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DETECTION OF LONG-TERM VEGETATION DEGRADATION IN BALUCHISTAN IN SOUTHWEST ASIA USING NDVI PRODUCTS OF THE MODIS SENSOR OF TERRA SATELLITE

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Abstract

The present study aimed at investigating the long-term degradation of vegetation in Baluchistan in southwest Asia. To achieve the objective NDVI products of the MODIS sensor on Terra Satellite (MOD13A3) with spatial resolution of 1×1 km for a period of 16 years (2000-2015) were used. After obtaining images from the NASA land processes distributed active archive center, all images downloaded for the study area were mosaicked and referenced by Universal Transverse Mercator Project System and by using the nearest-neighbour re-sampling method. Then, on a pixel-based scale, the trend of long-term changes in vegetation was studied using the seasonal Mann-Kendall non-parametric test. The results show that 1.23% of the total area under study had a long-term decreasing trend in vegetation. Out of this 1.23%, 0.33% were significant at a probability level of $\alpha = 0.01$, 0.24% was significant at a probability level of $\alpha = 0.05$, and 0.12% were significant at a probability level of $\alpha = 0.1$. The decreasing trend of 0.54% of them was not confirmed at any of the significant levels. Among the various types of vegetation, shrublands and croplands had the most significant long-term decreasing changes, which could be dangerous signs of ecotones degradation as well as weakening the sustainable rural livelihoods in this land.

Key words: Afghanistan, desertification, Iran, MODIS, NDVI, Pakistan, seasonal Mann-Kendall Nonparametric Test, trend

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1. Introduction

Each geographical unit, whether on a micro or macro scale, is made up of a biological system of living and non-living elements and components that have complex interactions with each other. In this regard, vegetation types, not only as a component, but as an identifying factor, can determine the general characteristics of other components in an ecosystem (Tavousi et al., 2010). Baluchistan has an arid and semi-arid climate as a geographical unit, regardless of the political divisions between Iran, Pakistan and Afghanistan. This arid and semi-arid climate has brought a very fragile ecosystem to this land. Long-term droughts, excessive and non-controlled use of surface and groundwater resources, rapid population growth, poverty, inappropriate management of land resources, overgrazing and deforestation (Ahmed et

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al., 2016; Ashraf and Routry, 2013; Qasim et al., 2011; Shirazi, 2006) are factors that exacerbate this fragility. Ashraf and Routary (2013) stated that Pakistan´s Baluchistan has experienced one of the most severe and longest droughts in its history between the years 1998 and 2005. During this period, crop products production declined by up to 50% and many gardens and springs were dried. In addition, there have been reports on the reduction in the level of groundwater in various parts of Baluchistan (Jamali, 2006). Khair et al. (2012) claim that a 75 m reduction in groundwater levels in the mountainous areas of northeast Baluchistan between the years 1998-2005 is due to the uncontrolled use of groundwater resources. They argue that this sharp decline in groundwater resources is a major and dangerous threat to local agriculture and the survival of its dependent communities. As vegetation in Baluchistan has undergone many changes over time due to various natural and human factors (Hussain and Durrani, 2007; Islam et al., 2008), these changes can affect ecosystem conditions and performance. Thus, the study of the vegetative cover's change trend can be of essential importance, especially in line with the management of the water resources, soil and vegetative cover.

Detecting the trends of vegetation changes over time using statistical methods and remote sensing has always drawn the attention of ecological researchers (Cohen et al., 2010; Mohammady et al., 2015; Shubho et al., 2015; Sinha et al., 2015; Sobrino and Julien, 2011; Verbesselt et al., 2010a, 2010b; Viovy et al., 1992). The reason for this consideration is the great importance of vegetation in various aspects of habitat, economic, energy production, soil erosion, and climate change among other (Eymen, 2018; Homayouni and Rezaei-Chiyaneh, 2017; Na et al., 2013).

Time series trends for vegetation data usually include gradual changes, although they may include more sudden changes. The gradual changes mainly reflect long-term changes in other factors such as land management, land erosion and climate change (Goetz et al., 2005). However, sudden changes can be due to disturbances such as fires, floods, urbanization, insect attacks or droughts (Lenton, 2013; Scheffer et al., 2001). These changes can be analyzed by studying the time series of the normalized difference vegetation index (NDVI). The normalized difference vegetation index (NDVI) is an indirect measurement of photosynthetic activity. The range of this index is between -1 for minimum and +1 for maximum photosynthetic activity. The normalized difference vegetation index (NDVI) is defined as follows (Eq. 1):

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

This index uses a fundamental principle, according to which, in the surfaces covered by vegetation, the Red (RED) and near-infrared (NIR) wavelengths are characterized by high and low absorption, respectively (Chen et al., 2003; Groeneveld and Baugh, 2007). The chlorophyll reflection in the red (RED) wavelength range is about 20 percent and in the near-infrared (NIR) wavelength is about 60 percent. The difference between the responses of the two bands allows the quantization of the energy absorbed by chlorophyll, thereby providing the classes representing the different levels of vegetation (Tucker and Sellers, 1986).

