	OLI_TIRS	30	7
37	166	20140828	“	“	“	“
37	166	20150819	“	“	“	“
37	166	20160805	“	“	“	“
37	166	20170808	“	“	“	“
37	166	20180811	“	“	“	“
37	166	20190814	“	“	“	“
37	166	20200816	“	“	“	“
37	166	20210819	“	“	“	“

NDVI calculation

In this step, to convert the radiance values recorded by the sensor into the surface reflectance, all values that are smaller than zero are multiplied by zero, then values that are greater than ten thousand (10000) are set equal to one, and finally, all values that are greater than zero and smaller than one are multiplied by the 1/10000 ratio. In this way, all values are in the range of zero and one, according to Equation 1:

Float ((MS le 0) ×0+ (MS ge 10000) ×1+(MS gt 0 and MS lt 10000) ×float (MS /10000/0)) (1)

Where the MS values are the multispectral bands of the Landsat 8 OLI sensor. Then the normalized difference vegetation index (NDVI) is calculated from Equation 2:

NDVI= (NIR-Red)/ (NIR+Red) (2)

Where, NIR and red are the near-infrared and red bands of Landsat 8, respectively. The numerical value of this index is between +1 and -1, and it has been proven that the closer this index is to +1, the higher the amount of vegetation (Yaghoobzadeh, 2015).

After preparing the NDVI maps, the studied area was classified into two classes: land with vegetation and land without vegetation (harvested area in August). In this research, NDVI values less than 0.2 belong to the class of land without vegetation, and more than that belongs to the vegetation class.

In the next step, the raster maps of NDVI were converted into vectors, and the vegetation area in hectares was obtained using the pixel size of the images. Finally, the change in vegetation area with time was plotted graphically.

Sentinel-1 radar images

In order to accurately identify crop areas, a vegetation map of the area was prepared using radar images. Suitable radar images of the Sentinel-1 satellite were downloaded from the https://scihub.copernicus.eu website. The radar images were from 2021 and the months of July, August, and September. Radiometric and geometric corrections and other processes were done on the images according to the diagram below:

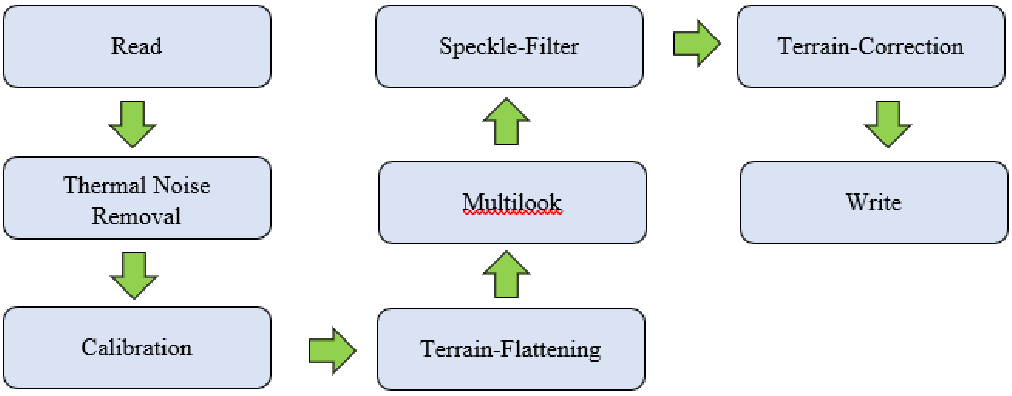


Fig 2. Processing steps performed on Sentinel 1 radar images

After performing the abovementioned processes, a suitable RGB image was created. Then sampling was done in different classes of land. The final land cover map was prepared a using random forest algorithm.

