Investigating Long-Term Changes Trend in Vegetation Time Series of Sistan Plain on a Pixel-Based Scale Using MODIS Sensor Products of Terra Satellite

Peyman Mahmoudi[1], Seyed Mahdi Amir Jahanshahi [2], Fatemeh Firoozi[3]
1- Department of Physical Geography, Faculty of Geography and Environmental Planning, University of Sistan and Baluchestan, Zahedan, Iran
2- Department of Statistics, Faculty of Mathematics, Statistics and Computer Science, University of Sistan and Baluchestan, Zahedan, Iran
3- Department of Remote Sensing and Geographical Information System (GIS), Faculty of Geography, University of Tehran, Tehran, Iran

p_mahmoudi@gep.usb.ac.ir
mjahan@math.usb.ac.ir
firozif@yahoo.com

Abstract

In order to assess the vegetation changes trend of Sistan plain located in the eastern part of Iran, NDVI products from MODIS sensor on Terra satellite (MOD13A3) at 1 km spatial resolution were used over a 15-year period (2000-2014) for three months of April, May and June. After obtaining images from the land processes distributed active archive center, all 45 images downloaded for the studied area were mosaicked and geo-referenced to the Universal Transverse Mercator projection system by nearest-neighbor resampling method. In the next step, the images were converted into an ASCII format. By doing this, the total number of pixels within the studied area was 30080 pixels. Finally, the vegetation change trend was evaluated using Sen's slope estimator nonparametric method for three-month of study and on a pixel scale. The results of this research showed that the highest increasing changes trend in NDVI was observed in the northwest of the plain, and the highest decreasing changes trend in NDVI was observed in the east and center of the plain. In addition, according to the results of this study, the use of Sen's slope estimator nonparametric method in the studies of vegetation coverage variation trend in arid regions resulting from NDVI products from MODIS sensor can be very efficient and useful.

Keywords: NDVI, MODIS Sensor, Trend, Sistan Plain, Sen's Slope Estimator, Iran

1. INTRODUCTION

A time series is simply a set of observations measured at successive points in time or over successive periods of time. Various time series analysis techniques are capable of extracting multiple overt and covert data used to identify the nature of the phenomenon concerned (Chandler and Scott, 2011). Time series analysis methods are used in two different domains: frequency and time. The variability of phenomena in the time domain in triple time periods reveals their oscillations, fluctuation and trends (Daneshmand and Mahmoudi, 2017). Meanwhile, the trend represents a general systematic linear or a nonlinear component that changes over time and does not repeat, or, at least, does not repeat within the time range.

Trend in time series of vegetation coverage data typically encompass gradual changes, although they may also occur abruptly or develop slowly over time. Gradual changes mainly reflect long-term changes in other factors, such as land management, land erosion and climate changes (Goetz et al., 2005). Whereas abrupt changes are normally caused by disturbances such as fire, flood, urbanization, insect attack, or drought (Scheffer et al., 2001; Lenton, 2013). These changes can be analyzed by investigating the normalized difference vegetation index (NDVI) time series. Normalized vegetation difference index (NDVI) is an indirect measure of photosynthetic activity. This index ranges from 0, the minimum, to 1, the maximum. The Normalized Vegetation Difference Index (NDVI) is defined as follows:

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

Normalized Vegetation Difference Index uses a fundamental principle, namely, surfaces with vegetation, red wavelength (RED) and near infrared (NIR) are characterized by high absorption and low reflection, respectively (Chen et al., 2003; Groeneveld and Baugh, 2007). The chlorophyll reflectance in the red wavelength range (RED) is about 20% and 60% in the near-infrared wavelength (NIR) and the difference between the responses of both bands allows quantifying the energy absorbed by chlorophyll, which thus represent different levels of vegetation cover (Tucker and Sellers, 1986).

A review of NDVI time series on an annual scale can provide for us a comprehensive and integrated view of photosynthetic activities in one area; while on a seasonal scale, this survey is able to separate compositions of evergreen and *deciduous* vegetation from each other and determine the *length of the growing season* for us. Furthermore, the review of the trend in *time series of normalized difference vegetation index* (*NDVI*) can help to identify recent changes in ecosystems on a local and global scale as well (Matias et al., 2013).