Investigation of time series of NDVI index at an annual scale can provide a comprehensive view of photosynthetic activity in an area, while at a seasonal scale, this investigation is able to distinguish evergreen and fallow vegetation compositions and determine length of the growing season for us. In addition, investigating the trend of the time series of NDVI can help identify recent changes in ecosystems at local and global scales (Matthias et al., 2013). Many researchers have emphasized the effectiveness of the NDVI and statistical models in investigating the trends of phenological changes at global level (Beck et al., 2006; Eklundh and Jonsson, 2003; Jamali, 2014; Jin and Eklundh, 2014; Olofsson et al., 2007; Verbesselt et al., 2006). Using MODIS sensor images of Terra Satellite, Jamali (2014) studied the trends of vegetation changes in the African coastal area by using the Mann-Kendall and ordinary least-squares regression (OLS) methods. The result of this study shows that the ordinary least-squares regression (OLS) statistical method yields better results than the Mann-Kendall method. The results of this study also showed that the estimation of time series of NDVI significantly depends on the source of the satellite data set, the relevant resolution and the statistical methods used. Beck et al (2006) also found good agreement between the statistical models used in the investigation of vegetation trends of the two islands of Fennoscandia and Kola Peninsula in Scandinavia during the 2000–2005 statistical period and stated that the use of statistical methods to investigate the trend of vegetation and verification along with field surveys is appropriate.

Therefore, according to the research background of this field, it is observed that the study of vegetation alterations in different geographical parts of the world has always been the focus of many researchers, especially researchers of remote sensing and environment. They used various satellite images and various mathematical and statistical methods and techniques to study this process. In this study, taking into account all past studies, we aim to investigate the vegetation trend changes in Baluchistan in the southwest of Asia by using the MODIS sensor images of Terra satellite and introducing a new scientific framework based on remote sensing and statistical knowledge.

2. Study area

Baluchistan is a vast territory situated in the southeast of the Iranian plateau and governed by the three neighboring countries of Iran, Pakistan, and Afghanistan. The Iranian part of this land is now a part of Sistan and Baluchistan province and the Pakistani part of it is the largest state in Pakistan called Baluchistan. The exact boundaries of this vast land are not completely clear (Frye and Elfenbein, 2019) and its approximate area is about 769,824 km², of which about 361,738 km² are located in Pakistan, 302,845 km² in Iran and 105,241 km² in Afghanistan (Fig. 1). Baluchistan is geographically divided into four areas of upper high lands, lower high lands, plains and deserts (Ahmad et al., 2014). Upper high lands with a height more than 1500 m above sea level and lower high lands between 600 m and 1200 m above sea level are located in the northeast and the southeastern of Baluchistan, respectively.

The plains are mainly located in the center and west of Baluchistan and the deserts are located in the north, northwest and parts of south and southwestern of Baluchistan (Government of Balochistan, 2019). The population of this land is approximately 15.7 million people, 78.5 percent of which are living in the Baluchistan province of Pakistan, 17.7 percent are living in the Sistan and Baluchistan province of Iran and the remaining 3.8 percent are living in Afghanistan.

As Baluchistan is located in the desert belt of the Northern Hemisphere, major part of it is dominated by sub-tropical high pressure cells. Thus, most of its area, with the exception of the northeastern part which is a mountainous area, has a dry and semi-arid climate. The mean annual temperature of this land varies between 15 and 40 C°, so that the lowest mean annual temperature is in the northeast and the highest is in the south coastal parts. The lowest precipitation in Baluchistan with mean annual precipitation between 50-100 mm is seen in the center and the highest precipitation with a mean annual precipitation of 600-650 mm is seen in the northeast.

