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A satellite bioclimatology of Baluchistan in Southwestern Asia

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सार – इस शोध पत्र का उद्देश्य दुनिया के शुष्क और अर्ध-शुष्क क्षेत्रों में से एक, अर्थात् दक्षिण-पश्चिम एशिया में बलूचिस्तान में वनस्पति की स्थिति के साथ तापमान औरवर्षा दो चरों के बीच संबंधों की जांच करना है,जो ईरान, पाकिस्तान और अफगानिस्तान तीन देशों द्वारा साझा किया जाना है। इन उद्देश्यों को प्राप्त करने के लिए, दो अलग-अलग डेटाबेस का उपयोग किया गया: 1. **टेरा उपग्रह के** MODIS NDVI 16-**दिवसीय मिश्रित उत्पाद** (MOD13A3), 1*1 **किमी स्थानिक विभेदन के साथ, जो** 17-**वर्ष की अवधि** (2000-2016) **के लिए नेशनल एरोनॉटिक्स एंड स्पेस एडमिनिस्ट्रेशन** (NASA) **के अर्थ ऑब्जर्विंग सिस्टम** (EOS) **डेटा गेटवे से प्राप्त किया गया था।** 2. **ईस्ट एंग्लिया विश्वविद्यालय की जलवायु अनुसंधान इकाई (सीआरयू) से उसी** 17 **साल की अवधि के लिए ग्रिडयुक्त मासिक तापमान और वर्षा डेटा प्राप्त किया गया था। पियर्सन उत्पाद-क्षण सहसंबंध गुणांक का उपयोग वनस्पति स्थिति और तापमान तथा वर्षा के दो जलवायु चर के साथ-साथ तीन समय अंतराल अर्थात् एक महीना, दो महीने और तीन महीने में संबंधों की जांच करने के लिए भी किया गया था। अलग-अलग समय अंतराल में औसत तापमान और मासिक एनडीवीआई के बीच सहसंबंध के विश्लेषण के परिणामों से संकेत मिलता है कि बलूचिस्तान के उत्तरी हिस्से में आर्द्र और अर्ध-आर्द्र क्षेत्रों में, एनडीवीआई ने एक साथ तापमान भिन्नता पर प्रतिक्रिया की, जबकिबलूचिस्तान के दक्षिणी हिस्से में शुष्क और अर्ध-शुष्क क्षेत्रों में, एनडीवीआई में तापमान के साथ एक महीने का अंतराल था। हालाँकि, अलग-अलग समय अंतराल में वर्षा और मासिक एनडीवीआई के बीच सहसंबंध के विश्लेषण के परिणामों से संकेत मिलता है कि एनडीवीआई ने एक साथ वर्षा भिन्नता पर प्रतिक्रिया की, अर्थात प्रत्येक महीने की वर्षा का उसी महीने के एनडीवीआई पर सबसे अधिक प्रभाव पड़ा।**

ABSTRACT. The present study is aimed at investigating the relationship between two variables of temperature and precipitation with vegetation dynamics in one of the arid and semi-arid regions of the world, *i.e.*, Baluchistan in Southwestern Asia, which is shared by the three countries of Iran, Pakistan and Afghanistan. In order to achieve the objectives, two different databases were used: 1. MODIS NDVI 16-day composite products (MOD13A3) of Terra satellite, with 1*1 km spatial resolution, which was obtained for a 17-year period (2000-2016) from the Earth Observing System (EOS) Data Gateway of the National Aeronautics and Space Administration (NASA); 2. Gridded monthly temperature and precipitation data was obtained for the same 17-year period from the Climate Research Unit (CRU) of the University of East Anglia. The Pearson product-moment correlation coefficient was also used to examine the relationship between vegetation dynamics and two climate variables of temperature and precipitation simultaneously as well as in three time lags, *i.e.*; one month, two months and three months. The results of the analysis of a correlation between the mean temperature and monthly NDVI in different time lags indicated that in the humid and semi-humid regions in the northern half of Baluchistan, NDVI simultaneously reacted to temperature variations, while in the arid and semi-arid regions in the southern half of Baluchistan, NDVI had a one-month time lag with temperature. However, the results of the analysis of a correlation between precipitation and monthly NDVI in different time lags indicated that NDVI simultaneously reacted to precipitation variations, that is precipitation of each month had the greatest effect on the NDVI of the same month.

Key words – Temperature, Precipitation, Vegetation dynamics, NDVI, MODIS, Pearson correlation coefficient, Time lags.

