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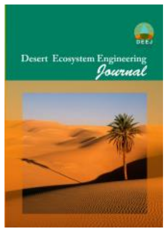

Assessing the Plans Designed to Combat Desertification Using Statistical Analysis of Satellite Images: A Case Study of Kashan Plain, Iran

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Abstract

Seeking to combat desertification as a major environmental hazard, especially in recent decades, experts have offered some projects to be implemented in this regard, trying to reduce the destructive effects of the phenomenon. Therefore, assessing the projects implemented in this regard can help improve the management of desertification and the adoption of relevant appropriate decisions in the future. This study, thus, set out to compare the alterations made in the vegetation of the Kashan plain as a result of the implementation of five desertification combat plans using statistical techniques and the Normalized Vegetation Index (NDVI) time series of Landsat satellite collected from the 2003 to 2020.

The study's results indicated that the average NDVI index in the studied areas increased following the implementation of the plans. On the other hand, the results of examining the trend of the NDVI index time series showed that vegetation density within the plain had an increasing trend throughout the study period. However, it was found that from 2008 to 2010, the trend changed in all five series, with positive trends being created or reinforced when the projects to combat desertification were carried out. Therefore, it can be concluded that the projects have at least increased the vegetation density, creating a positive trend with a gentle slope.

Keywords: Land Degradation, Kashan Plain, Vegetation, Land Use, Remote Sensing.

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1. Introduction

Environmental problem worldwide (Jafari et al., 2005), desertification may occur in all climatic conditions, the intensity of which depends on a region's humidity regime. Therefore, in regions with hot dry climates, the desertification process may be accelerated and turned into a disaster, bringing about the destruction of soil, water resources, vegetation, and other resources under natural and ecological conditions (Akbari et al., 2007; Akbari et al., 2020b).

On the other hand, desertification may occur as a result of natural and human factors (Arami et al., 2013). In a conference held by the UN in 1992 on Environment and Development, desertification was defined as land degradation in arid, semi-arid, and semi-humid arid areas which occurs due to various factors, including climate variations and human activities (Akbari et al., 2021). Therefore, taking into account the destructive effects of desertification, the relevant officials have implemented a wide variety of plans in different regions of Iran to prevent the development of desert areas.

The criteria for measuring sustainability in areas affected by the plans designed to combat desertification include vegetation, water erosion, wind erosion, salinization, and water resources. Meanwhile, plants play an important role in terms of the ecological structure of each region, soil protection, moisture retention, and increasing the penetration of precipitation (Nazari Samani et al., 2013). Therefore, vegetation is considered as a suitable criterion for assessing the development of desert areas or the success of projects to combat desertification (Li et al., 2017).

Remote sensing is a method commonly used for investigating vegetation changes, whose data help examine such changes over relatively long periods, reducing research costs (Liu et al., 2021). This study, therefore, sought to use remote sensing data and geographic information systems to investigate the vegetation changes in areas affected by the projects carried out to combat desertification in Kashan Plain in 2009, and to assess the success of such projects based on vegetation criteria. It is evident that assessing the success or failure of the implemented plans can be a basic factor in setting prospective plans to combat desertification.

Many studies have so far been conducted on the significance of vegetation changes in desertification and the assessment of desertification combat plans using the remote sensing method. For instance, Wakeel et al. (2005) investigated the changes induced by human activities in the forest vegetation from 1967 to 1997 using Landsat satellite data. Moreover, Hill et al. (2008) used the Normalized Vegetation Index (NDVI) to monitor vegetation changes on the land surface. On the other hand, Dawelbait and Morari (2012) investigated the desertification phenomenon in Sudan using Landsat satellite images, suggesting that the images performed well in identifying high-risk areas.

Sousa et al. (2012) also examined the process of desertification in Barbaras, Brazil using Landsat satellite images, indicating that preparing a map from satellite images with linear regression was a suitable method for monitoring desertification. Moreover, Li et al. (2013) used Landsat satellite images to investigate desertification and vegetation changes in China. Also, Vorovencii (2017) investigated the desertification process in Romania from 1984 to 2011 using remote sensing, citing human activities and natural factors as the main causes of desertification in the country. Furthermore, Filei et al. (2018) examined desertification in Mongolia using satellite images, proving that the decrease in precipitation and an increase in temperature played the most important role in the expansion of deserts.

