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EVALUATING VARIOUS METHODS OF VEGETATIVE COVER CHANGE TREND ANALYSIS USING SATELLITE REMOTE SENSING PRODUCTIONS (CASE STUDY: SISTAN PLAIN IN EASTERN IRAN)

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Abstract; As vegetation of any region can change over time due to various natural and human factors, the study of changes in the vegetation trend, especially in arid and semi-arid regions, has always been of great importance for the management of water and soil resources as well as vegetation. In this study, the NDVI products of Terra Satellite MODIS sensor (MOD13A3), with a spatial resolution of 1x1 km for a 15-year statistical period (2000-2014), were used to study the changes in the vegetation trend on a pixel-based scale during April, May and June in Sistan plain in eastern Iran. Four statistical methods, namely, simple moving average, simple exponential smoothing, double exponential ordering, and classical linear regression were used to detect long-term changes in the vegetation trend of this plain. The error rates of the models were then calculated using the three indicators of mean absolute deviation (MAD), mean square deviation (MSD) and mean absolute percentage deviation (MAPD). Analysis of these indicators showed that classical linear regression was the best model for detecting changes in the vegetation trend thanks to its lower error than others. Based on the selected statistical method, the most increasing and decreasing changes in the NDVI values were observed in the northeast, and the east and center of the plain, respectively. Finally, it was found that the use of trend analysis along with the classic linear regression method in a pixel-based scale could be a suitable method for revealing long-term vegetation changes in an arid and hyper arid climate.

Key words: NDVI, MODIS Sensor, Trend Analysis, Sistan Plain, Iran

1. INTRODUCTION

A time series is a set of time-ordered observations. In other words, a time series includes data obtained from observing a phenomenon over time. Time series are generally divided into continuous and discrete types. Continuous time series on a particular phenomenon are continuously collected. In contrast, discrete time series are usually collected at equal intervals through observing a phenomenon at certain times (Bozorgnia & Khorami 2007).

The first step in analyzing a time series is to identify their patterns. Regardless of fluctuations, the patterns in the time series can be classified into two main groups of trends and oscillations. Trends represent a systematic linear or nonlinear component that changes over time and will never be repeated. A trend can be steady or unsteady. Steady trends represent gradual changes of a phenomenon over time, either completely incremental or decremental; while an unsteady trend involves both incremental and decremental changes over time (Jamali 2014; Daneshmand & Mahmoudi 2017).

Detection of vegetation changes trend over time using statistical and remote sensing methods has received much attention by ecologists (Viovy et al., 1992; Cohen et al., 2010; Verbesselt et al., 2010a and b; Sobrino & Julien 2011; Shubho et al., 2015; Sinha et al., 2015; Mohammady et al., 2015) due to the importance of vegetation in terms of habitat, energy generation and other important impacts on the planet (Na et al., 2013; Homayouni & Rezaei-Chiyaneh, 2017; Eymen, 2018). Eastman et al., (2009) used a two-stage process called the Seasonal Trend Analysis (STA) to study the changes in the trend of time series obtained by satellite images such as the land surface temperature, the normalized difference vegetation index, sea surface temperatures, etc. In this two-stage process, they first identified the inter-annual harmonics, separately for each year using the harmonic analysis, and then extracted the parameters for each harmonic (amplitude and phase). They also studied the trend of time series of these parameters (amplitude and phase) using the Sen's slope estimator nonparametric method on a global scale. Given the fact that most detection methods are not able to detect land cover changes, especially vegetation changes in seasonal scales, Verbesselt et al., (2010a) proposed the Breaks for Additive Seasonal and Trend (BFAST) method for detection of this type of changes. In this method, the time and number of changes were repeatedly estimated; and the changes were determined by their size and direction. In a comparative study, Fensholt & Proud (2012) examined the trend of vegetation changes on a global scale using satellite products of MODIS and AVHRR sensors. The results of this comparative study revealed a general consistency between the trends derived from the implementation of the classic linear regression model on the NDVI products of these two sensors. However, differences were observed between the two databases in the arid, tropical, and Polar Regions. Olsson et al., (2005) studied the trend of vegetation changes on the southern fringe of the Sahara over a period of 18 years (1982-1999) using the NDVI products of the AVHRR sensor of the NOAA satellite. Their results showed an increasing trend in the vegetation of the region. The result was completely opposite to this prevailing view on the decreasing trend of vegetation changes in this region due to land degradation. According to Olsson et al., (2005) the increased precipitation in recent years, land use changes and migration caused this incremental trend in the region.

Several studies have been conducted on the trend of vegetation changes in Iran. Shafei & Hosseini (2011) studied the trend of vegetation changes in Sistan plain in eastern Iran using remotely sensed products from 1990 to 2006. Their results indicated a significant decreasing trend in the vegetation so that the vegetation decreased from 101,247 hectares in 1990 to 26475 hectares in 2006. By monitoring the changes in the Hamoun triple lakes and the surrounding land cover in Sistan plain in eastern Iran using Landsat satellite images, Shakeryari et al., (2016) found a degradation trend in the Hamoun triple lakes in a 38-year period (1977-2017). The trend of land cover changes around the lakes also showed a decrease in the area of canebrakes, barren lands and saline lands and an increase in the area of vegetation.

According to the literature, vegetation changes, especially in arid and semi-arid regions, have received much attention by remote sensing and environmental researchers in recent years. Various satellite imagery, as well as different mathematical and statistical techniques have been used to study these trends. Regardless of the physical causes of vegetation changes, the obvious and latent features of their time series, such as trends, cycles and oscillations, have also been taken into consideration. In line with previous studies, this comparative study examines some statistical methods used in the study of vegetation changes. Choosing the best method, the trend of vegetation changes in one of the most arid climatic plains of Iran, i.e. Sistan plain in eastern Iran is studied.