1. Introduction

Climate is one of the most important factors affecting the ecosystem dynamics on both local and global scales. Among the climate variables, two variables of temperature and precipitation have the greatest effect on spatial-temporal patterns of vegetation dynamics (Tan 2007; Song and Ma 2011). The relationship between precipitation and vegetation growth is often more complicated compared to temperature. However, in general, to better understand the response of vegetation to the spatial-temporal variations of precipitation and temperature calls for investigation of Biosphere-Atmosphere relation. In this regard, satellite images provide a unique opportunity to study and assess vegetation. The Normalized Difference Vegetation Index (NDVI) is an indirect measurement of photosynthetic activity. It ranges from -1 for a minimum photosynthetic activity to +1 for maximum photosynthetic activity. The NDVI is calculated as:

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

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).

In recent literature, NDVI can be seen to play a key role in long-term monitoring of vegetation conditions (Nemani and Running 1989; Stoms and Hargrove 2000; Mazvimavi 2003; Wang *et al*., 2004; Maselli *et al*., 2006; Ma and Veroustraete 2006; LeMarie *et al*., 2006; Jovanovic *et al*., 2018). Many researchers have used this index to study the temporal and spatial variations of vegetation and its relationship with precipitation and temperature in different parts of the world (Malo and Nicholson 1990; Di *et al*., 1994; Goward and Prince 1995; Richard and Poccard 1998; Chen *et al*., 2001; Yu *et al*., 2003; Alwesabi 2012; Veysipanah 2014). Many of these studies have indicated that NDVI follows precipitation with different time lags (Nicholson and Farrar 1994; Farrar *et al*., 1994; Richards and Poccard 1998; Duplessis 1999; Li *et al*., 2002; Foody 2003; Ma and Veroustraeta 2006), which can be due to the relative dryness of the site (Richards and Poccard 1998), soil type (Farrar *et al*., 1994; Fisher and Levine 1996), topography (Jobbagy *et al*., 2002) and the composition and structure of the vegetation (Peters *et al*., 1997; Davenport and Nicholson. 1998). Therefore, the sensitivity of the NDVI values to precipitation fluctuations is different in various regions (Richards and Poccard 1998) whose time lag ranges between one and two months (Nicholson and Farrar 1994; Richards and Poccard 1998).

Ichii *et al*., (2002), in their comprehensive study, investigated the relationship between NDVI and two climate variables of temperature and precipitation on a global scale for the period 1982-1990. The results showed that increased NDVI in the middle and high latitudes of the Northern Hemisphere was related to the increased temperature and reduced NDVI in semi-arid regions in low latitudes was related to the declined precipitation. Ma and Veroustraete (2006), in their study on the changes in NDVI and its relationship with meteorological variables in the Heihe River Basin situated in the northwest of China, showed that precipitation and its changes were the main factors causing the vegetation changes in this basin. Also, some studies on a global scale have shown that global warming has resulted in increased vegetation in low latitudes of the Northern Hemisphere (Myneni *et al*., 1997). However, it has been observed that with increasing precipitation, there has been a decrease in NDVI values in some mountainous regions, which is attributed to the effects of snow (Los *et al*., 2001). Besides, it has been reported that there is a negative relationship between precipitation and NDVI in humid areas (Nicholson et al. 1990; Nemani *et al*., 2003). In arid regions, a positive relationship between precipitation and NDVI and a negative relationship between temperature and NDVI, indicate that access to moisture, limits plant growth in these areas (Los *et al*., 2001).