On the other hand, Lamqadem et al. (2018) evaluated and mapped desertification in Morocco using remote sensing, and Mutti et al. (2020) used NDVI time series to model and predict desertification in Brazil. In Iran, Hanteh et al. (2004) investigated the plans to combat desertification in the Aghazi Ganges area in the Zarand Saveh, showing the positive and negative results of Atriplex cultivation. Moreover, Jafari et al. (2005) evaluated the changes made in soil and vegetation following the implementation of the desertification combat project in Lamerd Plain, Fars province.

Furthermore, Soltaninejad et al. (2019) assessed the plans carried out to combat desertification in Shahdad, Bam, and Garmsar by examining the changes in NDVI, suggesting that the area of the lands covered by vegetation had increased over 30 years. However, while many studies have been carried out in this regard in Iran, the plans implemented to combat desertification in Kashan Plain have not been carefully assessed. Therefore, the current study set out to evaluate such projects in Kashan Plain using satellite images.

2. Materials and Methods

2.1. The Study Area

This study sought to investigate the plans carried out in 2009 to combat desertification in Kashan Plain, which is located in northern Isfahan province. Marked from A to E, the areas examined in the study included five districts located in the central parts of the plain, measuring 676.058 hectares in total. Figure 1 shows the location of the study areas and Table 1 displays the area of each region.

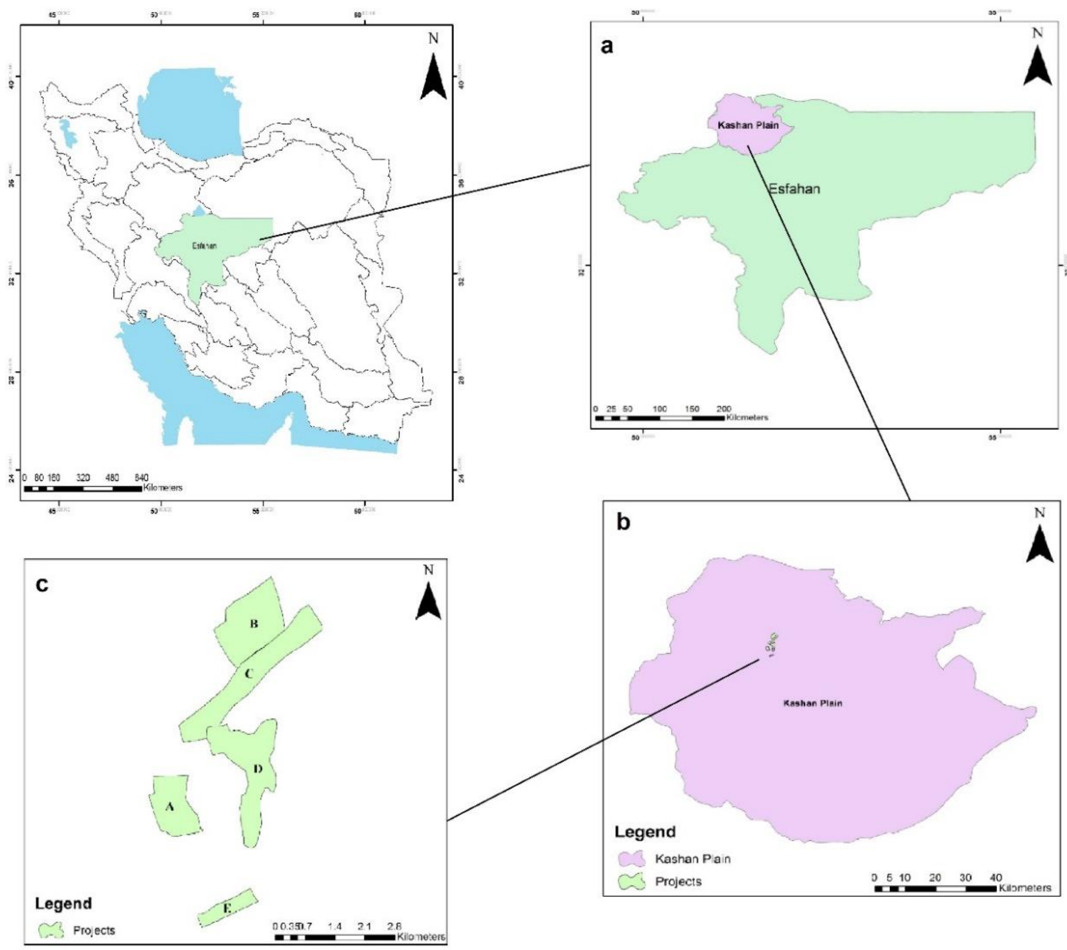

Figure (1): a) Location of Kashan plain in Isfahan province; b) Location of the areas where the desertification combat projects were implemented, and c) The Study Area