Many researchers have emphasized the efficiency of NDVI index and statistical models in assessing the trend of global plant phenology changes (Eklundh and Jönsson, 2003; Olsson et al., 2005; Verbesselt et al., 2006; Beck et al., 2006; Olofsson et al, 2007; Jamali, 2014; Jin and Eklundh, 2014). Using MODIS sensor on the Terra satellite, Jamali (2014) evaluated the trend of vegetation cover variations in the Sahel area of Africa using Mann-Kendall statistical and ordinary least-squares regression methods (OLS). The result of this study indicates that the least squares regression statistical method (OLS) gives us a better result than the Mann-Kendall method. It was also shown that the estimation of the NDVI time series depends to a great extent on the source of satellite data, resolution, and statistical methods used. In addition, in a study on the vegetation cover trend of two Fennoscandia and Kola Peninsula islands during the statistical period of 2000-2005, Beck et al. (2006) reached a good agreement between the statistical models used and demonstrated that statistical methods are suitable tools for examining vegetation trends and verification with field visit.

In their monitoring the trend changes in three wetlands of Hamoun and land cover of surrounding area in a 38-year period (1977-2014) using satellite remote sensing products, Shakeryari et al. (2016) came to the conclusion that the changes made in the three wetlands of Hamoun were negative in the first (1977-1988) and the second periods (1988-1988), but in the third period (2000-214), the changes were made with a positive slope towards the restoration of wetlands. In *general*, *however*, the changes trend in the three wetlands of Hamoun has been toward loss of wetlands in the studied periods. Land cover changes around the lake also indicate that the land area belonging to the classes of canebrake and barren lands and saline soils has been decreasing and the vegetation class has been increasing.

According to the results of above-mentioned studies, it can be said that the assessment of vegetation variations in different parts of the world has always been *an issue* of *concern for* many researchers, especially remote sensing and environmental researchers. To evaluate this trend, they utilized various satellite images and mathematical and statistical techniques and methods. By taking into consideration all previous studies, this study intends to investigate the changes in vegetation trends in one of the dry and hyper-arid plains of the world called Sistan plain in eastern part of Iran as a case study using MODIS sensor on a Terra satellite and introduces a new scientific framework based on two remote sensing and statistics knowledge. Therefore, in what follows, after the introduction of the study area, the methodology will be fully presented and, finally, the results will be presented in two discussion and conclusion sections.

2. LOCATION OF THE STUDY AREA

The Sistan Delta in Iran is located at the end of a closed basin named Hilmand. The entire contributing basin is about 200,000 km2 and is largely located in Afghanistan. The Iranian part, the delta plain (ca. 2500 km2) and part of the surrounding wetlands system (ca. 5000 km2), covers less than 5% of the total basin area. The river system discharges into an inland depression which, when sufficient water is available, forms the Hamoun Lakes. These lakes are one of the main and most valuable aquatic ecosystems in Iran and are registered wetlands in the UNESCO world network of biosphere reserves (WNBR) and in the convention on wetlands of international importance (Ramsar convention). A unique feature of the lakes is that they are fresh, despite that they are seemingly at the end of a closed basin. Actually they are not the end. During periods of very high flows the lakes spill into the Shile River and to the Goud-e-Zereh. This ‘flushing’ happens on average each 8-11 years. The Goud-e-Zereh is the real terminal lake of the basin and is very saline (Van Beek and Meijer, 2006).

The Sistan inland delta has a population of some 400,000 people. The economy is strongly dependent on agriculture (irrigated and non-irrigated) and the goods and services provided by the wetlands. The irrigation system of about 120,000 ha has recently been rehabilitated. Three reservoirs (Chahnimeh) have been constructed for public water supply with a fourth reservoir under preparation. The inflowing rivers from Afghanistan support the irrigated agriculture in the Sistan delta but are also the source for the lake system around the delta (Van Beek and Meijer, 2006).

According to Köppen climate classification, this region has a very warm and dry desert climate. The average annual rainfall in this plain is very low (between 50 and 55 mm), 7% of the average annual precipitation in the world. Its annual evaporation rate is very high and about 4800 mm. The average maximum temperature is 34.5 degrees Celsius and the average minimum temperature is 8.5 degrees Celsius. The most important weather characteristic of the region a northerly wind, known as the "wind of 120 days", blows during the summer months from June to September and the direction of the wind is from northwest to southeast and the maximum speed of these winds is 100 kilometers per hour.