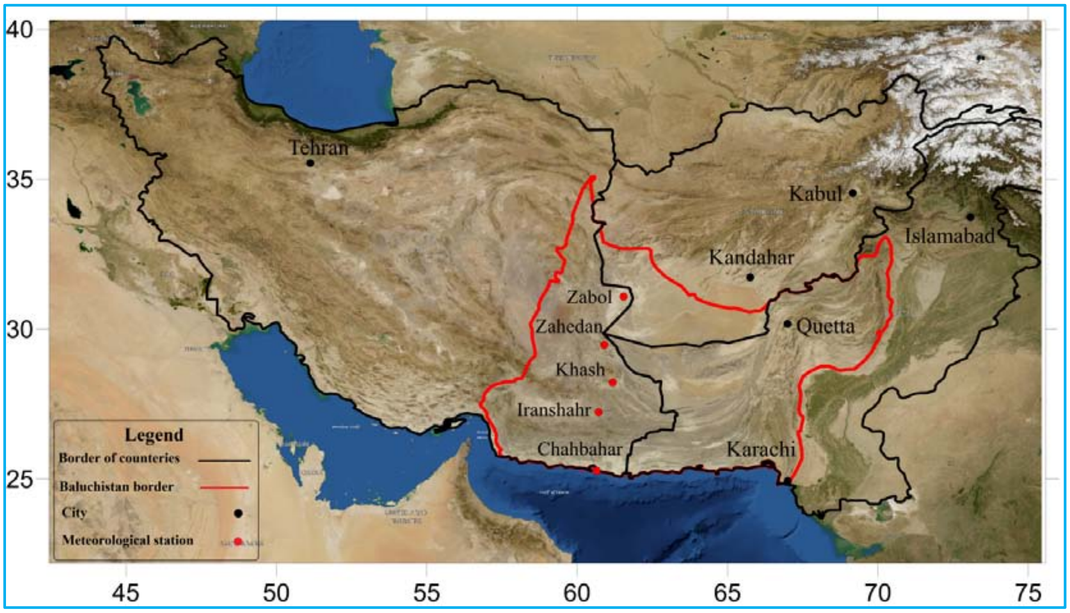

Fig. 1. Geographic location of Baluchistan in Southwestern Asia, shared by the three countries of Iran, Pakistan and Afghanistan

The first attempts to use NDVI to monitor vegetation changes in arid and semi-arid regions have been made in the 1980s, when researchers showed that there is a very close relationship between NDVI and precipitation at both seasonal and annual time scales (Gray and Tapley 1985; Tucker *et al*., 1985; Justice and Hiernaux 1986; Townshend and Justice 1986; Nicholson *et al*., 1990). This relationship allowed the use of NDVI time series for drought monitoring and development of early warning systems in areas with sparse terrestrial rainfall networks (Henrichsen and Durkin 1986; Hielkema *et al*., 1986; Tucker 1986; Hutchinson, 1991). However, various factors such as seasonal variations in atmospheric water vapor (Justice *et al*., 1991), atmospheric aerosol content (Vermote *et al*., 1997) and large areas of bare soil in arid and semi-arid regions (Huete 1985; Huete and Tucker 1991) can make significant variations in NDVI values while these factors have no relationship with active vegetation. However, this index is still a very good index for monitoring various vegetation parameters such as a green leaf area index (LAI), biomass, percent green cover, green biomass production, and finally the fraction of absorbed photosynthetically active radiation (Tucker 1979; Asrar *et al*., 1984; Sellers 1985).

Baluchistan is a vast territory in the southeast of the Iranian plateau, which is administered by the three countries of Iran, Pakistan, and Afghanistan. Since it is located in the desert belt of the Northern Hemisphere, a large part of it is dominated by subtropical pressure cells, and most of it is comprised of arid and semi-arid regions. Low rainfall and its inadequate temporal-spatial distribution, high temperature, complex topography, long-term droughts, rapid population growth, poverty, inadequate management of land resources, overgrazing and deforestation (Shirazi 2006; Qasim *et al*., 2011; Ashraf and Routrary 2013; Ahmed *et al*., 2016) make the relationship between vegetation dynamics and meteorological variables such as temperature and precipitation very complex in this part of the world. Firouzi *et al*., (2018) have used Moderate Resolution Imaging Spectroradiometer normalized difference vegetation index (MODIS NDVI) data obtained from the Terra Satellite for April, May, and June and monthly precipitation and temperature data (October to September) acquired from the Zabol Meteorological Station for a period of 15 years (2000-2014) to investigate the relationship between two climatic variables of precipitation and temperature with vegetation dynamics in Sistan plain situated in the east of Iran (the northwest of Baluchistan). The results showed that there was no correlation between MODIS NDVI related to April, May, and June and the average temperature of the previous months. Regarding precipitation, the only precipitation in May had moderate correlations of 0.603 and 0.542 with the MODIS NDVI related to the same month and the previous month (April), respectively.

Keeping in view the rich research background on the relationship between climate variables and vegetation