2. STUDY AREA

Sistan is an ancient land with various names. As this region was inhabited and green, it has been known as Iran's barn. Despite its location in the Central Asian part of the Iranian plateau, Sistan basin is divided between Afghanistan, Pakistan and Iran, and about one-third of it with an area of about 8,117 km^2 and a population of 400,000 people is located in Iran (Figure 1). Sistan is an almost flat land that attracts all the water from rainfalls and surface runoff. The area of wetlands (lakes) in the region accounts for less than 5% of the total area of the basin. When enough water is available, Hamoun triple lakes (Hamoun-e-Puzak, Hamoun-e-Sabouri and Hamoun-e- Hirmand) are formed. These lakes are among the most important and valuable freshwater ecosystems in Iran both in the past and present time; and their names have been recorded in the list of UNESCO World Network of Biosphere Reserves (WNBR) (UNESCO, 2018) and The Ramsar Convention on Wetlands of International Importance (Ramsar Convention, 2020). Four artificial lakes (Chahnimeh) have also been created to cover the general use of water in the plain. In addition to providing the water needed for aquaculture, the rivers originating from Afghanistan and flowing into this plain are the other sources of water for the Hamoun triple lakes (Van Beek & Meijer 2006). The average annual precipitation in this plain is very small and varies from 50 to 55 mm, about 7% of the average annual precipitation in the world. The annual evaporation rate in Sistan plain is very high and reaches about 4800 mm. The average maximum and minimum temperatures in this plain are 34.5℃ and 8.5℃, respectively. The main atmospheric feature of feature

Figure 1. Geographical location of Sistan plain in eastern Iran

of Sistan plain is 120-day winds with a speed of up to 100 km/h that blow from northwest to southeast from early June until late September (Zomorodian, 1989).

Sediments of Hirmand River cover almost the entire Iranian part of Sistan plain and provide one of the most fertile lands for agriculture in Iran, if there is enough water for agriculture. But due to the shortage of precipitation and water flow into this plain, the efficiency and fertility of this land cannot be maximized. The total under-cultivation area of Sistan plain in normal conditions is about 110 thousand hectares. This amounts 140 thousand hectares in desirable conditions. Of this, 98 percent are wheat, barley, melon, and watermelon lands, and 2 percent are garden products such as grapes and dates (Van Beek & Meijer 2006).

3. MATERIALS AND METHODS

Considering vegetation and climatic features of Sistan plain, 45 series of NDVI products of Terra Satellite MODIS sensor (MOD13A3) were downloaded from EOS data gateway. The data were collected from 2000-2014 (a 15-year period) during April, May and June, when the vegetation in the study area is maximum. Normalized difference vegetation index (NDVI) is an indirect measure of photosynthetic activity. NDVI ranges from -1 for minimum photosynthetic activity to +1 for maximum photosynthetic activity. NDVI is defined as follows:

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

In this index, red (RED) and near infrared (NIR) wavelengths are characterized by high absorption and low reflectance rates of vegetation. The chlorophyll reflectance in the RED and NIR wavelength ranges is about 20 and 60%, respectively. The difference between the responses of both bands allows for quantifying the energy absorbed by chlorophyll; and thus, the classes representing different levels of vegetation (Stoms & Hargrove 2000). After obtaining the images, all of them were mosaicked for the study area and georeferenced with the Universal Transverse Mercator Project System using the Nearest-Neighbor Resampling Method (Stefanov & Netzband 2005; Hao et al., 2012). In the next step, all 45 downloaded images were separately converted to ASCII format and saved. Given the spatial resolution of 1 x 1 kilometer for each image, the total number of pixels per image within the boundaries of the study area was 30080 pixels.

For the revelation of the type of land cover/land use changes, the Global Land Cover Type Product of the MODIS Sensor of Terra and Aqua Satellites, called MCD12Q1 were also used for a period of 13 years from 2001 to 2013. This product includes various classification schemes that in this research, the 14-class University of Maryland classification (UMD) system was used. The reason for choosing this system has been its greater correspondence with the realities of land cover in Sistan compared to other classification systems. The UMD classification system was for the first time introduced in 2000 at the University of Maryland on AVHRR data. In this classification system, a hierarchical tree structure based on minimum annual red band reflectance, peak annual NDVI, and minimum blue band brightness are used to classify the data into 14 classes (Hansen et al. 2000).

Subsequently, using the R software, the NDVI time series of all 30080 pixels were separately prepared for April, May, and June and the entire statistical period. Finally, the changes in the vegetation of each pixel were investigated using simple moving average, simple exponential smoothing, double exponential smoothing and classic linear regression. Then, the error rate of each model was calculated using the mean absolute deviations (MAD), and mean square deviations (MSD). Subsequently, the best model for studying the trend of vegetation changes in Sistan plain was selected. Moreover, field surveys were conducted to verify the results of the selected statistical model. Finally, some residents aged more than 50 years were interviewed. The mathematical foundations of each of the models used in this study are briefly explained bellow:

3.1. Simple moving average method

Moving average is one of the most important and widely used methods for analyzing the trend of changes in a time series. Various types of moving averages are used to display variations of a variable with time. Among them, simple moving average is one of the simplest and most widely used methods. The basis for this approach lies in the idea that any large random variation at any moment of time, if averaged with neighboring points, will render an insignificant impact. Therefore, every actual observation (XT) is replaced by its own average and N neighboring points (Chou 1989). The simple moving average method is defined by equation (2) (Chou, 1989).

$$M_T = \frac{X_T + X_{T-1} + \cdots + X_{T-N+1}}{N} \qquad (2)$$

3.2. Simple and double exponential smoothing method

Exponential smoothing weighs observations unevenly, so that recent observations take a higher weight than previous observations. The exponential smoothing method was introduced by Robert Macaulay in 1931 and developed by Robert G. Brown during World War II (Yaffee & McGee, 2000). The simple exponential smoothing method is used when the studied variable is constant over time. However, the double exponential smoothing method is used if the studied variable linearly changes with time. The simple and double exponential smoothing methods are defined by equations (3) and (4), respectively.

$$S_T = \alpha X_T + (1-\alpha) S_{T-1} \qquad (3)$$

$$S_T^{[2]} = \alpha S_T + (1-\alpha) S_{T-1}^{[2]} \qquad (4)$$

Where S_T is the value smoothed at T and α is the smoothing factor ranging from 0 to 1 (Brown 1963).