Validation and accuracy assessment

The error matrix was used to evaluate the accuracy of the classified map obtained from the radar images. Kappa coefficient, overall accuracy, producer accuracy, user accuracy, commission and omission parameters were used to evaluate the results. The overall accuracy is obtained from the ratio of the number of correctly classified pixels to the total number of classified pixels in all classes. Which can be calculated from the following relationship:

$$OA = \frac{1}{N}\Sigma P_{ii} \quad (3)$$

Where OA is overall accuracy, is the sum of elements of the principal diameter of the error matrix, and N is the total number of training pixels.

Due to the defects in the overall accuracy of executive tasks, the kappa coefficient is also used to determine the classification accuracy. Because of this index, incorrectly classified pixels are also considered. The Kappa coefficient is calculated according to the following relationship:

$$Kappa = \frac{p_0 - p_c}{1 - p_c} \quad (4)$$

Where is the correct observation and is the expected agreement. Producer accuracy indicates the probability that the producer has assigned a pixel to a certain class if its true class is known, and in the error matrix, it is the ratio of correct pixels to the total number of pixels in a column.

The user accuracy is the probability of classifying a certain class in the map according to the same class in the ground, and in the error matrix, it is the ratio of correct pixels to the total number of pixels in a row.

The error of commission is a percentage of pixels that do not belong to the desired class, but are placed in that class, and the error of omission is the percentage of pixels that actually belong to the desired class, but are mistakenly placed in another class (Lennon, 2006).

Mann-Kendall test for trend and Sen's slope estimation

In order to estimate the trend in the time series of area change in the studied region, the Mann-Kendall test was used and the nonparametric Sen's method was used to determine the slope of a linear trend.

When the data values *xi* of a time series can be assumed to obey the model below, the Mann-Kendall test is applicable:

$$x_i = f(t_i) + \varepsilon_i \tag{5}$$

Where *f(t)* is a continuous monotonic increasing or decreasing function of time and the residuals ε_i can be assumed to be from the same distribution with a zero mean. It is therefore assumed that the variance of the distribution is constant over time.

We want to test the null hypothesis of no trend, *Ho*, i.e., the observations *xi* are randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. For time series with less than 10 data points, the S test is used, and for time series with 10 or more data points the normal approximation is used. The S test was used in this study because our data was less than 10 points. The Mann-Kendall test statistic *S* is calculated using the following formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \tag{6}$$

Where x_j and x_k are the annual values in years *j* and *k*, *j* > *k*, respectively, and

$$sgn(x_j - x_k) = \begin{cases} 1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{cases} \tag{7}$$

If *n* is 9 or less, the absolute value of *S* is compared directly to the theoretical distribution of *S* derived by Mann and Kendall (Gilbert, 1987). The two-tailed test is used for four different significance levels α: 0.1, 0.05, 0.01 and 0.001. At a certain probability level, H_0 is rejected in favor of H_1 if the absolute value of *S* equals or exceeds a specified value *Sα/2*, where *Sα/2* is the smallest *S* that has a probability less than *α/2* to appear in the absence of a trend. A positive (negative) value of *S* indicates an upward (downward) trend.

Sen's method

To estimate the true slope of an existing trend (as change per year), Sen's nonparametric method is used. Sen's method can be used in cases where the trend can be assumed to be linear. This means that *f(t)* in equation (1) is equal to:

$$f(t) = Qt + B \tag{8}$$

Where Q is the slope and B is a constant.

To get the slope estimate *Q* in the equation above, the slopes of all data value pairs must be calculated.

$$Q_i = \frac{x_j - x_k}{j - k} \tag{9}$$

Where *j>k*.

If there are *n* values *xj* in the time series, we get as many as *N = n(n-1)/2* slope estimates *Qi*. Sen's estimator of slope is the median of these *N* values of *Qi*. The *N* values of *Qi* are ranked from the smallest to the largest and Sen's estimator is

$$Q = Q_{\left[\frac{N+1}{2}\right]} \; if \; N \; is \; odd \qquad (10)$$

$$Q = \frac{1}{2}\left(Q_{\left[\frac{n}{2}\right]} + Q_{\left[\frac{N+2}{2}\right]}\right) if \; N \; is \; even \qquad (11)$$

A 100(1-α)% two-sided confidence interval about the slope estimate is obtained by the nonparametric technique based on the normal distribution. The method is valid for *n* as small as 10 unless there are many ties (Salmi *et al*., 2002).