Table (1): The area of the studied areas

Project	Area (hectares)
A	100.716
B	164.13
C	190.107
D	181.997
E	39.108
Total	676.058

2.2 Data

This study used NDVI images extracted from Landsat 7 and 8 satellites from 2003 to 2020 to investigate vegetation changes in the study area. Accordingly, an average NDVI image was calculated for each year, leading to a total of 17 average images for the statistical period with a spatial resolution of 30 meters. It should be noted that NDVI images for the years 2003 to 2012 and 2013 to 2020 were obtained from Landsat 7 and 8 satellites, respectively. Then, NDVI time series were extracted from the average images (17 images) to form the basis for investigating the trend of vegetation changes in the areas where the plans to combat desertification were carried out. Moreover, the precipitation data for the years 2003 to 2020 were collected from Kashan station to examine the changes in the annual precipitation rate.

2.3 Method

This study compared the average NDVI values before (2003 to 2008) and after (2009 to 2020) the implementation of the plans to combat desertification in Kashan Plain using the paired T-test. Then, the researchers examined the trend of the changes made in the vegetation density of the regions where the plans were implemented. Considering the length of the statistical period (17 years), linear regression was used to investigate the trend based on Sen’s slope method. Accordingly, the line’s slope is estimated according to the median of all possible slopes, whose equation is as follows:

$$1 \leq i < j \leq n \text{ و } b = median\left(\frac{Z_i - Z_j}{t_i - t_j}\right) \quad (1)$$

Where b is the line’s slope, Zi represents the i-th observation, Zj shows the j-th observation, ti indicates the i-th time, and tj stands for the j-th time (Sen, 1968).

On the other hand, the changes in the NDVI trend were examined to more accurately assess the influence of desertification combat plans on vegetation density in the study area using the Pettitt method. In this regard, the following equation was used to calculate Petit's statistic (Jaiswal et al., 2015):

$$\text{where } U_t = \sum_{i=1}^{t} \sum_{j=t+1}^{n} sign(x_i - x_j) \quad (2)$$

$$sign(x_i - x_j) = \begin{bmatrix} 1, if\ (x_i - x_j) > 0 \\ 0, if\ (x_i - x_j) = 0 \\ -1, if\ (x_i - x_j) < 0 \end{bmatrix}$$

Moreover, the test statistic (k) and its confidence level (ρ) for samples with length n can be calculated via the following equations:

$$k = \max|U_t| \quad (3)$$

$$\rho = \exp\left(\frac{-k}{n^2 + n^3}\right) \quad (4)$$

Accordingly, in cases where ρ is smaller than a certain confidence level, the null hypothesis is rejected and a change in trend is confirmed (for more information about this test, refer to Jaiswal et al. (2015)). Therefore, should the plans implemented to combat desertification succeed in creating a change in the vegetation density of the region, the change can be identified through the above-mentioned method. Finally, the annual precipitation changes in Kashan station were investigated from 2003 to 2020, considering the influence of precipitation on vegetation. It should be noted that the calculation phases of the current study were carried out using R programming language.

3. Results

3.1 Spatial distribution of the NDVI

Figure 2 shows the long-term average value of the NDVI in Kashan plain and the areas where the plans to combat desertification were implemented from 2003 to 2020. Accordingly, a major part of the Kashan Plain’s area lacks vegetation. On the other hand, areas covered by vegetation are mainly observed in the form of scattered streaks in the central, northern, and southern regions along the northwest-southeast direction, and some eastern parts of the region.

However, the density of vegetation in all parts of the mentioned areas varies from very weak to moderate, with no part of the Plain possessing above-average vegetation density.

The average value of NDVI in areas where the plans to combat desertification were implemented varied from 0.06 to 0.08, indicating a very low density of vegetation. However, while in some eastern and western parts of the region, the vegetation density approaches the average rate, the land surface in all five studied areas is mainly sandy with very little vegetation.