3.3. The Classic linear regression method

Equation (5) represents the general form of the classic linear regression equation, where y is the output variable, $x_1, x_2, \ldots, x_n$ are the input variables, and $a_0, a_1, \ldots, a_n$ are the coefficients of the equation.

$$y = a_0 + a_1 x_1 + \ldots + a_n x_n + \varepsilon \qquad (5)$$

The single-variable classic linear regression defined by equation (6) is used in this study.

$$y = a_0 + a_1 x + \varepsilon \qquad (6)$$

Suppose that a set of the pairs of observational variables is available as $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$. Generally, by minimizing the sum of squares errors between observational and computational data using the $\sum_{i=1}^{n} \left[y_i - (a_0 + a_1 x_1) \right]^2$ relation, the equation coefficients are calculated as follows.

$$a_1 = \frac{m \sum_{i=1}^{m} x_i y_i - \sum_{i=1}^{m} x_i \sum_{i=1}^{m} y_i}{m \sum_{i=1}^{m} x_i^2 - \left(\sum_{i=1}^{m} x_i \right)^2} \qquad (7)$$

$$a_0 = \frac{\sum_{i=1}^{m} y_i - a_1 \sum_{i=1}^{m} x_i}{m} \qquad (8)$$

where a_0 is the y-intercept and a_1 is the slope or change of y with a unit change in x (Mahmoudi et al. 2019). A criterion is required to select the appropriate model among the studied models. The quality of a model is always evaluated by examining the predicted error rate $(x_t - \hat{x}_t)$ denoted by ε_t. In this regard, three criteria namely Mean Absolute Deviations (MAD), Mean Square Deviations (MSD) and Mean Absolute Percentage Deviation (MAPD) were used to select the best model. MAD, MSD and MADP are defined as follows:

$$\mathrm{MAD} = \frac{1}{n} \sum_{i=1}^{n} |x_t - \hat{x}_t| \qquad (9)$$

$$MSD = \frac{1}{n}\sum_{i=1}^{n}(x_t - \hat{x}_t)^2 \quad (10)$$

$$MAPD = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{x_t-\hat{x}_t}{x_t}\right| \times 100 \quad (11)$$

As an advantage of MAPD, the error rate in the studied time series is measured by percentage and is not affected by the measurement unit. Compared with MAD, MSD considers a heavier penalty for errors. It is noteworthy that MAD and MSD are not of statistical significance alone. In other words, MAD and MSD are significant when they are compared with each other. In contrast, the percentage criteria are not only comparable with each other, but also are significant on their own (Bozorgnia & Khorami 2007).

4. RESULT AND DISCUSSION

Some vegetation maps of the study area were prepared by the Terra Satellite MODIS for a 15-year statistical period (2000-2014) separately for April, May and June when the vegetation is higher due to agricultural activity. For example, Figure 2 shows the vegetation maps during April for the entire 15-year period. These images clearly show the dynamics of vegetation as well as the spatial variations of the water masses of Hamoun triple lakes in different years. As clearly seen, there is an increase in the vegetation in 2007, 2010, 2011, and 2012. In contrast, a decrease in the vegetation is observed in 2001, 2002, 2004, and 2006. It is noteworthy that the conditions prevailed in April are also observed in May and June (no image presented).

In line with the same dynamics of vegetation in Sistan plain, the trend of vegetation changes in 30080 pixels within the boundaries of the study area was separately evaluated in April, May and June using the simple moving average, classic linear regression and simple and double exponential smoothing methods. Upon obtaining the results of the above four methods, the preliminary studies showed that simple moving average and simple exponential smoothing are not suitable models for studying vegetation changes because of this fact that both of these methods can be used when the studied variable is constant with time. In other words, these two methods always use the latest smoothed value to generate a new data. It should be noted that the 15-year period is a short period of time for using these two methods, especially the simple moving average method. The graphs of all four models for three sample pixels with an incremental (increasing), decremental (decreasing), or without any trend are respectively shown in Figures. 4-6. The geographic location of these selected pixels is also shown in Figure. 3. The graphs clearly show the modelling of the trend through these four models. These graphs can greatly simplify judgment about their strengths and weaknesses. However, MAD, MSD, MAPD criteria were used for choosing the best method from the two remaining methods, namely, the classic linear regression and the double exponential smoothing. At this stage, the error rate of these two methods was calculated for all 30080 studied pixels using these three criteria. Then, the average total error of 30080 pixels was calculated. The average values obtained for the whole region are listed in Table 1.

As seen, MAPD, MAD, and MSD show the least error for the classic linear regression model in all three months. Therefore, based on the results of these three criteria, the classic linear regression method was selected to examine its effectiveness in studying the trend of vegetation changes in Sistan plain.

After determining the classic linear regression as the best model, the slope of changes trend of 30080 pixels in the study area was calculated. Then the results were drawn up in the form of concurrent maps separately for April, May and June (Fig. 7). These maps facilitate spatial analysis of the trend of vegetation changes in Sistan plain. Comparing the concurrent maps in April, May and June (Fig. 7), almost identical spatial patterns are observed in all the three months. No vegetation, or if any, a very thin vegetation, is observed in the desert area in the southwest of Sistan plain. Despite sporadic spots with a negative slope, the trend of changes in this part of the plain is insignificant.