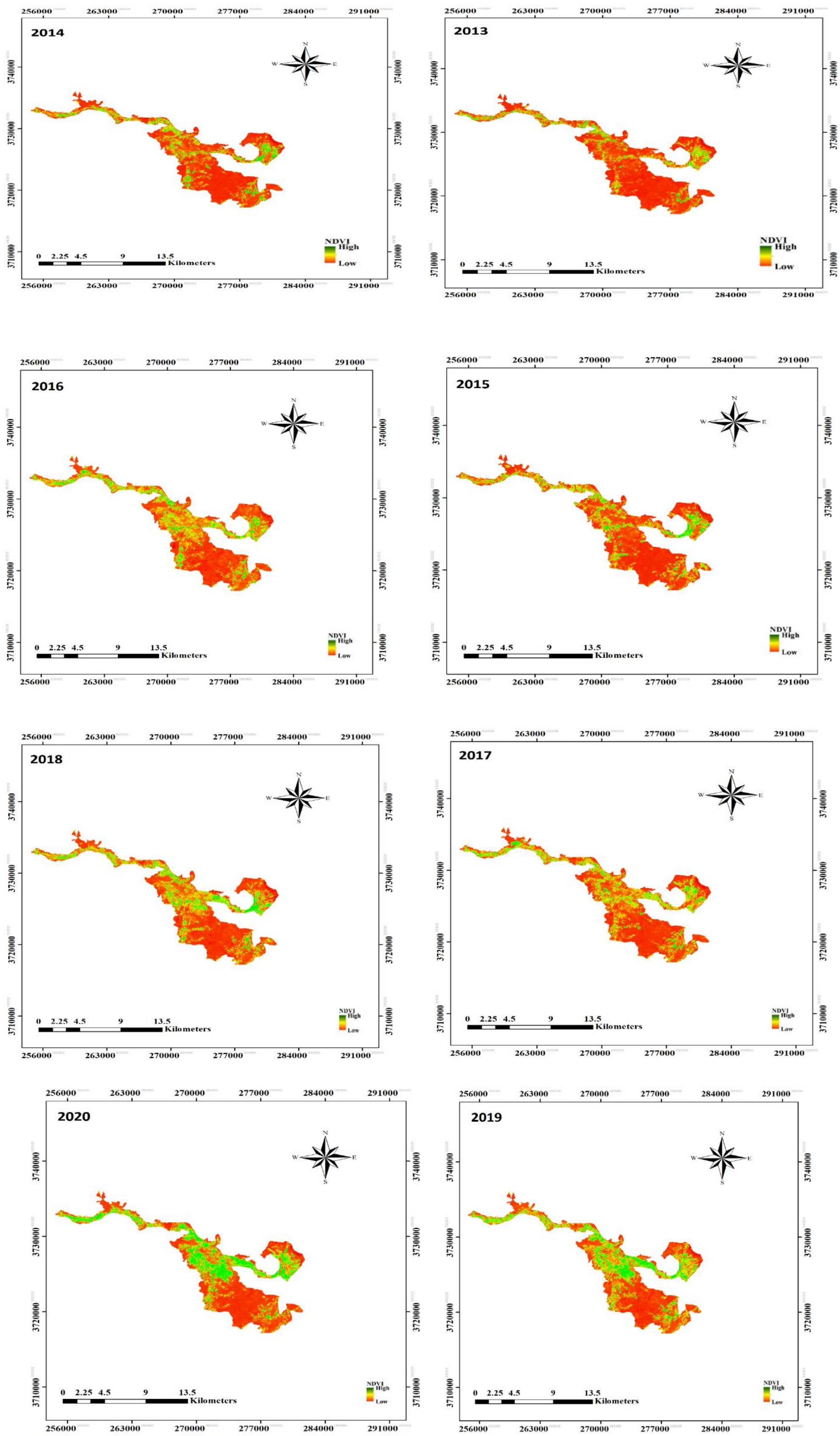
Groundwater changes

Using the groundwater data given by Lorestan Regional Water Company, a water table level change map was created. The data included the water depth of the wells in the region during 2005 to 2021. The water table map was obtained by using the IDW algorithm. In order to create the maps, ArcGIS 10.8.2, ENVI 5.3, SNAP 7.0, and Excel 2021 were used.