3. Data and methods

In this study, the NDVI products of MODIS sensor on Terra satellite called MOD13A3, was used to study the vegetation change trends in Southwest Asia for a 16-year period (2000-2015). These data can be extracted from NASA land processes distributed active archive center. The MODIS NDVI is calculated from the reflectance of surfaces in the red band (610-680 nm) and near infrared (780-880 nm) bands, and corrections related to molecular scattering, ozone absorption, and aerosols are performed on them. The spatial resolution of this NDVI database is 1000 m and its temporal resolution is 16 days (Hao et al., 2012; Olofsson et al., 2007). Based on the vegetation status of the land and based on its climate characteristics, 408 series of MODIS NDVI images were ordered from the Earth Observation System (EOS) data gateway for a 16-year period from 2000 to 2015. Then, monthly mean images were calculated from the 16-day images, and then, all of them were converted to the mosaik for the study area using the universal transverse Mercator project system and by using the nearest- neighbor resampling method (Hao et al., 2012; Stefanov and Netzband, 2005). After downloading the images and forming their database, the next step is to determine the method of extracting. In this step, all of the 204 images obtained from the 16-day images were first converted and saved in the ASCII format. Given the spatial resolution of 1×1 km per pixel in each image, the total number of pixels of each image studied within the boundaries of the area was more than 769,824 pixels (a total of 157,044,096 pixels with NDVI values were analyzed).Then, using programming in R software, monthly time series of NDVI of all 769,824 pixels were prepared separately and for the entire statistical period studied.

Fig. 1. Geographical location of Baluchistan in Southeast Asia, which is shared by three countries: Iran, Pakistan, and Afghanistan

It should be noted that the method for obtaining NDVI time series was such that the monthly average NDVI was measured for each point by averaging the values of both images that were available for each month. Finally, by joining the average monthly values of each time series, their corresponding NDVI values are obtained. In the end and using seasonal Mann-Kendall test, the trend of the vegetative cover's change was examined in every pixel.

The seasonal Mann-Kendall test is a nonparametric test developed for the first time by Hirsch and Slack (1984) to detect trends in data with seasonal nature. Suppose $X=(X_1, X_2, ..., X_n)^T$ is a time series of the independent values of the desired variable and $X_i=(X_{i1}, X_{i2}, ..., X_{ij})$. Here, n is the number of years and j is the number of seasonal (month) data of the desired variable for each year. In this test, the first season (first month)'s data are compared only with the first season (first month)'s data in every year; the second season (second month)'s data are compared only with the second season (second month)'s data in every year and this is consecutively done for all the seasons till the end.

The null hypothesis (H_0) is that there is no monotonic trend over time. This statistic is defined based on (Eq. 2) for the gth season:

$$S_g = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \operatorname{sgn}(X_{jg} - X_{ig}),\ g = 1,2,...., m \tag{2}$$

According to Hirsch et al. (1982), the seasonal Mann-Kendall test statistics, Ŝ, is calculated for the whole series based on (Eq. 3):

$$\hat{S} = \sum_{g=1}^{m} S_g \tag{3}$$

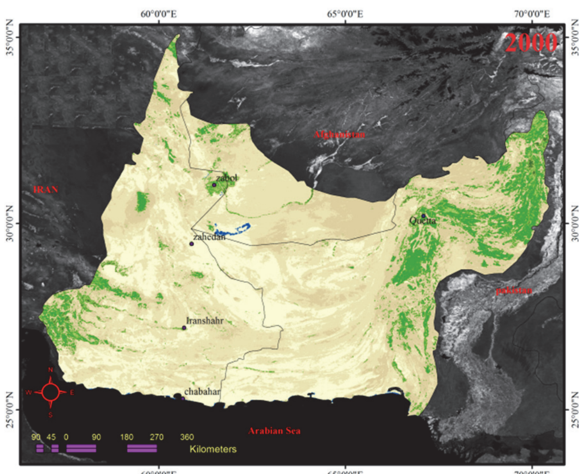
To receive more information on this test, see Hirsch and Slack (1984), Libiseller and Grimvall (2003), and Morell and Fried (2009). Significance of trends was also tested in three levels of $\alpha = 0.01$, $\alpha = 0.05$ and $\alpha = 0.1$ in this study.

To determine the type of land cover in this area, MODIS Global Land Cover Type Product called as MCD12Q1 was used. This type of MODIS product consists of five main layers in which different types of land cover have been identified and mapped using different classification systems. This study uses the UMD classification system, which was first developed and introduced in 2000 at the University of Maryland. In this classification system, land cover is classified into 12 different classes on a global scale (Hansen et al., 2000).