According to these maps, it is clearly demonstrated that the highest trend of positive changes is observed in the northeast of the plain with urban and rural settlements. It should be mentioned that the significance of all trends was examined at a probability

Table 1. The average error rates of trend analysis and double exponential smoothing based on three criteria of MAD, MSD and MAPD for NDVI time series of Sistan plain in eastern Iran

	MAPD		MAD		MSD	
	Double Exponential Smoothing	Trend Analysis	Double Exponential Smoothing	Trend Analysis	Double Exponential Smoothing	Trend Analysis
April	14.4	13.5	0.1000	0.0135	0.0020	0.0003
May	3.7	3.2	0.0030	0.0029	0.0002	0.0001
June	3.8	3.6	0.0030	0.0029	0.0010	0.0001

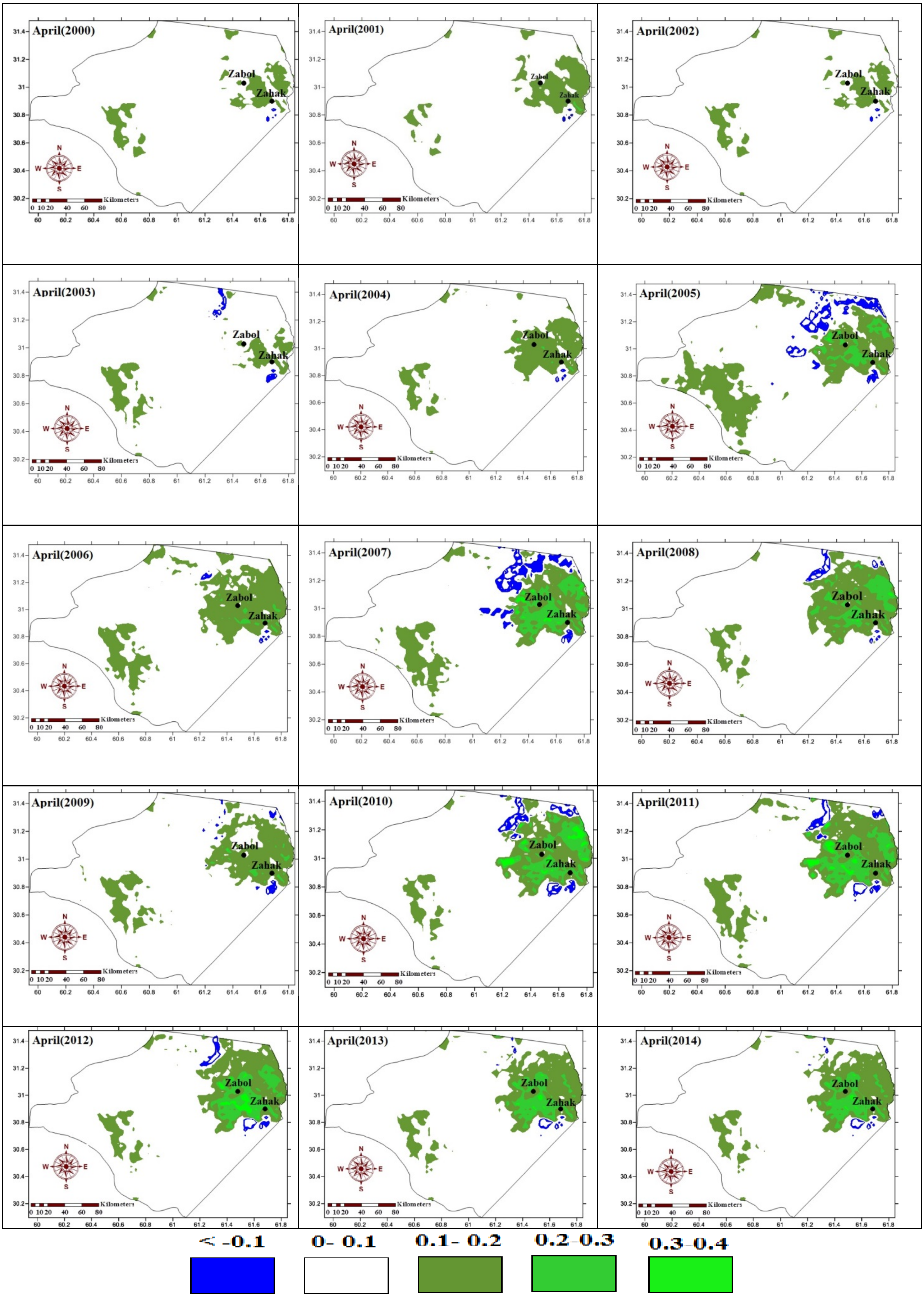

Figure 2. Vegetation maps (MODIS NDVI) of Sistan plain in April for the period 2000-2014 (The upper left is taken in 2000 and the bottom right in 2014)

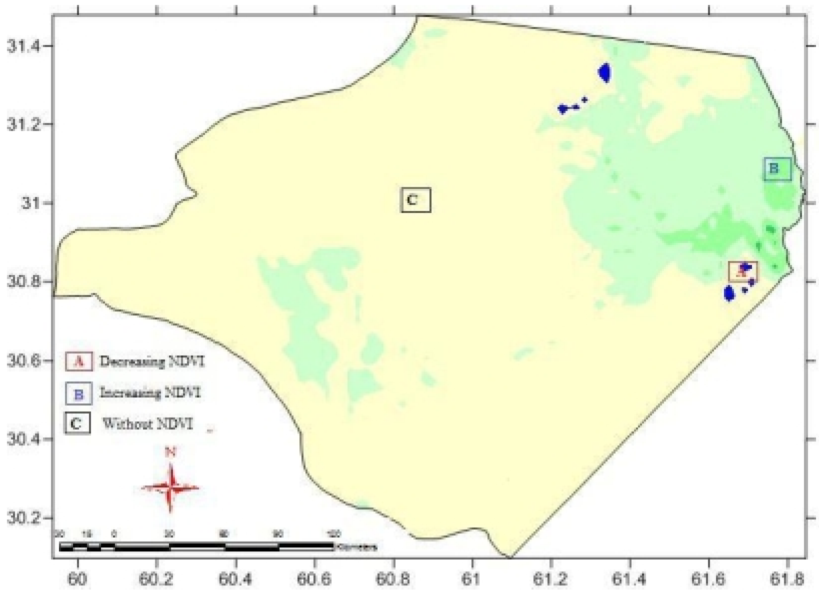

Figure 3. Geographical location of the selected pixels for plotting the graphs of simple moving average, classical linear regression as well as simple and double exponential smoothing