Results and Discussion

The crop cover changes in the main part of the study area are shown in Figure 3. The crop cover for rice has increased significantly since 2013. In the past, in the summer season, especially in August, the crop cover area was reduced after harvesting the spring crops. But with the extension of rice cultivation in the region, this trend has reversed, and the crop cover in the region has increased in the summer. The reason for the increase in rice cultivation in the region is the high price of this product on the market; this issue has caused the cultivation of other products to be abandoned. In the past, only some summer crops, such as cucumbers and fodder crops, have been cultivated in a limited area. The small amount of vegetation in 2013 is mainly related to these crops. But in 2021, most of the vegetation will be related to rice cultivation (Figure 3). Based on NDVI images, the area under cultivation of summer crops has increased in recent years. These changes are mainly in the northwestern and central parts of the region. Because they are located upstream of the river, their access to water takes priority. In addition, the field conditions for farming in these areas are better. The changes in 2020 and 2021 are such that the area of fallow land is almost zero. In 2021, all arable land was used for rice cultivation. Since agricultural lands are bounded by the mountains from the south and part of the west, the land under rice cultivation could not be expanded. The largest expansion of cultivated rice land in the center of this region occurred due to its flatness. In Figure 4, cultivation changes in the center of this region during the years 2013 to 2021 are shown.

To get more detailed information, the cultivated area in August 2021 was also determined with radar images. To avoid repeating the results, only the map for 2021 is shown (Figure 5). According to Table 2, the area of vegetation in this map was 4113 hectares, which is almost close to the area calculated from the NDVI map of 2021. The validation results of this map are shown in Table 3. According to the Kappa coefficient and overall accuracy, with values of 72% and 82%, respectively, this map has good validity. Extracting the same results for the rest of the year showed the amount of vegetation has increased from 2564 hectares in 2013 to 4771 hectares in 2021, which is almost 1.8 times (Figure 6). The net water requirement of rice is about 10,000 cubic meters during the growing season in this area (Ghorbani Vaghei *et al*., 2021). This amount is about twice as much as other summer crops in this region. However, the water loss


2014
2013
2016
2015
2018
2017
2020
2019
N
S
W
E
NDVI
High
Low
0 2.25 4.5 9 13.5 Kilometers
256000 263000 270000 277000 284000 291000
3710000 3720000 3730000 3740000

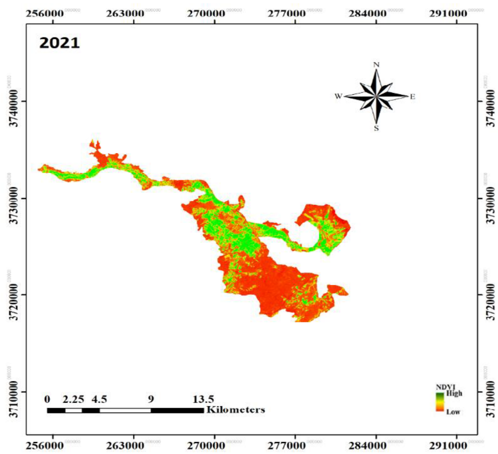


Fig 3. NDVI changes in the Beiranshahr region from 2013 to 2021 in August

is high due to the soil texture, seepage from the rice basins, and the irrigation method. This issue increases the gross water requirement for rice by about 1.5 times. For this reason, one hectare of rice consumes about three times as much water as other summer crops. In addition, due to the changes in rice cultivation area, water consumption has increased by more than 33 million cubic meters in 2021 compared to 2013. This condition is more critical due to the fallowness of rice cultivated land in the past. Indeed, considering that the Beiranshahr region is located in a semi-arid climate, the increase in rice cultivation in the region can cause great damage to water resources.