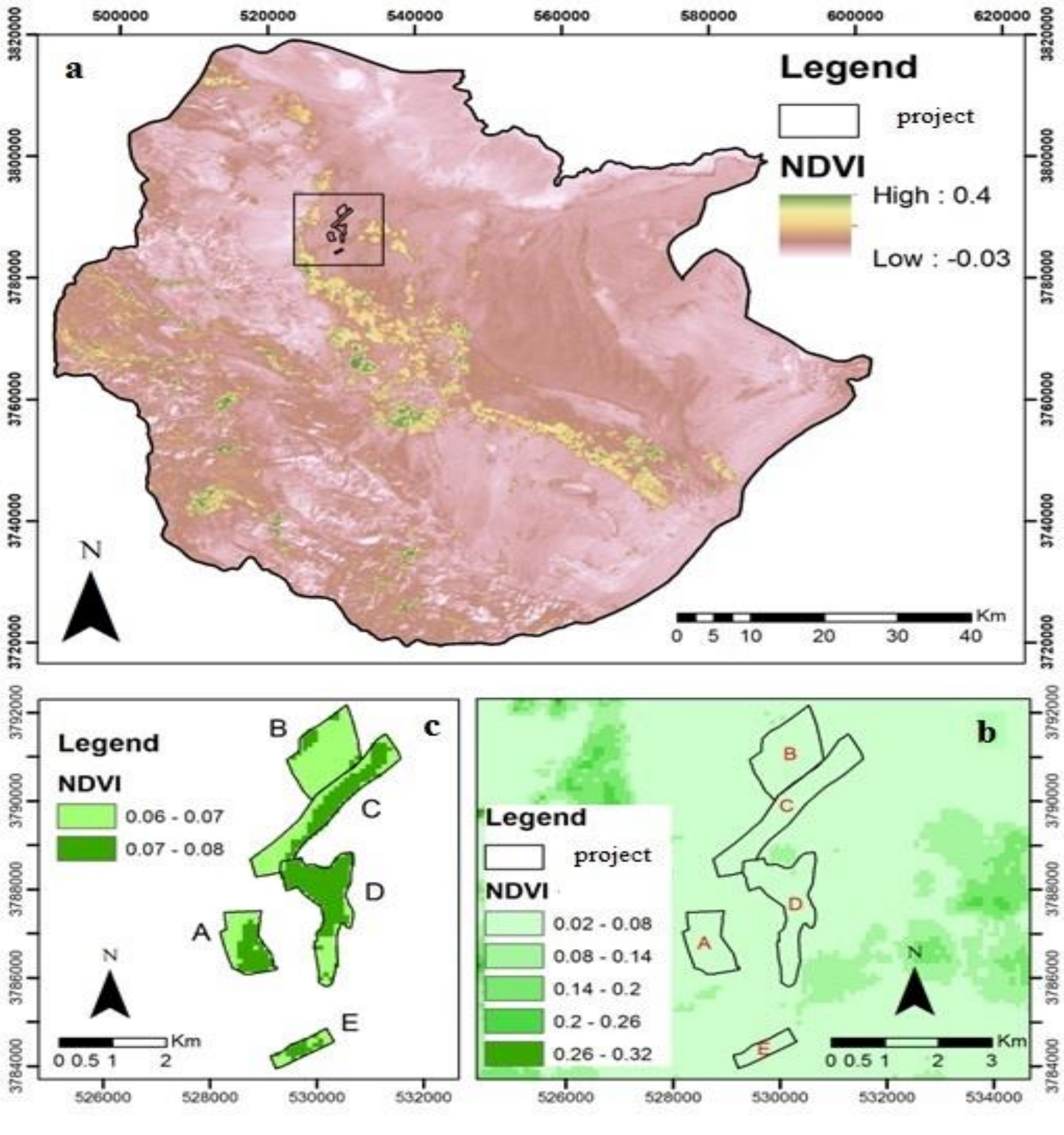

Figure (2): Spatial distribution of the average NDVI value in Kashan Plain (a), the site where the desertification combat plans were implemented and its surroundings (b), and the site where the desertification combat plans were carried out from 2003 to 2020 (c)

3.2 Comparison of the average vegetation density before and after the implementation of desertification combat plans

Table 2 shows the average NDVI values in the areas where the plans to combat desertification were implemented. The values belong to the 2003-2008 period (before the implementation of the plans) and the 2009-2020 period (after the implementation of the plans). Accordingly, the average value of NDVI in all five studied areas was found to be 0.06 before the implementation of desertification combat plans, which was increased by 0.01 to 0.02 after the plans were carried out, with the average NDVI value reaching 0.08 in A and D areas, and 0.07 in other three areas, respectively. Although such increases seem very small and insignificant, the difference observed in the average values of the two periods is significant in all five areas according to the statistical t-test. In this regard, the lowest significant level belonged to area B, which confirms the change in the average NDVI value from the first period to the second one with a 98% confidence level. The difference in NDVI is significant in the other four areas with 99% confidence level and more.