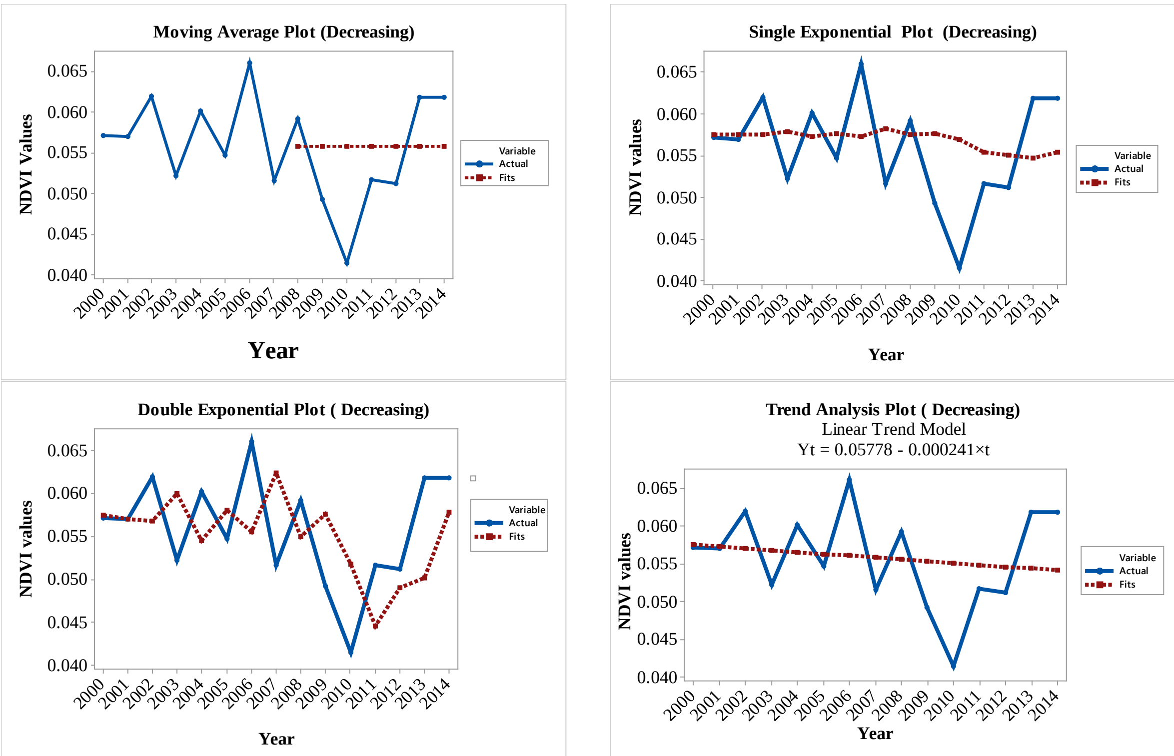

Figure 4. The graphs for a selected pixel with a decreasing trend (Box A, Figure. 3) for simple moving average, classical linear regression, simple and double exponential smoothing

level of α = 0.05. Therefore, all 30080 trend line slopes obtained at a probability level of α = 0.05 were tested. Figure 7 shows the results for the three studied months. In these maps, the trend of the changes slope is divided into three main categories of a significant increasing trend (green), a significant decreasing trend (red) and no significant trend (white).

The maps indicate a decreasing trend in the NDVI values in Chahnimeh(s) and around them, and in the spots in the center of the plain from 2000 to 2014. This decreasing trend can be due to two very different reasons. The development of artificial lakes in Chahnimeh(s) in the east of the plain has changed the nature of the Earth's reflection in the infrared region. As the water masses always have negative NDVI values, this negative trend in NDVI values could indicate the development and expansion of artificial lakes of Chahnimeh(s). But in other parts of the plain with a negative trend, abandoning agricultural lands due to long hydrological droughts and being far from the Hirmand River flow caused this decreasing trend. The decreasing trend in these areas was clearly seen in field observations in May. Figure 8 shows an example of this decreasing trend. In contrast, the increasing trend in the NDVI values is concentrated in the east and northeast part of the