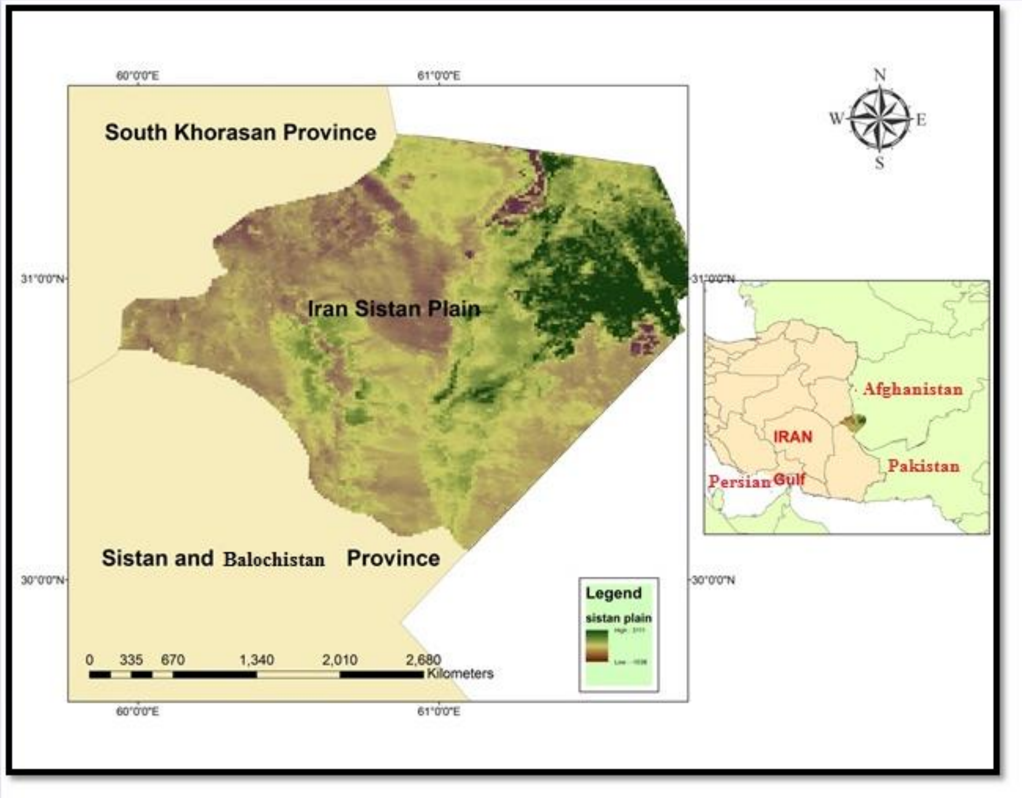


Figure 1. Geographical location of Sistan plain, Iran

3. MATERIALS AND METHODS

In order to assess the vegetation coverage change trend of Sistan plain over a 15-year period (2000-2014) NDVI products from MODIS sensor on Terra satellite (MOD13A3) were used in this study. These data can be extracted from the land processes distributed active archive center. The NDVI was calculated from the MODIS surface reflectance of the red band (610–680 nm) and near infrared band (780–890 nm), which were corrected with molecular scattering, ozone absorption, and aerosols. This 1000-m spatial resolution NDVI dataset has a temporal resolution of 16 days (Olofsson et al., 2007; Hao et al., 2012). According to local land cover and climatic characteristics, a 45 series of MODIS NDVI images for a 15-years period starting from 2000 to 2014 and for the three months of April, May and June, the maximum vegetation cover in the study area, were ordered from the EOS data gateway website. Then, all of them were mosaicked and geo-referenced to the Universal Transverse Mercator projection system by nearest-neighbor resampling method (Stefanov and Netzband, 2005; Hao et al., 2012).

The next step will be to create a database of images, how to extract and adjust the data. At first, 45 images were individually downloaded, converted and saved in ASCII format. According to spatial resolution of 1 from 1 km per image, the total number of pixels per image within the boundaries of the study area was 30080 pixels. Then, the NDVI time series of all 30080 pixels for three months of April, May and June were separated and prepared for the entire statistical period studied using the software R. Finally, the trend in *vegetation-cover changes* in each pixel was investigated using the Sen's slope estimator nonparametric method. In what follows, the computational steps of this approach have been completely presented.

This method was originally developed by Thiel in 1950 and was then extended by Sen in 1968. Like many other nonparametric methods including Mann-Kendall, this method is also based on analyzing the difference between observations of a time series. This method can be used when the trend in the time series appears to be linear. This implies that $f(t)$ in Equation 2:

$$f(t) = Qt + B \tag{2}$$

Where Q denotes the trend line slope and B is constant.

In order to calculate the trend line slope, Q, the slope between each pair of observational data should be firstly calculated using Equation 3:

$$Q_i = \frac{x_j - x_k}{j-k} \tag{3}$$

Where $j > k$. Here, in this equation, x_j and x_k denote observational data at times of j and k, respectively. Using this equation, a slope is obtained for each pair of observational data. A time series is calculated from the slopes when they are placed next to each other. This implies that if there is a N in the time series (n = 33), then we will have $N = n(n-1)/2$ which will estimate the slope Q_i.