Table (2): Comparison of average NDVI values before and after the implementation of desertification combat plans

Plan	*Minimum index*		*Maximum index*		*Average index*		*t statistic*	*P value*
	Before the implementation of the plans	*after the implementation of the plans*	*Before the implementation of the plans*	*after the implementation of the plans*	*Before the implementation of the plans*	*after the implementation of the plans*		
A	0.02	0.05	0.09	0.13	0.06	0.08	4.1-	0.001
B	0.04	0.04	0.08	0.11	0.06	0.07	2.6-	0.02
C	0.03	0.07	0.08	0.13	0.06	0.07	2.8-	0.01
D	0.03	0.07	0.1	0.14	0.06	0.08	4.1-	0.001
E	0.04	0.07	0.08	0.11	0.06	0.07	3.8-	0.002

3.3 Investigating the trend of the NDVI in areas affected by desertification combat plans

Figure 3 shows the NDVI time series in the areas where the plans to combat desertification were implemented. It also displays the trends of such series in the entire period, and the year when the change occurred in the trend (black dashes). Moreover, the figures show the trend line before and after the occurrence of the change. On the other hand, Table 3 displays the equations by which the trends and the years when the change occurred in such trends were calculated.

According to Figure 3 and Table 3, NDVI time series in all five studied areas had a significant increasing trend (with more than 99% confidence level) throughout the study period, with the index annually increasing by 0.002 on average (0.02 in ten years) in areas A and D, and by 0.001 per year (0.01 in ten years) in areas B, C, and E. Therefore, it could be argued that the vegetation density has been increasing from 2003 to 2020 in the studied areas with a gentle slope.

However, the examination of the changes in trend value revealed significant changes in all the five time series investigated. Moreover, the year when such changes occurred was specifically concurrent with the year when the plans to combat desertification were carried out (2009). in this regard, the year 2010 was identified as the time when changes occurred in areas A, D, and E, and the year 2008 was found as the year when changes were made in areas B and C.

Investigating the trend of time series before and after the occurrence of such changes showed that just in area A, the NDVI time series had a significant positive trend before the year when the changes occurred. However, the slope of changes was equal to 0.001 before 2010, which increased to 0.003 after the occurrence of changes. On the other hand, it was found that no significant trend dominated the NDVI time series in the other four areas before the year when the changes occurred. Nonetheless, after the changes occurred in areas B and C, the NDVI trend increased by 0.002 per year in areas B and C, by 0.003 in area D, and by 0.001 per year in area E. Therefore, it could be argued that the implementation of desertification combat plans has led to an increase in or the formation of significant positive trends in vegetation density in all five areas.