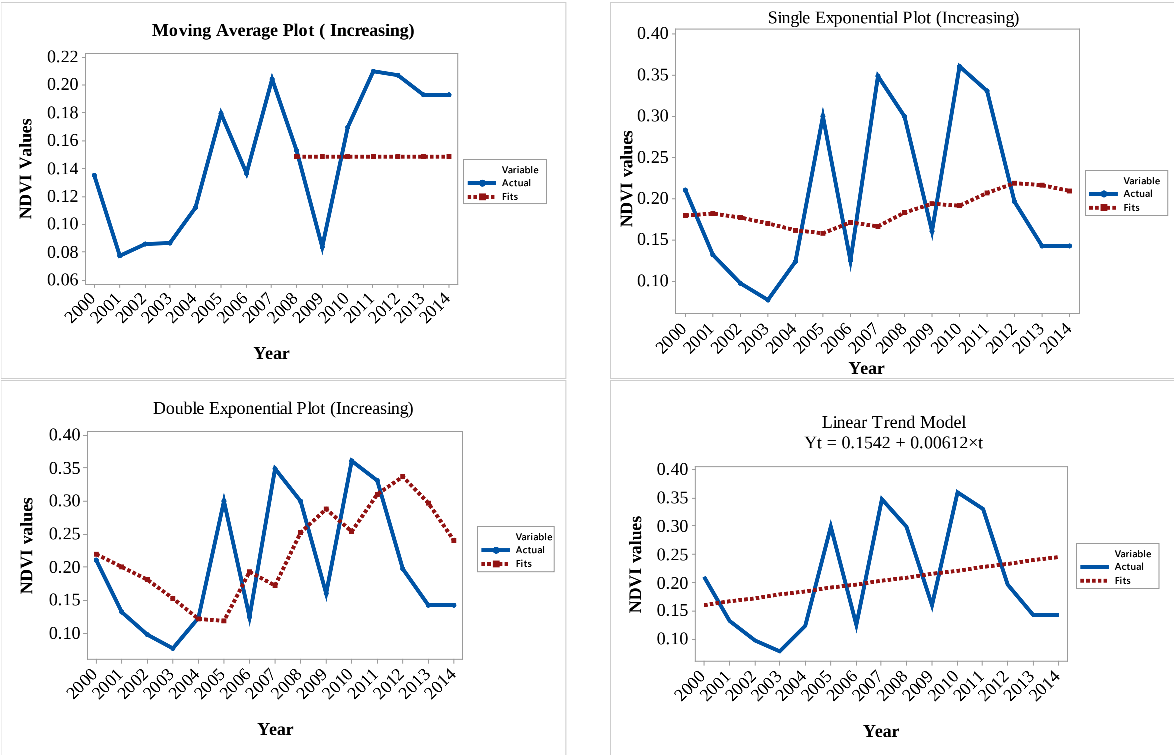

Figure 5. The graphs for a selected pixel with a decreasing trend (Box B, Figure. 3) for simple moving average, classical linear regression, simple and double exponential smoothing

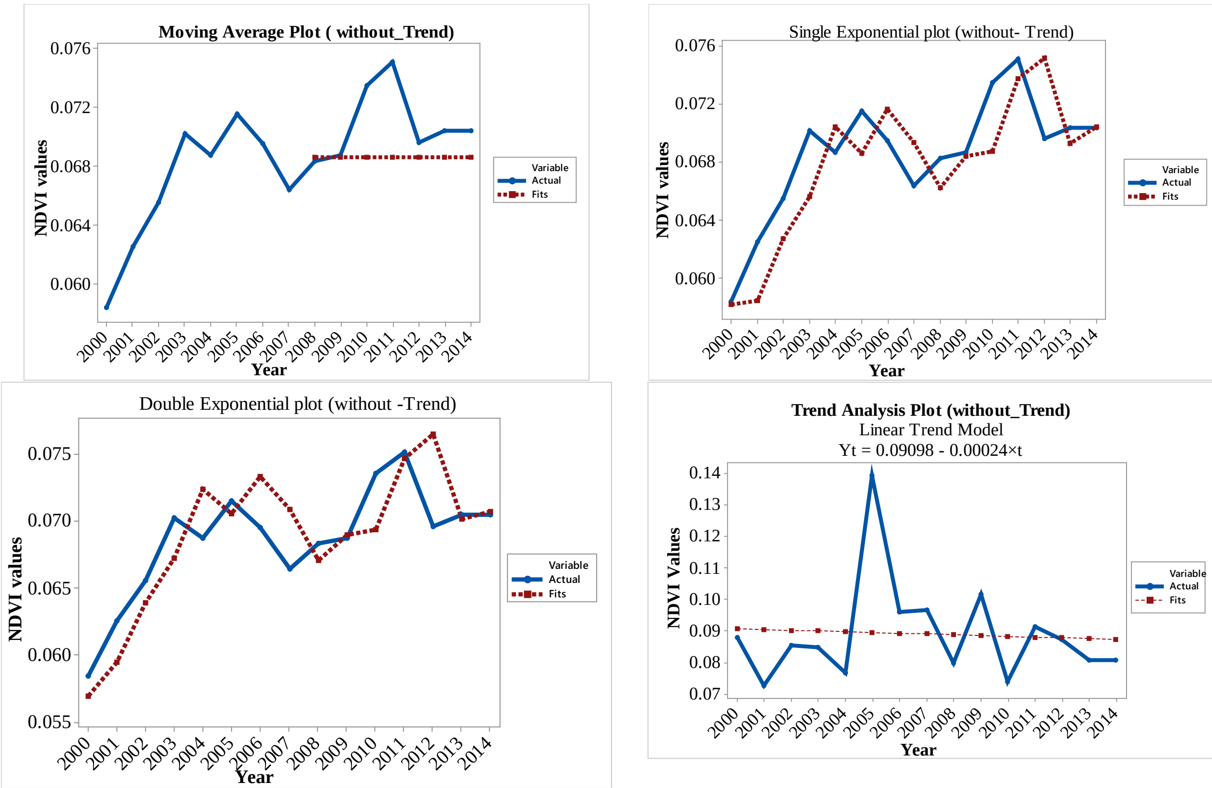

Figure 6. The graphs for a selected pixel without any trend (Box C, Figure. 3) for simple moving average, classical linear regression, simple and double exponential smoothing