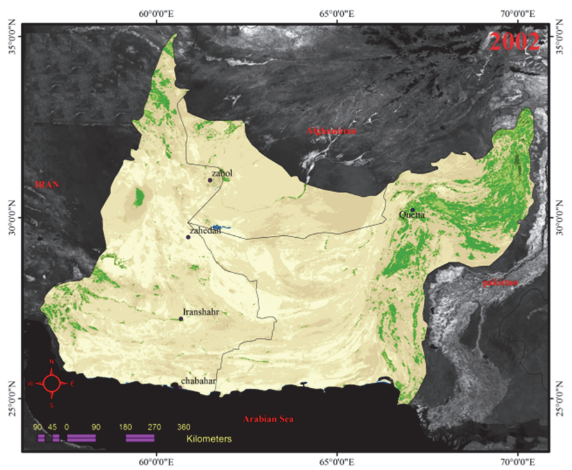
Finally, after identifying areas with vegetation degradation (decreasing trend), field surveys were performed and in-person interviews were conducted with villagers (people over 50 years of age), experts (academic experts in agriculture, natural resources, environment and water resources) and local authorities. In these interviews, more emphasis was put on identifying the causes of plant degradation given the high experience and knowledge of the inhabitants of these areas.

4. Results and discussion

Baluchistan vegetation maps were prepared on a monthly scale for the entire 16-year period. The maps clearly show both intra-annual and inter-annual changes of vegetation dynamics in this land (due to the large number of maps, it was not possible to bring them into one article). In Fig. 2 (a-h), for example, vegetation dynamic maps of March month for 8 years out of the 17 years (2000, 2002, 2004, 2006, 2008, 2010, 2012 and 2014) are presented to show the annual vegetation dynamics. In these maps, NDVI values equal to and greater than 0.3 were defined as vegetation, values between 0 and 0.3 were defined as non-vegetation lands and values below zero were defined as aquatic zones. As the maps show, the density and spatial distribution of the vegetation show large variations from one year to another year, indicating the vegetation dynamics of this area and the effect of various human, environmental and climatic factors on them.



(a)



(b)