Next, the median of studied time series should be calculated. To do this, N of Q_i should be arranged from small to large and then the median of the time series is determined using one of the following equations. If the number of time series observations is odd, equation 4 is used and equation 5 for even number:

$$Q = Q_{[(N+1)/2]} \tag{4}$$

$$Q = \frac{1}{2}\left[Q_{[N/2]} + Q_{[(N+2)/2]}\right] \tag{5}$$

As a result, the trend line slope Q_{med} is calculated. If the trend of line slope is positive, it represents an *increasing trend* and a negative *slope* a decreasing trend.

Then, the slope obtained is tested at a confidence interval of α= 0.05. The following is used to perform this test:

$$C_a = Z_{1-\alpha/2}\sqrt{VAR(S)} \tag{6}$$

Where Z refers to the standard normal distribution statistic in a two-way test which $Z = 1.96$ for confidence level of α= 0.05 and $VAR(S)$ also refers to the parameter variance. To calculate the parameter value S as well as $VAR(S)$, the following steps should be followed:

- Calculating the difference between individual series sentences with each other and applying the sign function and extracting the parameter S

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n}\operatorname{sgn}(x_j - x_k) \tag{7}$$

Where n denotes the number of series observations (15 years), x_j and x_k also denote the data of j and k series, respectively.

- The sign function is calculated as follows:

$$\operatorname{sgn}(x) = \begin{cases} +1 & if \quad (x_j - x_k) > 0 \\ 0 & if \quad (x_j - x_k) = 0 \\ -1 & if \quad (x_j - x_k) < 0 \end{cases} \tag{8}$$

- Calculating the variance S by one of the following relationships. If the number of series data is greater than 10, Equation 9 can be used and if it is smaller than 10, the equation 10 is used.

$$VAR(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t(t-1)(2t+5)}{18} \tag{9}$$

$$VAR(S) = \frac{n(n-1)(2n+5)}{18} \tag{10}$$

Where n refers to the number of observational data, m refers the number of series with at least one duplicate data, and t denotes the frequency of the same valuable data also.

Finally, the lower and upper limits of the confidence interval are calculated using the following equations:

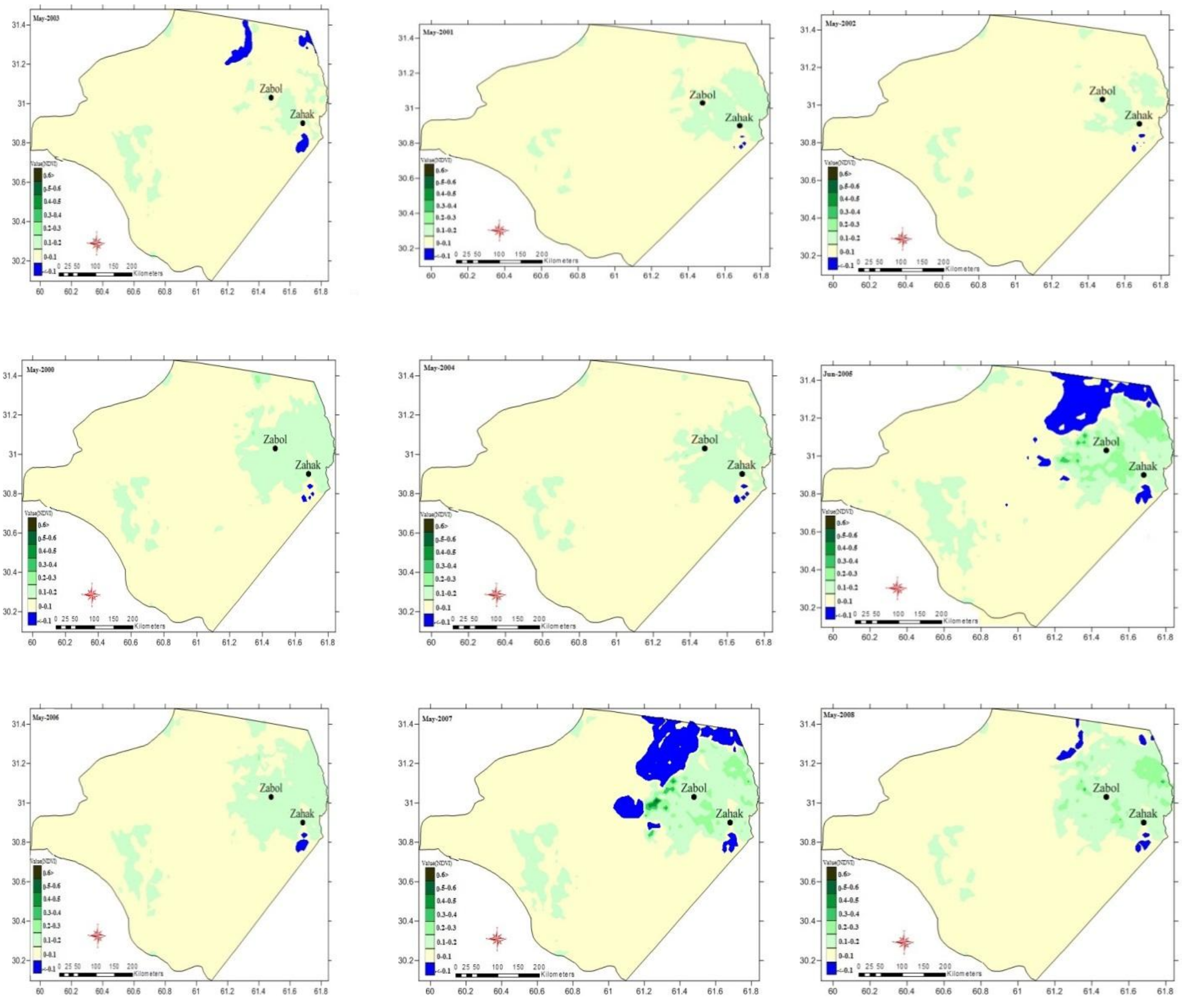
$$\begin{cases} M_1 = \dfrac{n' + C_a}{2} \\ M_2 = \dfrac{n' - C_a}{2} \end{cases} \tag{11}$$