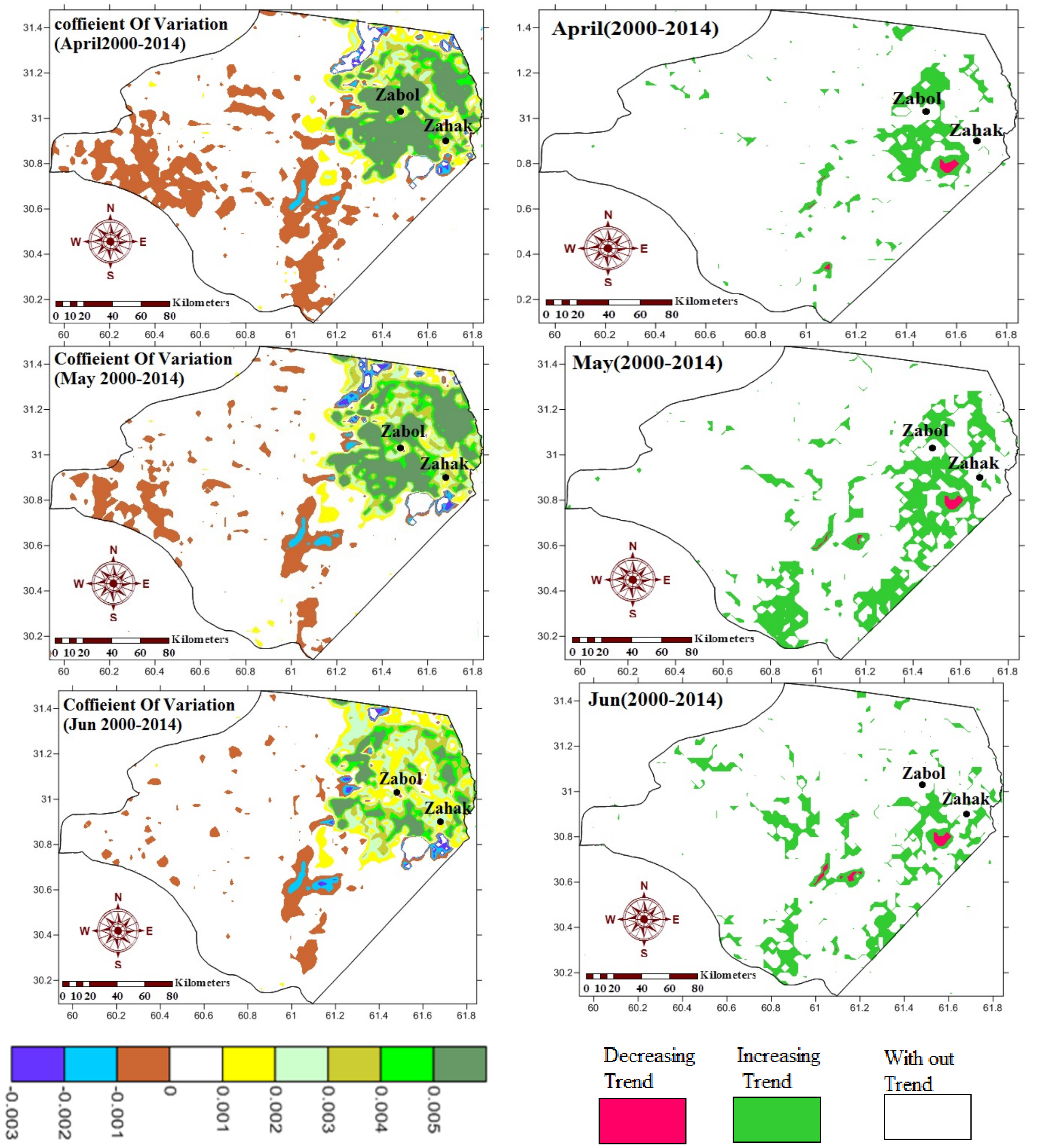

Figure 7. The concurrent maps of April, May and June (on the left) and the map indicating the significance of trends for April, May, and June (on the right) during 2000-2014

plain where the villagers have drilled low-depth wells due to severe climatic conditions and other environmental stressors such as the 120-day Sistan winds. Severe fluctuations in the Hirmand River water flow, inappropriate seasonal distribution of water, land development in the Hirmand Valley in Afghanistan, construction of reservoirs in Afghanistan and severe droughts in the region are among the reasons for drilling the low-depth wells. Drilling of the low-depth wells caused the development and expansion of agriculture in this part of the plain, leading to an increase in NDVI values. Agricultural products in most pixels in this part of the plain include wheat, barley, sorghum, forage millet, garlic and onion. In addition to crops, horticultural products such as grapes, dates or gaz forest are also observed. This increasing trend is also partly due to drying up of Hamoun triple lakes to provide agricultural lands. Unfortunately, Halostachys belangriana plants began to grow in the Hamoun lakes because of soil salinization.

It is noteworthy that over 59% of the river water flows into the plain in spring and 41% in other 9 months. With increasing temperature and melting of the snow above the Hillmand Hill basin in Afghanistan at the beginning of spring, the water inflow increases and reaches its peak in June (Javan & Heydari Mokarar 2011).

Finally, changes in the types of various classes of land cover in Sistan plain were also considered. Investigating these changes can be a great help to complete the results obtained from the analysis of the trend of vegetation changes. It is observed based on Figure 9 that all land cover classes existing in Sistan plain except the urban and built-up lands class have changed significantly from year to year during the 13 years under study (it is necessary to mention that in Figure 9 in order to avoid the compactness of the columns and their illegibility, only the changes related to 2001, 2007 and 2013 have been mentioned). As it is observed in Figure 9, most of the changes have been related to the classes of water bodies, grasslands and