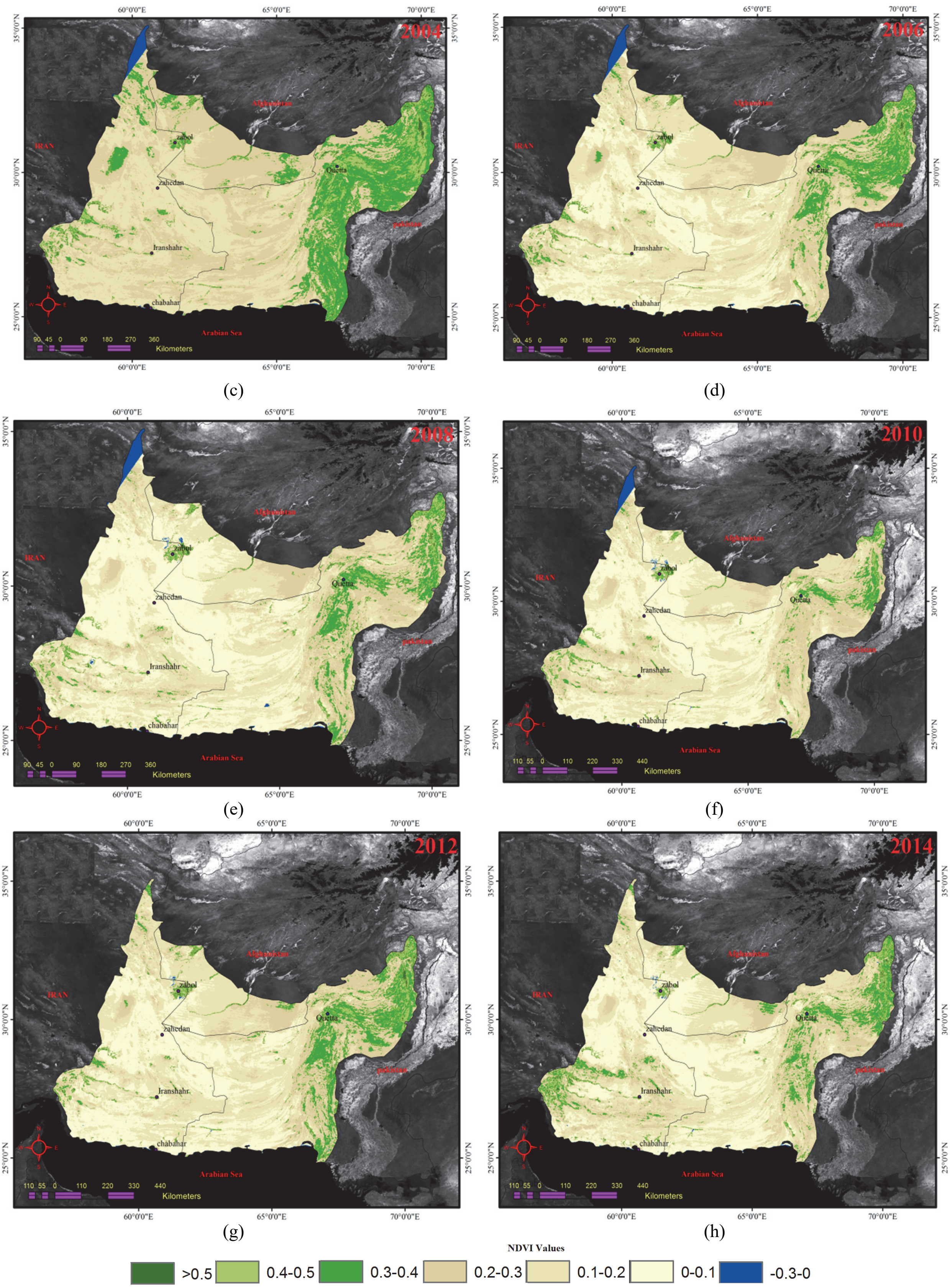


Fig. 2. An example of the dynamics maps of the March vegetation produced by NDVI of MODIS sensors for the years: a) 2000, b) 2002, C) 2004, d) 2006, e) 2008, f) 2010, g) 2012 and g) 2014 in the land of Baluchistan in Southwest Asia

The trend of changes in NDVI values on a pixel-based scale was estimated using the seasonal Mann-Kendall non-parametric method for all pixels located within the boundaries of the study area (a total of 769824 pixels). The slope of the obtained trends can be classified into three classes: increasing (positive trends), decreasing trends (negative trends) and no trend, according to their direction. In this study, since the main objective was to detect negative trends in long-term vegetation changes, all pixels with negative NDVI changes trend were extracted, and then, their spatial distribution was plotted in Fig. 3. On this map, trends with increasing (positive) changes are marked with white color. These areas are geographically considered as environmentally sustainable areas. By counting all the pixels with a decreasing trend (negative), it was found that 8639 pixels equal to 1.23% of the total area of study area had this type of trend. As seen in Fig. 3, pixels with decreasing (negative) trend in the 6 zones have a high density and spatial concentration that their range has been approximately marked using black circles and with one of the English capital letters. These areas are located respectively in the southeast (A), northwest (B), northeast (C), west (D and F) and east (E) of Baluchistan based on their importance (Fig. 3). As shown in Fig. 3, the Iranian part of this land has had the most decreasing (negative) changes trend in NDVI values compared to the other two parts (Pakistan and Afghanistan). Significance of trends obtained at different probability levels is also an important point considered in many studies related to the trend of changes. In this study, all the obtained trends were evaluated at three probability levels $\alpha = 0.01$, 0.05, 0.1. In Map 3, the pixels whose slope changes were significant at three probabilistic levels of $\alpha = 0.01$, 0.05, 0.1 are respectively marked in red, brown, and blue.

Pixels whose change trend was negative, but their significance has not been confirmed at any of the three probability levels, are marked in yellow color. Out of these 8639 pixels that their changes trend was negative, 2582 pixels were significant at a probability level of $\alpha = 0.01$, 1862 pixels were significant at a probability level of $\alpha = 0.05$, and 919 pixels were significant at a probability level of $\alpha = 0.1$. The decreasing trend of 4195 pixels was not confirmed at any of the significant levels.

If the pixels that their trend of changes was significant at different probability levels fall into three classes: 1- degraded areas, pixels that their decreasing trend is confirmed at 99% and 95% probability levels 2- areas being degraded, pixels their decreasing trend was confirmed only at the 90% probability level 3- Areas susceptible to degradation, the pixels that their decreasing trend is not confirmed at any of the 99, 95 and 90% probability levels. Degraded areas and the areas susceptible to degradation have a higher percentage.

In order to better understand the behavior of NDVI time series behavior in areas with decreasing trend, three time series of three different pixels in areas A, B and C were selected (Fig. 5). These pixels were selected so that in addition to their long-term behavior in time series, their decreasing trend was also confirmed at different probability levels (Fig. 4). By examining these figures, it was found that the intra-annual and inter-annual vegetation behaviors in the selected areas were very different from each other (Fig. 4). The reason for this difference is probably due to the different vegetation types in these areas. Hence, for example, Fig. 5 shows the land cover map of Baluchistan in year 2001, prepared using the UMD classification system and by using the MODIS sensor data.

The approximate positions of the regions selected were specified in Fig. 5 to plot these three diagrams. Region A, which is related to the southwest of Baluchistan, is classified as two grasslands and croplands (Fig. 4a).