For more certainty, the cultivated area in August 2021 was also determined with radar images. To avoid repeating the results, only the map for 2021 is shown (Fig. 5).

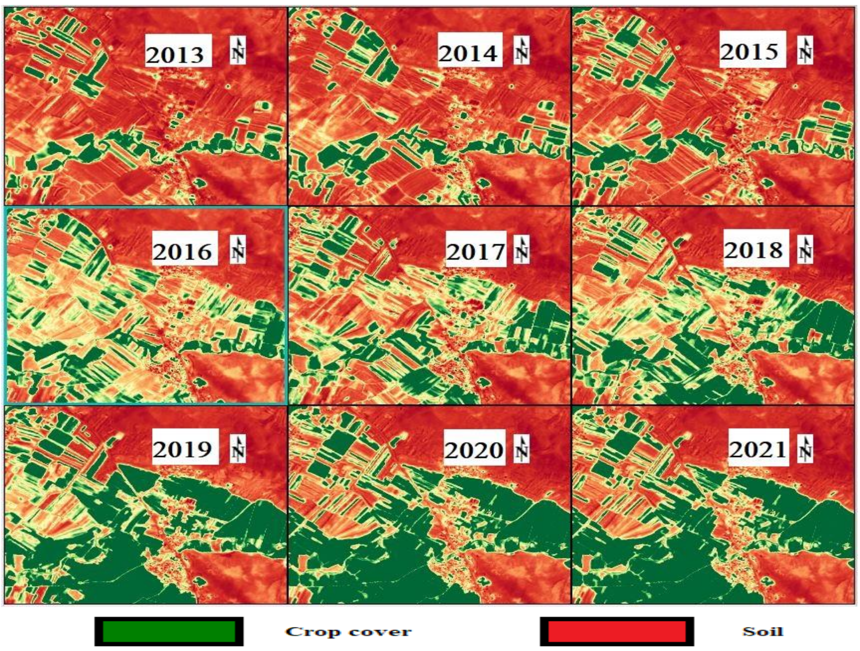


Fig 4. Vegetation changes trend in a part of the region in August from 2013 to 2021

According to Table 2, the area of vegetation in this map was 4113 hectares, which is almost close to the area calculated from the NDVI map of 2021.
The validation results of this map are shown in Table 3.

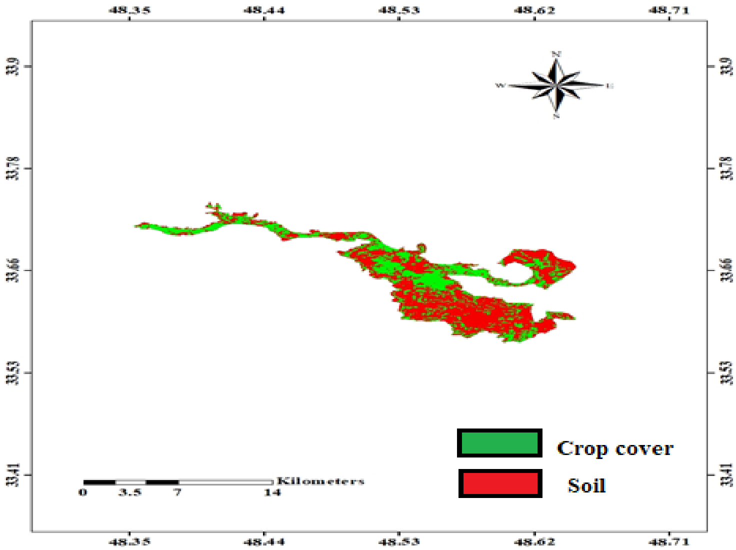


Fig 5. Map produced using Sentinel 1 radar images

Table 2. The area of rice fields according to the map extracted from Sentinel 1 radar images