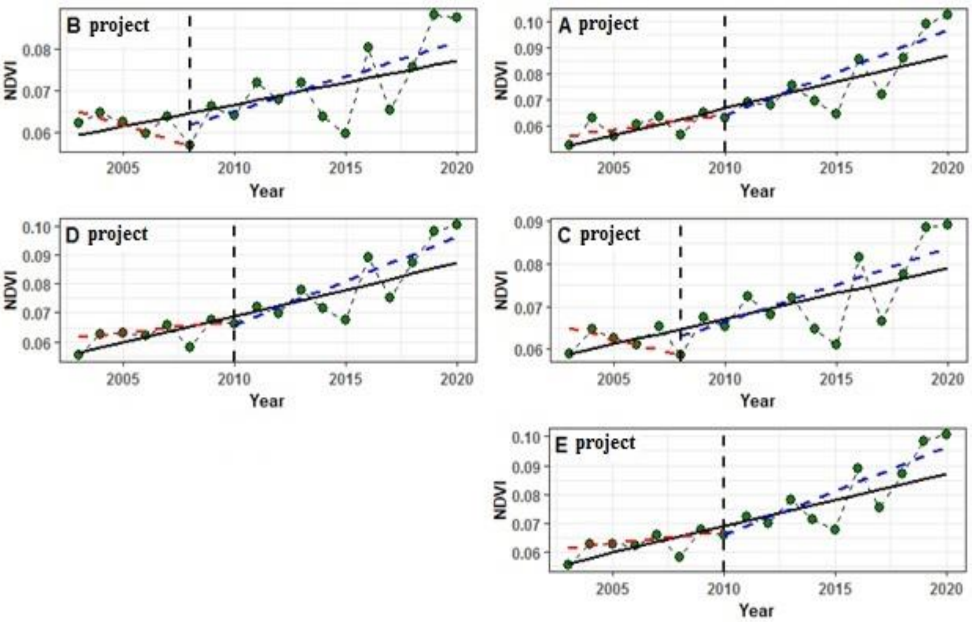

Figure (3): The time series of the average NDVI value at the implementation site of each project (black solid line: the trend in the entire period; red dashed line: the trend before the occurrence of changes; blue continuous dashed line: the trend after the occurrence of changes; black vertical dashed line: the place where the changes occurred in the trend

Table (3): The trend of the average NDVI at the implementation site of each project

project	*The trend f the entire period*		*The year of the change in the trend*	*The trend before the change*		*The trend after the change*	
	P value	Script equation		*P value*	Script equation	*P value*	Script equation
A	0	$NDVI = 0.05 + 0.002t$	2010	0.01	$NDVI = 0.06 + 001t$	0	$NDVI = 0.04 + 0.003t$
B	0	$NDVI = 0.06 + 0.001t$	2008	0.14	$NDVI = 0.07 + 002t$	0	$NDVI = 0.05 + 0.002t$
C	0	$NDVI = 0.06 + 0.001t$	2008	0.99	$NDVI = 0.07 + 001t$	0	$NDVI = 0.05 + 0.002t$
D	0	$NDVI = 0.05 + 0.002t$	2010	0.1	$NDVI = 0.06 + 001t$	0	$NDVI = 0.04 + 0.003t$
E	0	$NDVI = 0.06 + 0.001t$	2010	0.23	$NDVI = 0.06 + 0004t$	0	$NDVI = 0.06 + 0.001t$

3.4. Investigating changes in precipitation from 2003 to 2020

Considering the important role of precipitation in vegetation changes this section reports the results of examining the annual precipitation changes in Kashan station throughout the study period (2003 to 2020). According to Figure 4, the highest and lowest amount of annual precipitation belonged to 2011 and 2017, with the rate being 173 mm and 65.8 mm, respectively. The point to consider in the annual precipitation time series is the lack of a significant trend, with the p-value obtained as 0.9 after calculating the trend. Therefore, while the average amount of precipitation experienced no significant increase or decrease during the study period, the NDVI time series had a significant increasing trend. However, the index underwent significant jumps from 2008 to 2010. Therefore, it can be concluded that the NDVI's increasing trend in the studied areas was independent of the precipitation trend.

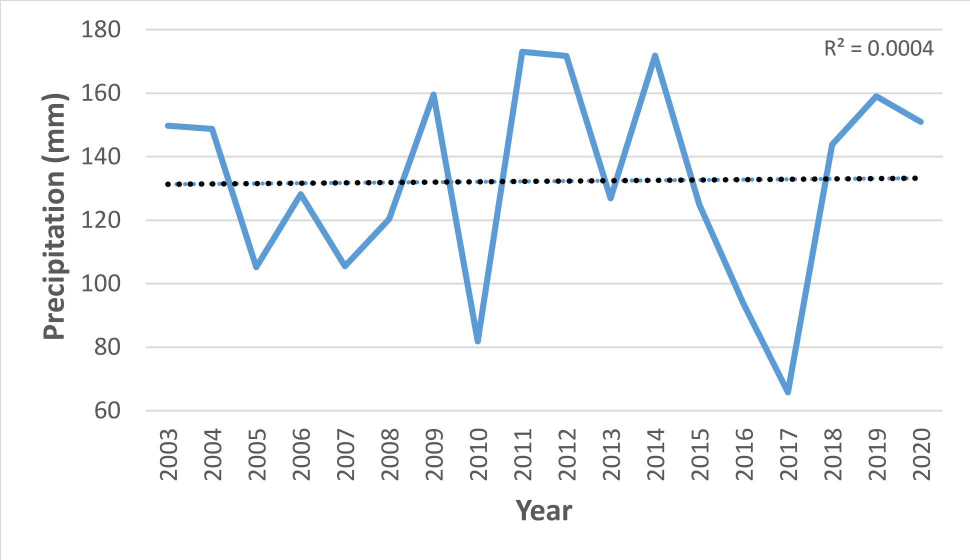

Figure (4): Annual precipitation time series in Kashan station during the study period (2003 to 2020)