Where n' denotes the number of slopes obtained by Eq. 9.

Now we extract the M1th and the M2 +1th of slopes among the calculated slopes. If the zero ranges between the two extracted slopes above, the H0 is accepted and the lack of trend in the data series is confirmed. Otherwise, the H0 is rejected and the trend is accepted at the confidence level. Finally, in order to obtain the B value in equation (1), N number of differences $x_i - Qt_i$ is calculated. Then the median values give an estimate of B (Alijani et al., 2011).

4. DISCUSSION AND RESULTS

Vegetation cover maps obtained from processing images of MODIS sensor from Terra satellite for three months of April, May and June for years 2000 to 2014 were prepared for the study area (Fig. 2). These three months were chosen because the region has rich vegetation during these 3 months. Figure 2 represents a sample of vegetation cover maps for May for the entire 15-year study period. These images clearly show the dynamics of vegetation over the years. According to the images obtained during May, Hamoun triple lakes and Chahnimeh inflowing from the Hirmand River were dried in years 2000, 2001, 2002 and 2004, and the vegetation has reached its lowest level.



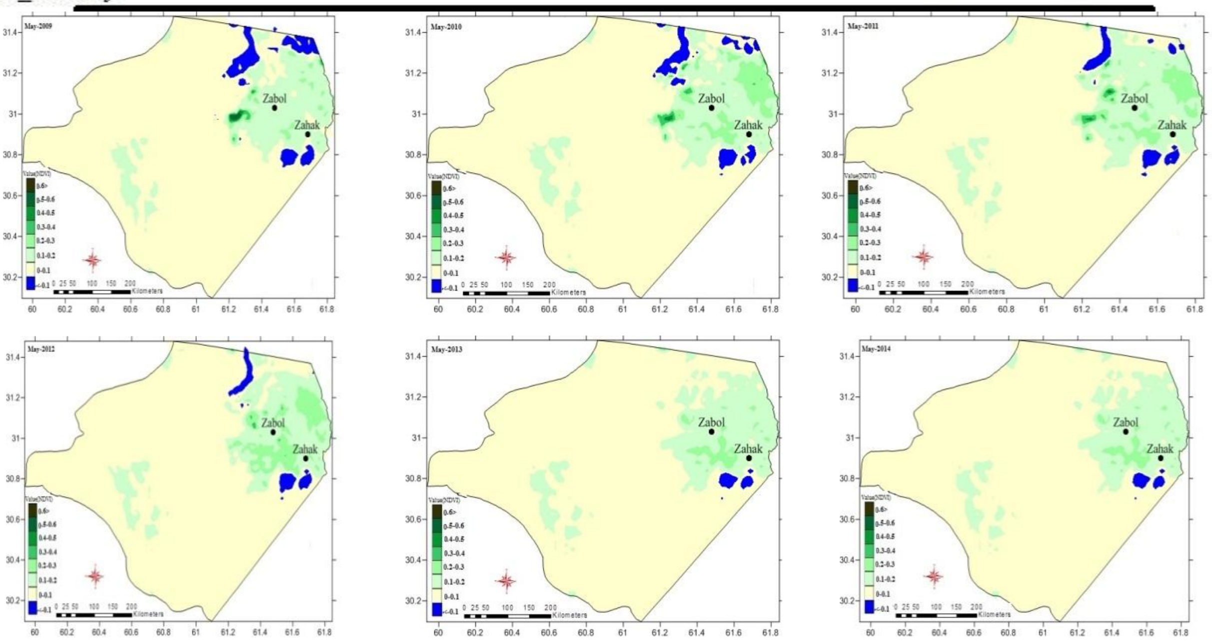


Figure 2- Vegetation maps (MODIS NDVI) of May for Sistan Plain in the period 2000-2014. (Top left for 2000 and lower right for 2014)

In line with the same vegetation dynamics in Sistan plain, the *slope values for* changes *trend* in the *normalized difference vegetation index* (*NDVI*) were separately calculated for all 30080 pixels located in Sistan Plain by April, May and June months and using the Sen's slope estimator nonparametric method. Then, the *slope* values of the obtained trends were prepared in the form of simultaneous maps for spatial analysis (Fig. 3). Comparison of simultaneous maps of April, May and June showed that the spatial patterns were almost the same for every three months (Fig. 3). These maps clearly show that the maximum changes in slope trend have been observed in the northeast of the plain where urban and rural settlements are located. In this part of the plain, the slope changes have been completely increasing. Agriculture became also widespread in this part of the plain due to the inflowing of Hirmand River. However, the point that should be considered in analyzing the increasing trends in NDVI magnitudes in the north and north-east of the plain is that an increase in the NDVI values is not related to agricultural development alone and thus to the increase in vegetation density. Rather, the *drying* up of the triple lakes of Hamoun has been a very contributor to this trend. Because as we know, blue masses in NDVI index are represented with negative or near zero values and *the drying* up of these water masses causes a change in the reflectance of the earth's infrared waves and leads its values to the positive side. In addition, the negative values on the slope of the change trend are very limited and are