Total area (hectare)	10466.48
Rice cultivation area (hectare)	4113.33

Table 3. Accuracy coefficients of the classified map using Sentinel -1 radar images

Class	Producer accuracy	User accuracy	Omission	Commission	Kappa	Overall accuracy
Mountainous area	93	96	6.67	3	0.72	82
Other crops	67	74	33.3	25.9		
Rice	85	77	15	22.7		

Table 4. The calculation of the Mann-Kendall test for data time serie

Name	area
Years	2013 - 2021
n	9
Test S	27
Signific.	**
Q	2.30E+02
B	3.14E+03

This map has good accuracy, according to the Kappa coefficient and overall accuracy of 72% and 82% respectively.
Extracting the same results, for the other years, showed the amount of vegetation has increased from 2564 hectares in 2013 to 4771 hectares in 2021, which is almost 1.8 times.
The calculation of the Mann-Kendall test for trend and the nonparametric Sen's method for magnitude of the trend are presented in Table 4 and Figure 6.

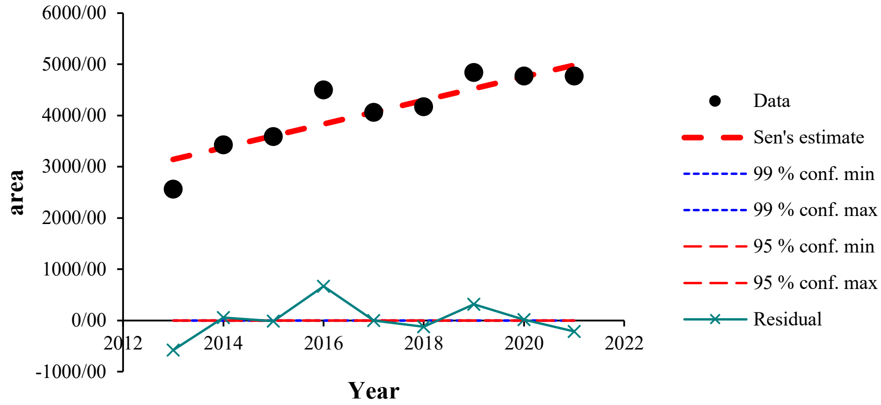


Fig 6. Trend statistics of vegetation area in Beiranshahr region in August from 2013 to 2021

As can be seen from Table 4, the S test is significant at the 0.01 level of significance statistically, and a positive increasing trend exists in the data series. The trend seems to be monotonic and thus the Mann-Kendall test is suitable. In table 4, Q and B are the slope and constant of the estimated equation for the illustrated line in Figure 6. Kamkar *et al*., (2019) detected the rice and soybean grown fields and their related cultivation areas using Sentinel-2 satellite images in summer cropping patterns to analyze temporal changes in their cultivation area in Golestan province, Iran. They concluded that the soybean cultivation areas which is an alternative plant for rice in summer cropping, has decreased compared to past years and rice cultivation has increased.

Zhang et al. (2017) showed that acreage derived from the MODIScrop maps was generally consistent with that reported in the FAO data (a relative error of <4.1% for rice and <6.1% for maize, and <9.0% for soybean except for in 2004, 2008, and 2009) and the maps derived from the LScrop (a relative error of about 5% in 2013, and 7% in 2008 and 2014).

The net water requirement of rice is about 10,000 cubic meters during the growing season (Ghorbani Vaghei *et al*., 2021). This amount is about twice as much as other summer crops in this region. Although the water loss is high due to the soil texture, seepage from the rice basins, and the irrigation method, This issue increases the gross water requirement for the rice by about 1.5 times. For this reason, one hectare of rice consumes about three times as much water as other summer crops. In addition, due to the changes in rice cultivation area, water consumption has increased by more than 33 million cubic meters in 2021 compared to 2013. This condition is more critical due to the fallowness of rice cultivated land in the past. Indeed, considering that the Beiranshahr region is located in a semi-arid climate, the increasing rice cultivation in the region can cause great damage to water resources. The map of the increase in the depth of water table level in the region is shown in Figure 7.