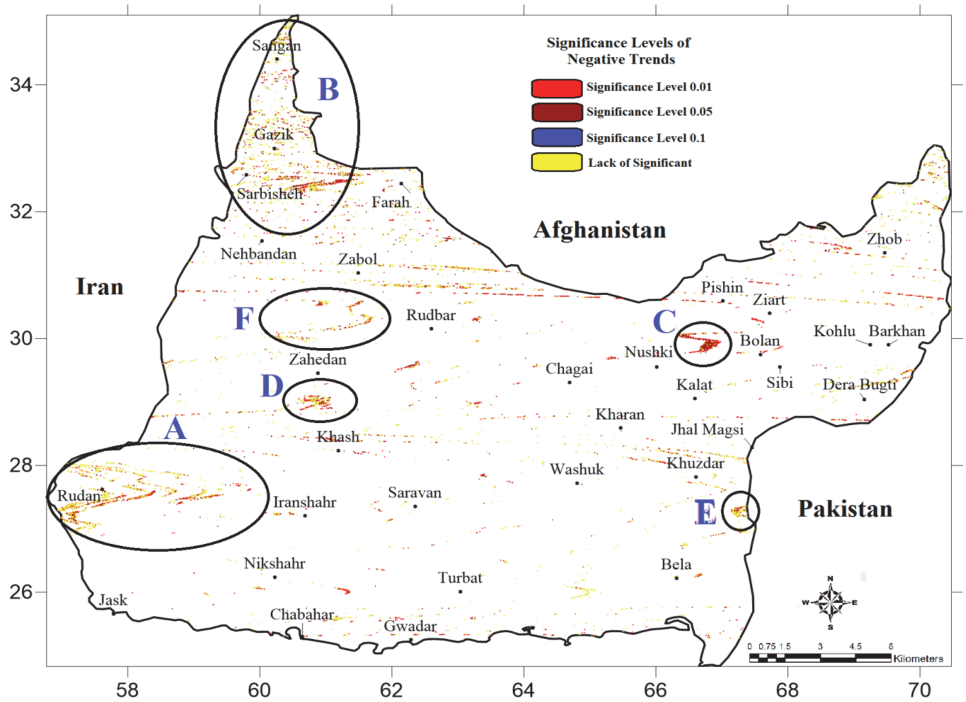
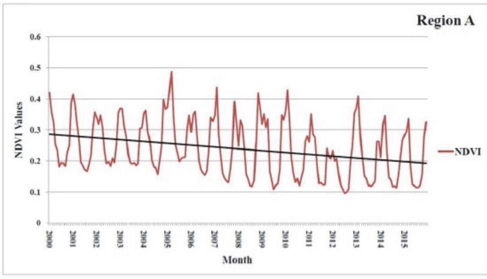
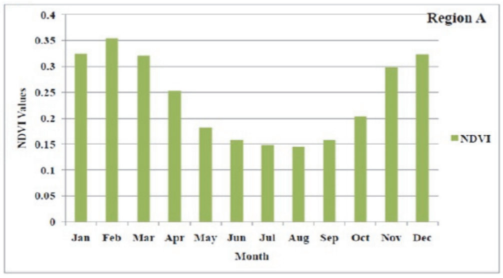


Fig. 3. Map of spatial distribution of pixels with decreasing (negative) trend along with their statistical significance level in Baluchistan in Southwest Asia

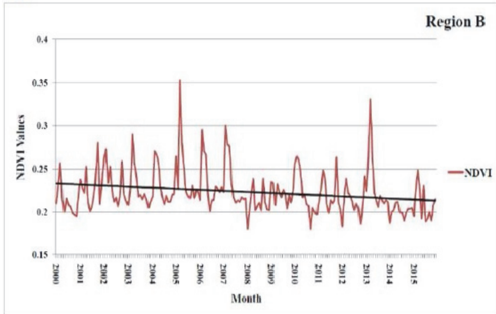


(a)



(b)

(c)



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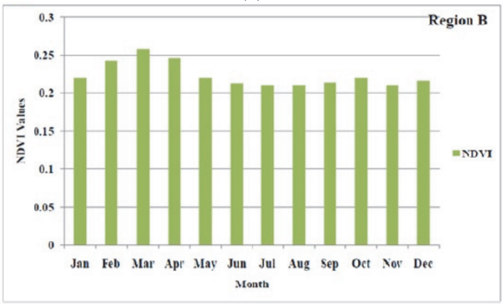