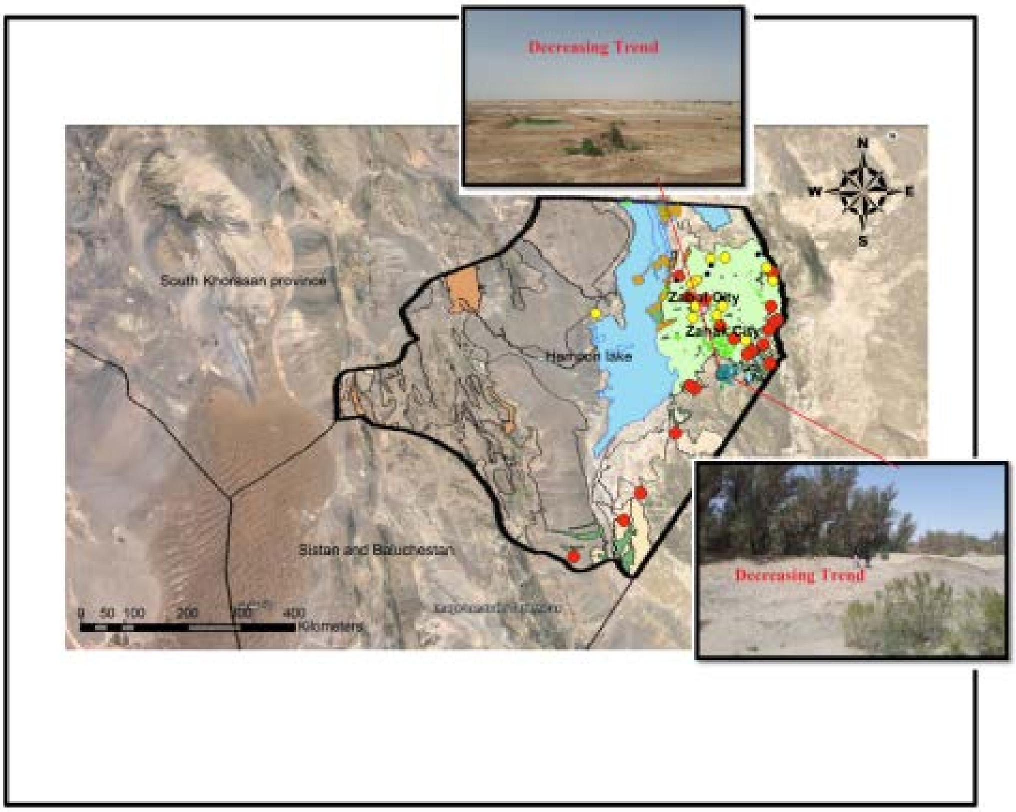

Figure 8. Areas with a decreasing trend, prepared during a field visit to Sistan plain in May

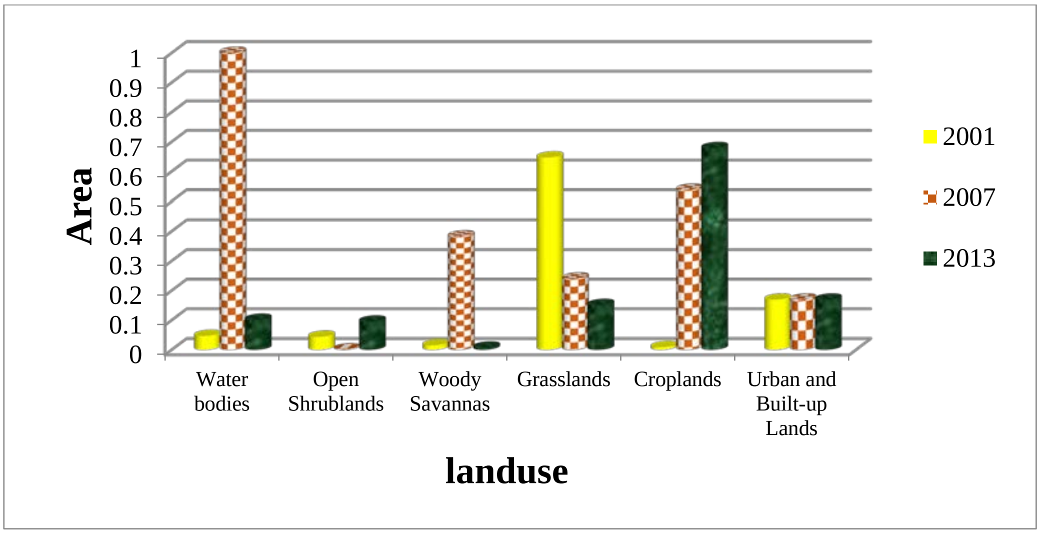

Figure 9. Variations of different types of land cover / land use in Sistan plain between 2001 and 2013 from the UMD classification system (in %)

croplands. Grasslands have had decline changes and croplands have had incremental changes. Water bodies have also had decline changes in their area, regardless of 2007. The results of this investigation compared with the results obtained from the analysis of the trend of long-term vegetation changes in Sistan plain show a very good correspondence. The drying up of Hamoon International Wetlands, the disappearance of grasslands and the development of agricultural lands, especially on the bed and margin of Hamoon International Wetlands, have been the changes that have caused a change in the long-term trend of vegetation in this plain.

5. CONCLUSION

The trend of vegetation changes in Sistan plain in eastern Iran was studied using four simple statistical methods of moving average, simple exponential smoothing, double exponential smoothing, and classic linear regression. The results showed that the simple moving average and simple exponential smoothing are not suitable for studying vegetation changes; because these two methods are basically used for predicting future values. These two methods should be used for predicting future values with caution, because the methods use the last smoothed value of the past, not those in the time series to predict the future values of the variables studied. Comparison of the two remaining methods, namely, the classic linear regression and double exponential smoothing showed that the classic linear regression method could be a more suitable model for studying the vegetation changes in Sistan plain due to a lower error rate. This method has already been confirmed by some researchers such as Fensholt & Proud (2012) and Jamali (2014).

According to the results, the most significant changes in the NDVI values were observed in the northeast of Sistan plain, where about 400,000 people live. This increasing trend in NDVI values was due to two different factors, namely, drying up of Hamoun triple lakes and consequent changes in the reflection pattern of long infrared wavelengths, and development of agriculture in the dry lake bed in recent years. However, the largest decreasing trend was observed in the NDVI values in the east and center of the plain. The surface area of the regions with a decreasing trend was much lower than that with an increasing trend. The remoteness of existing water sources (being far from Hirmand River) is the main reason for construction of Chahnimeh artificial lakes (the change in the reflection pattern of infrared wavelengths) and abandonment of agricultural lands, especially in the center of the plain.

It was found that the use of classic linear regression method in a pixel-based scale could be effective in detecting long-term vegetation changes in an arid and hyper arid climate. The use of this method will also be more effective when its results are analyzed along with the land use map changes in the study area. However, it should be pointed out that there are potential sources of errors that can affect the final results in these analyses. The errors resulting from the measurement instruments (sensors), called measurement uncertainty, and those arising from NDVI values may cause uncertainties in the results. Finally, it is recommended to compare this method with nonparametric statistical methods such as the Sen's slope and Mean-Kendall estimators.

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