4. Discussion and Conclusion

This study sought to investigate the influence of desertification combat plans on the improvement of regional vegetation in Kashan Plain from 2003 and 2020 using the standard NDVI. The data extracted from Landsat 7 and 8 satellites were also used to calculate the time series of the index. Accordingly, the examination of the trend of NDVI changes generally revealed that the implementation of such plans led to a significant improvement (95%) in vegetation. It was also found that the while average NDVI value was 0.06 in all five studied areas before the implementation of the plans to combat desertification, it was significantly increased by 0.01 and 0.02 after the implementation of such plans, with the average NDVI value reaching 0.08 in areas A and D, and 0.07 in other three areas.

Moreover, the results of the examination of the NDVI time series trend suggested that vegetation density had a significant trend throughout the study period in all five studied areas where the plans to combat desertification were carried out, getting increased by a gentle slope. However, the value of the trend underwent significant changes from 2008 to 2010 in all five series. In other words, before the 2008-2010 period, merely area A witnessed an increase in vegetation density, and the other four areas experienced no significant change in the trend. Also, no significant changes were found in the trend of the annual participation rate from 2003 to 2020. Therefore, it could be argued that the positive trends in the series were created or increased under the influence of desertification combat plans.

Accordingly, it can be concluded that the plans implemented to combat desertification increased the vegetation density and also created a positive trend with a gentle slope, whose realization is evident before and after the implementation of the plans. Some other studies have also reported the same findings. For instance, in a study on the desertification process in Taibad from 1977 to 2016, Sarparast et al. (2020) reported an improvement in vegetation after the implementation of desertification combat plans.

Moreover, Soltaninejad et al. (2021) investigated the trend of NDVI changes in Landsat satellite images in the Shahdad plain of Kerman, finding that the area of vegetation-free regions had decreased by more than 35% throughout their study period. Other similar studies also stress the improvement of NDVI, and therefore vegetation density in areas where the plans to combat desertification were carried out (Akbari et al., 2021; Akbari et al., 2020a; Eskandari Dameneh et al., 2021; Jafari & Abedi, 2021).

The implementation of the plans to combat desertification directly affects the region's soil by improving the vegetation. Increased input of organic matter into the soil, improvement of the soil's permeability and moisture storage, protection of the soil against wind erosion, preserving of the soil's organic matter, the improvement of the rooting conditions, and the establishment of new seedlings affect the improvement of vegetation sequentially (Amiraslani & Dragovich, 2011; Geeson et al., 2015; Zhang et al., 2018).

However, one of the most important requirements for the long-term effectiveness of desertification combat plans is the correct management of the area, including proper irrigation, pruning, protection against grazing, and replacement of the dead seedlings with new ones, which may play a role in the success or failure of the plans.

Considering the continuous improvement of vegetation in the studied areas in Kashan plain, it can be concluded that the areas have been managed properly. Nonetheless, it should not be noted that the slow process of changes in the region results from the plain's harsh environmental conditions and low precipitation rate (which rarely exceeds 100 mm per year), requiring the irrigation of the seedlings within the first in one or two years of the implementation of the desertification combat plans. In this regard, as the seedlings of the region have been properly irrigated, the effect of the management plan can be well understood.

Moreover, while the implemented plans have failed to make great tangible changes in vegetation, the trend of long-term changes in the median of the data shows a significant increasing trend with a gentle slope. On the other hand, the jump in the trend reveals the influence of the implemented plans on vegetation changes.

Finally, it is recommended that satellite images with higher spatial resolution be used. Furthermore, considering the positive trend of the implemented plans to combat desertification in Kashan plain, it is recommended that the plans continue to be implemented and monitored in the region, some appropriate decisions are made for their management, and that they are implemented in a wider extent so that the region's vegetation is improved.

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