visible as small spots and sometimes large in the east and center of the plain. This downward trend in the NDVI values in the east of the plain coincides with the development of *Chahnimeh artificial lake* for urban and rural drinking water and the development of the agricultural sector. The rest of the plain area which is desert and without any vegetation as well as the human population has not experienced a particular trend. The significance of the obtained trends at the confidence level of $\alpha = 0.05$ is a very important point that has received much attention in many studies of the changes trend. In this study, all the trends obtained at the probabilistic level $\alpha = 0.05$ were also evaluated. The significance of the results regarding the trends is presented in three separate maps for April, May and June months in Fig. 3. In these maps, the significance of the trends has been statistically analyzed for each pixel. Pixels with an increasing and significance trend in the probability level $\alpha = 0.05$ were represented with green color; the pixels with a decreasing trend and significance on the probability level $\alpha = 0.05$ were represented with red color and finally, pixels without significant trend were represented with white color. According to these maps, an increasing trends in NDVI values in the northeast of the plain which have the highest slope values, were also significant at the level of $\alpha = 0.05$. Furthermore, the presence of distinct spots in the east and center of the plain reveals that the decreasing trend in the NDVI values has been statistically significant. To verify the results, the author conducted field visits and several oral interviews with informants and old people residing in the Sistan Plain. For a better understanding of these changes, the areas captured with GPS and screenshots of different plains were shown in Figure 4. The results of the interview with informants and old people of the plain indicate that factors such as the abandonment of agricultural land for various reasons, including long-term droughts and hydropoletic conflicts between Iran and Afghanistan were the main reasons for the existence of areas with a declining and significant trend especially in the center of the plain and caused a decreasing access to the Hirmand River water resources and *mandatory migration* from rural *areas to cities* or doing false occupations. As noted above, pixels with an increasing trend were related to the drying of *triple Hamoun lakes* as well as agriculture sector. An interesting point during this research and field observations was the use of dry beds in *triple Hamoun lakes* for planting some agricultural crops. In *general*, *however*, the dominant products of this plain are mostly wheat, barley, melon and watermelon and their irrigation is entirely dependent on *Chahnimeh artificial lake*. In addition, the increasing trend for some products in different parts of the plain is related to vineyards, dates or Tonook Gazmeh forests.