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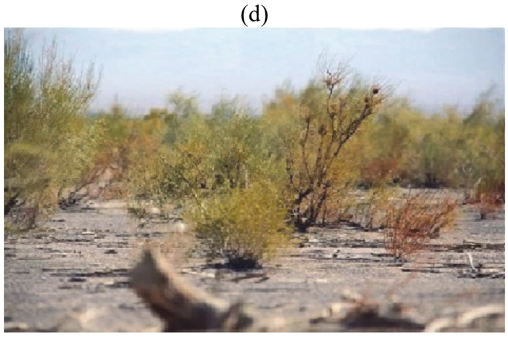

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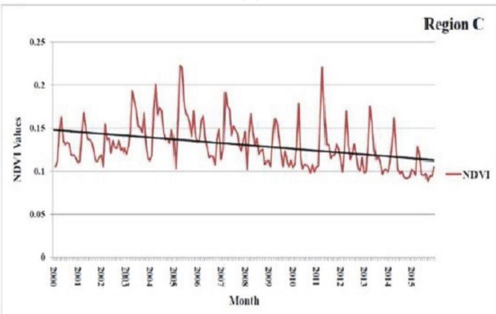
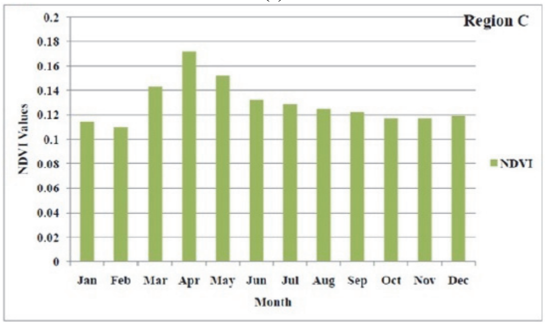


(g)



(h)

(i)

Fig. 4. (a) Diagram of Intra-annual long-term changes trend of NDVI belong to Region A, (b) Diagram of average inter-annual changes of NDVI belong to Region A, and (c) image of vegetation landscape belong to Region A, d) Diagram of Intra-annual long-term changes trend of NDVI belong to Region B, e) Diagram of average inter-annual changes in NDVI belong to Region B, f) image of vegetation landscape belong to Region B, g) Diagram of Intra-annual long-term changes trend of NDVI belong to Region C, h) Diagram of average inter-annual changes of NDVI belong to Region C, and i) image of vegetation landscape belong to Region C, Identified in Fig. 5.

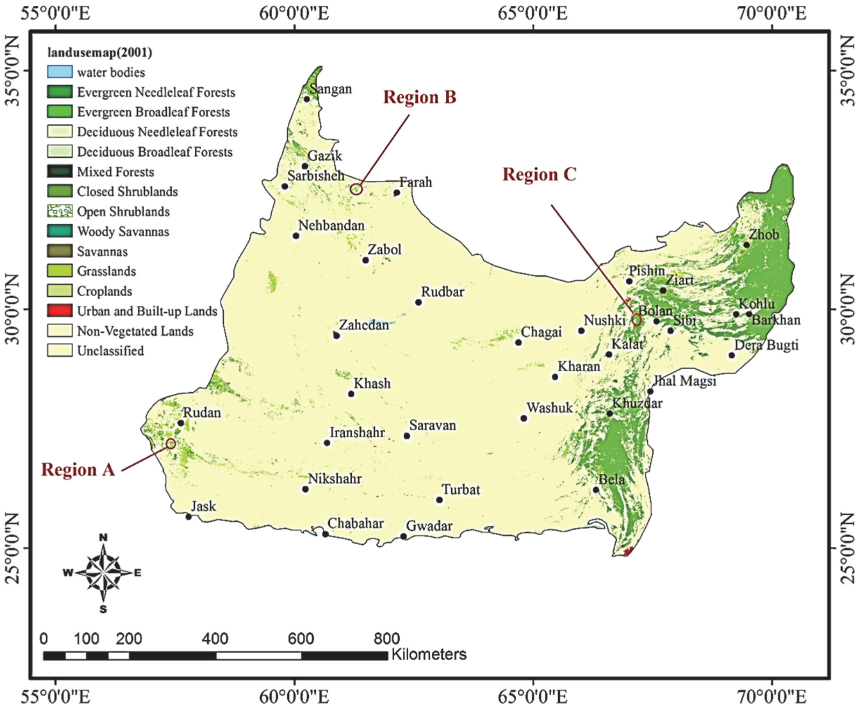


Fig. 5. Baluchistan land cover map in the year 2001 derived from the UMD classification system

In the diagram related to time series of this area, a distinct intra-annual periodic behavior is shown, so that the highest NDVI values are observed during winter months and the lowest values are observed in summer months (Fig. 4a). The same periodic regular behavior is also observed on an annual scale. This type of regular periodic behavior of NDVI on the inter-annual and intra-annual scales is mostly related to the tropical crop fields such as *mango* and *jujube* and other products such as *onion*, *potato*, *eggplant*, *wheat* and *maize* grown in the area.