According to the map, the reservoir's depth has increased by 1 to 10 meters over the last ten years. The changes in water table depth in the central areas, which have the largest area under rice cultivation, are

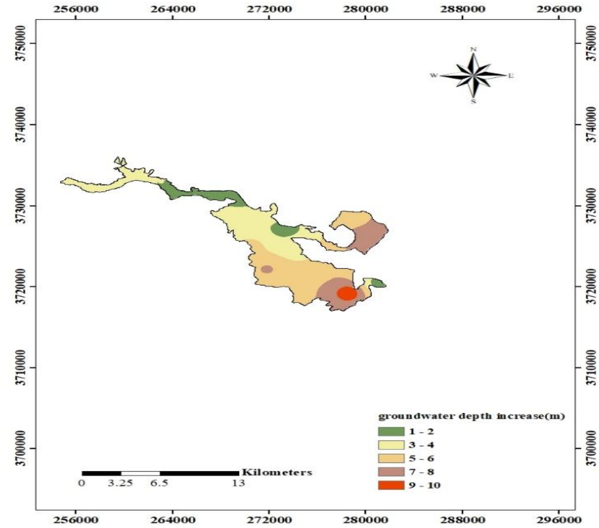


Fig 7. changes of water table depth during 2013 to 2021in Beiranshar region, Iran

Fig 8. the status of the river in 2013 (up) and the holes dug in 2021 (down)

between 3 and 6 meters. The map marks two areas with lower water level changes, between one and two meters, in green. The permanent river in this region experiences a low flow in the summer due to a decrease in rainfall and a lack of snow reserves in the upstream mountains. The image related to this river in 2021 is shown in Figure 8. With the occurrence of drought in the region in recent years, the farmers dug the riverbed to get water. Figure 8 shows a photo of the holes drilled by farmers in the river bed.

Although these problems are related to climate change and recent droughts, the increase in rice cultivation cannot be ignored. Some researchers relate the problems of water resources in Iran only to drought, climate change and structural factors (Mardani et al., 2016; Zarepour Moshizi *et al*., 2022), but social problems such as inflation and income reduction, which lead to encouraging farmers to grow rice, are mostly ignored. Most of the world's people, especially in the MENA region, will experience a severe water crisis by 2050. For this reason, most Iranian researchers stated that Iran would face a worrying prospect if they did not set the correct management and suitable domestic and international policies for the future (Rezayan and Rezayan, 2016). However, it is possible to prevent the increase in the cultivation of crops with high water consumption, such as rice, by solving social problems in areas where there was no history of rice cultivation until a decade ago. This will help save water resources and manage them better.

Most people in the world, especially in Africa and the Middle East, will experience severe water crises by 2050. Iran will face the worrying prospect that if it does not set the correct management and suitable domestic and international policies for the future (Rezayan and Rezayan, 2016), Drying lakes and rivers demonstrate the critical level of water situation in Iran that is escalated by frequent droughts and overuse of surface and groundwater, so that this country is facing water bankruptcy where water demand exceeds the natural water supply (Madani et al., 2016).

Conclusion

Paddy rice distribution maps are of great importance for assessing and understanding water use at regional, national, and global scales. The results of this research showed that the area under rice cultivation in the Biranshahr region has increased significantly from 2013 to 2021. In general, increasing the planting of water-consuming crops such as rice in arid and semi-arid regions can endanger the water resources of the region, and in the long term, the region will face serious challenges. Therefore, it is recommended to limit the cultivation of rice in the region and cultivate crops with less water consumption instead. The development of pressurized irrigation systems in the region can help save water consumption. Local farmers neglect the water shortage and its future problems due to a lack of awareness; therefore, it is the responsibility of the government to inform the local farmers and conserve the groundwater resources.

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