The area of each of the three categories of trends is given in Table 1. During 15 years period from 2000 to 2014, the share of regions with an increasing trend was 8272 square kilometers and the share of regions with a decreasing trend of 611 square kilometers. As mentioned above, it is clear that the drying up the *triple Hamoun lakes* and converting them into agricultural land is considered one of the reasons for the increasing share of trends which is not a reasonable and acceptable reason for the strength and improvement of agriculture in this Area.

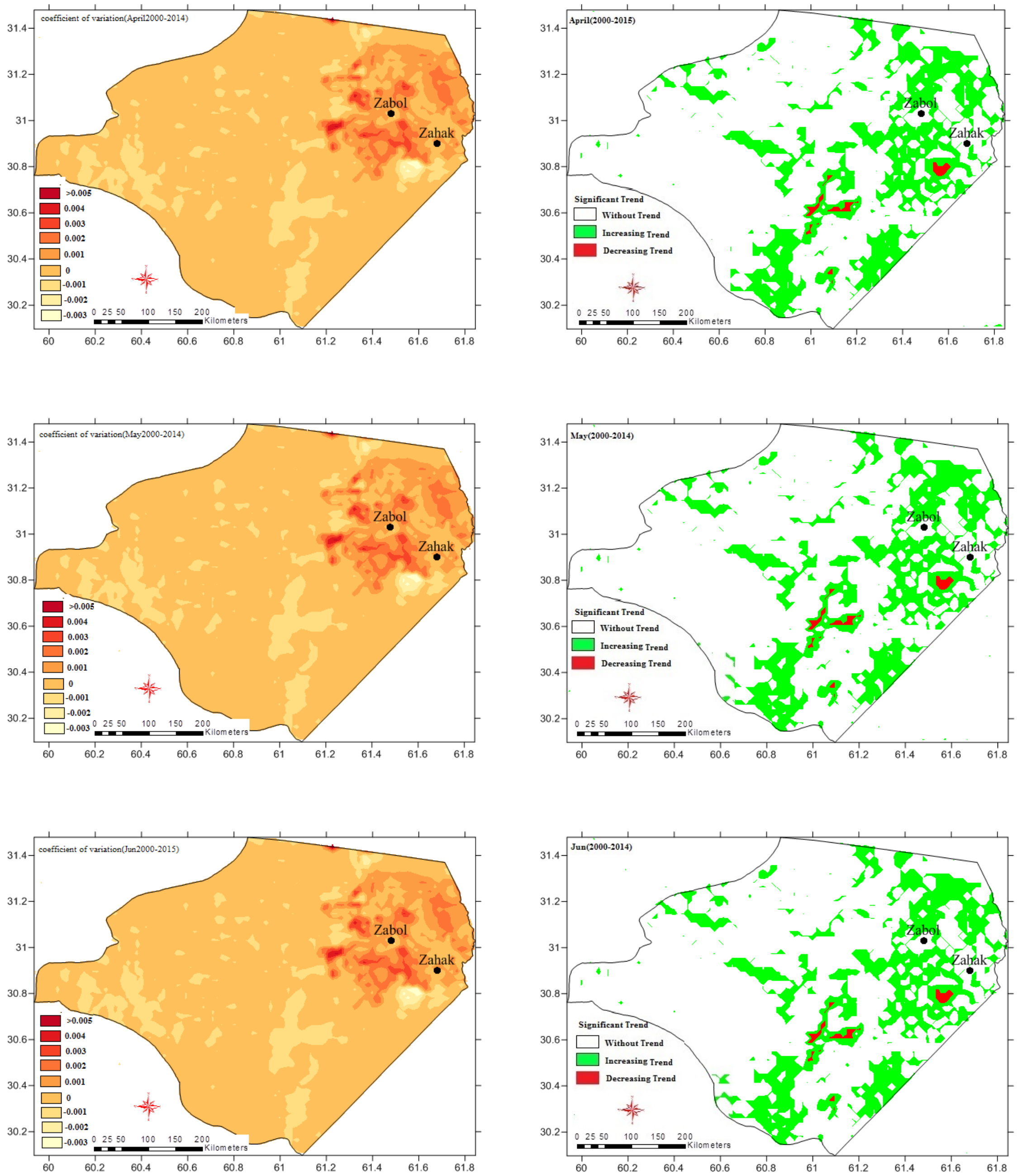


Figure 3. Simultaneous trend map for April, May and June months (left) and significant trends of April, May and June months in years 2000-2014 (right)

Table 1. The area of the pixels with decreasing trends, increasing trends and lack of trends in Sistan Plain in three months of April, May and June (km^2)