Region B, which is related to the northwest of Baluchistan, is one of the selected areas having the largest area in terms of decreasing trend (Fig. 5). The dominant vegetation in this area is mostly shrubland. Among the most important plant species of this area, we can refer to *Haloxylon*, *Pistacia atlantica*, *Zygophyllum*, *Mugworts*, *Tamarisk*, *Ficus johannis*, and *Milkvetch*.

Intra-annual changes of this type of vegetation are very low and have a maximum in winter months and a minimum in summer months (Fig. 4b). However, on its inter-annual scale, large fluctuations are seen from one year to another year, so that it is difficult to find a particular order in it (Fig. 4b). However, region C, selected between Nushki and Bolan in the northwest of Pakistan, is an ecotone that determines the boundary between shrubland, and grassland vegetation. In fact, Ecotone, a transitional area of vegetation between two different plant communities, such as forest and grassland. The decreasing trend changes in NDVI values of this ecotone were very tangible and detectable. In this area, which belongs to the upper high lands zone, inter-annual and intra-annual time series changes are approximately similar to the selected region B in the northwest of Baluchistan (Fig. 4c). The most common plant species of ecotone are *Artemisia*, *juniper*, and *Pine.*

In the field surveys and interviews performed by villagers (people aged over 50 years), experts and authorities living in the desired area, it was found that various factors were involved in the degradation of vegetation in these areas. These factors also varied from one area to another. Review of the results of interviews in southwestern of Baluchistan showed that long-term droughts, drilling of unauthorized wells alongside the rivers and wetlands due to over-development of agricultural activities and lack of allocation of water right by upstream dams, respectively, played the greatest role. The factors affecting the decreasing trend of changes in vegetation in the northwest of Baluchistan are somewhat more complex compared to other areas. In these areas, droughts, the hydraulic problems on the Hirmand River between the two countries of Iran and Afghanistan, the drying of the three international wetlands of Hamoon, inappropriate water resources management and migration, respectively, played the greatest role. However, in the Pakistani part of Baluchistan, it was found that factors such as droughts, excessive and uncontrolled use of groundwater resources, poverty, deforestation to use trees as fuel, overgrazing and poor natural resource management, respectively, played the greatest role.

5. Conclusions

Vegetation degradation is a very serious issue in Baluchistan in the southwest of Asia shared by three countries of Iran, Pakistan and Afghanistan. This degradation can cause many problems such as environmental crises, ecosystem instability, extinction of plant and animal biodiversity, adaptation changes in rural livelihood patterns, and increased vulnerability of poor rural communities. Investigating long-term vegetation changes using the seasonal Mann-Kendall test showed that 1.23% of the total study area (8639 pixels out of 769824 pixels) had a long-term decreasing trend in vegetation.

Out of the 1.23%, 0.33% were significant at a probability level of 99%, 0.24% was significant at a probability level of 95%, and 0.12% were significant at a probability level of 90% were significant. In 0.54%, decreasing trend was not confirmed at any of the significant levels. Moreover, considering the division of areas into three categories, namely degraded areas, degrading areas and areas prone to degradation, it was observed that the degrading areas and areas prone to degradation have a high share of areas.

Among the different types of vegetation, shrublands and croplands have had the most long-term decreasing changes. This could be a dangerous sign of the destruction of the ecotones as well as weakening the sustainable rural livelihoods in this land. In interviews with villagers, experts and local authorities, it was found that the most important factors affecting these changes could be long-term droughts, excessive and uncontrolled use of groundwater resources, inappropriate water resources management, overcooked livestock grazing, deforestation and hydraulic problems among the countries of this area, especially between Iran and Afghanistan, in the downstream of the Hirmand basin.

However, it has to be noted that there were limitations in this research and they should be taken into account in the future studies, including the cases of the vivid similarity of the sandy hills and vegetative cover's reflection range in the dry regions to the extent that the sandy hills may be even taken as the vegetative cover in some of the images and in some of the regions (in this study, the northern section of the studied region that was situated along the borders with Afghanistan had such conditions).

The analyses may be prone to errors in case of having been not familiarized with the study region. Therefore, it is recommended for future studies to focus on other indicators, particularly those that are probably more fitted for arid areas. Due to the high spatial resolution of images of MODIS sensor on Terra satellite, employing images with lower spatial resolution, such as Landsat images, along them can be useful both for verification and more accurate analysis.

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