Trend	April month	May month	June month
decreasing trends	611	611	611
increasing trends	8272	8272	8272
lack of trends	7654	7654	7654

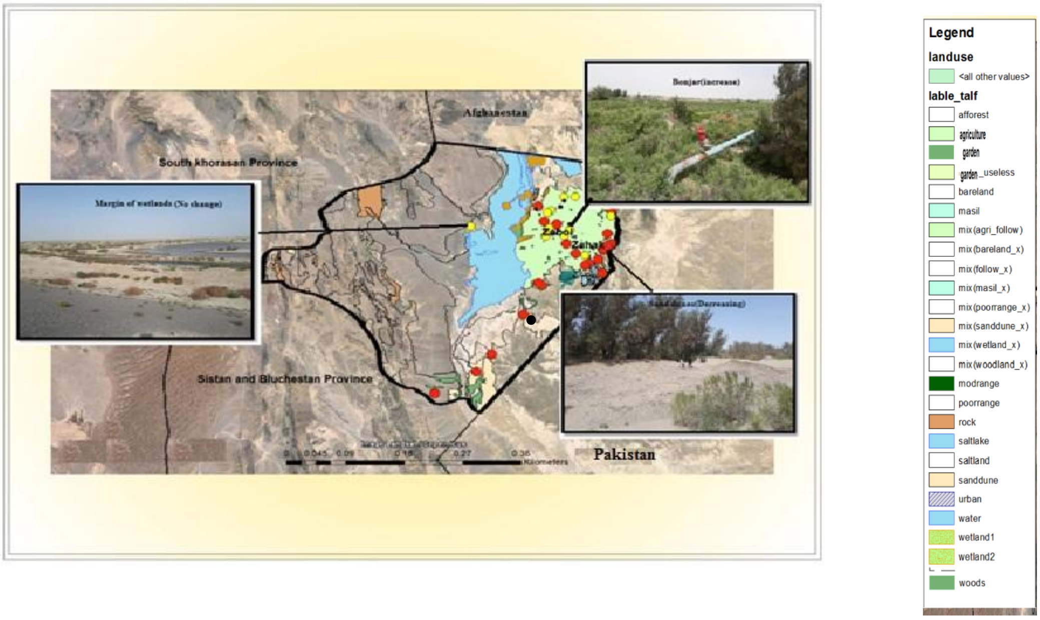


Figure 4. Land use map and points harvested using GPS with images from Sistan Plain

5. CONCLUSION

This study examined the vegetation changes trends using Sen's slope estimator nonparametric method in the eastern part of Iran, one of the driest regions of the world. The results of this study showed that the highest increasing changes trend in NDVI was observed in the northeast of the plain, where an approximately 400,000 of the population lives in these areas. This increase in the NDVI index resulted from two different factors. The first factor is the drying up of the triple Hamoun wetlands and thus a change in the reflectance pattern of long infrared wavelengths and the second factor is the agricultural development in the dry lake bed in the recent years. Long-term droughts, hydropoletic conflicts between Iran and Afghanistan, and lack of proper management of water resources in the plain can be cited among the main reasons for drying up these wetlands. However, due to the presence of poor soil organic matter in these areas and the difficult access to water resources in arid areas, this increase can cause a lot of problems in the future. In addition, the research findings of Shakeryari et al. (2016) indicates that the extent of the triple Hamoun wetlands has been reduced during a statistical period of 38 years and a rise has been observed in plain vegetation cover which are consistent with the results of this research based on the land use change in the triple Hamoun wetlands and their conversion into agricultural land. However, the highest decreasing change trend in NDVI was observed in the east and the center of the plain. The regions with a declining trend have a much smaller area than those with an increasing trend. The development of *Chahnimeh artificial lake* (a change in the reflectance pattern of infrared wavelengths) and the abandonment of agricultural land, especially in the center of the plain, were due to the remoteness of the existing water resources (long distance from the Hirmand River). According to the results of this study, the use of Sen's slope estimator nonparametric method in the studies of vegetation coverage variation trend in arid regions resulting from NDVI products from MODIS sensor can be very efficient and useful. Since this method is based on the difference between observational data, so it is independent of statistical distribution and it is more suitable for series with high skewness or kurtosis than other parametric methods, such as classical linear regression. Therefore, the results section of the research is fully consistent with the findings of previous researcher studies such as Verbesselt et al. (2006), Eklundh and Jönsson (2003), Beck et al. (2006), Jamali (2014) and Jin and Eklundh (2014) used this method to investigate the trends of vegetation changes in their studied areas.

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