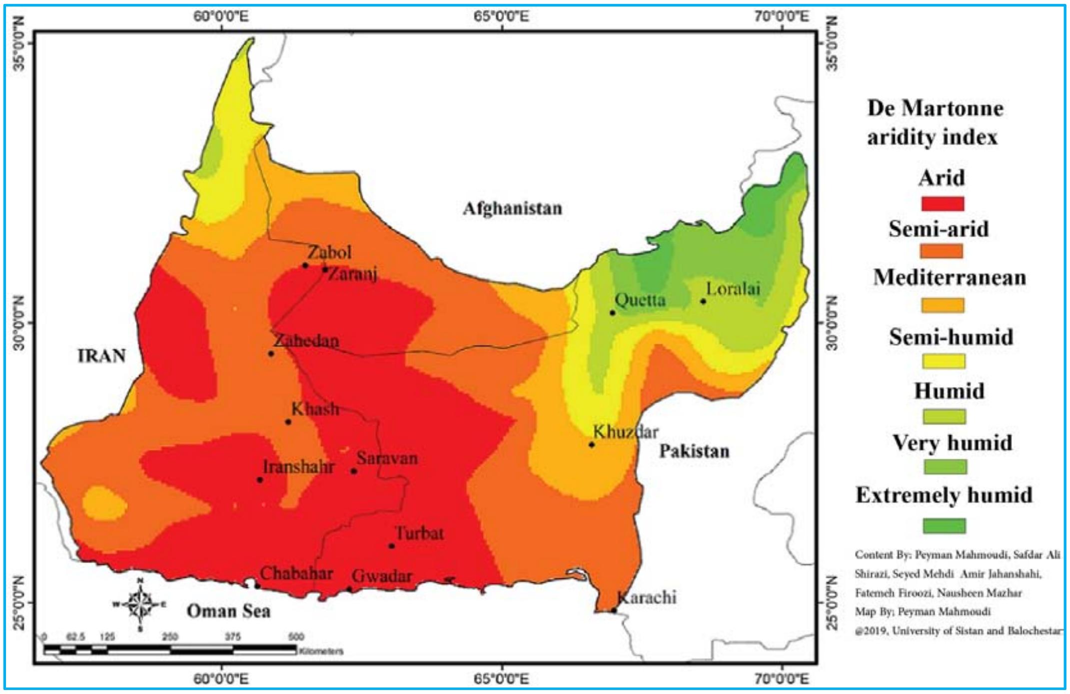

Fig. 2. Climatic classification of Baluchistan territory, according to the De Martonne climate classification (De Merton 1909)

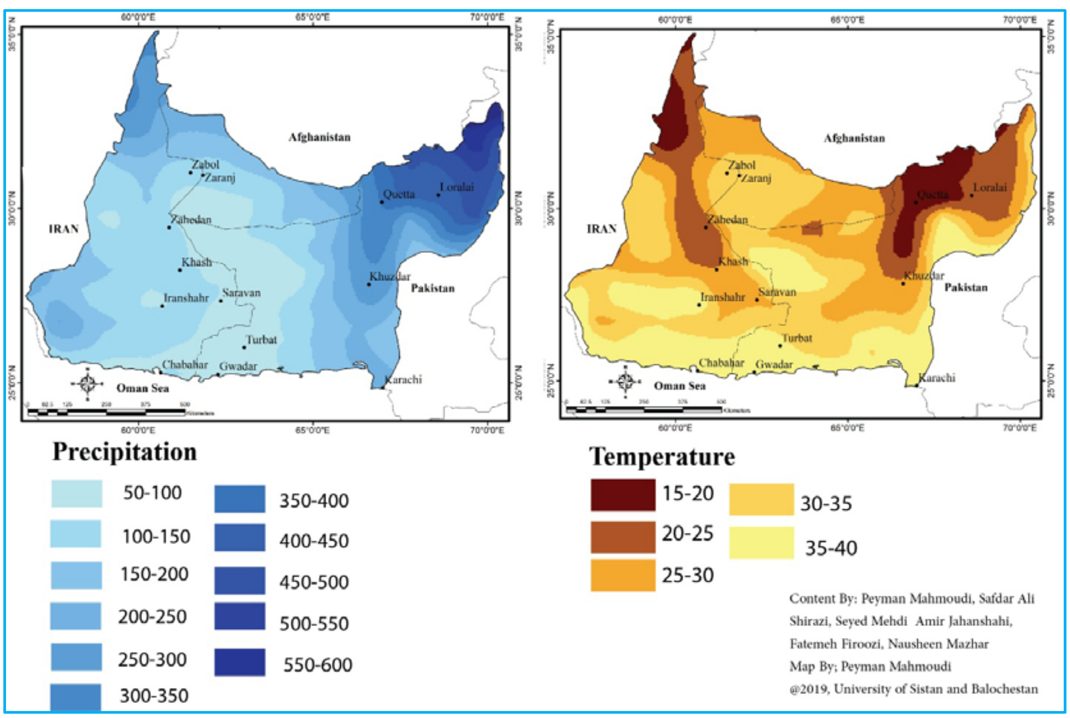

Fig. 3. Spatial distribution of average annual temperature in °C (right map) and average annual precipitation in mm, in Baluchistan (left map)

dynamics in different parts of the world, the present research aimed at performing a comprehensive study on the relationship between two variables of temperature and precipitation with vegetation dynamics in one of world's arid regions, using satellite remote sensing data and gridded temperature and precipitation statistics.

2. Data and methodology

Baluchistan is 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 area is now part of Sistan and Baluchestan province and its Pakistani part is also the largest province in Pakistan, which is called Pakistani Baluchistan. The border of this vast region is not exactly clear (Frye and Elfenbein, 2019). Its area is about 769,824 km^2, of which about 361,738 km^2 are in Pakistan, 302,845 km^2 are in Iran, and 105,241 km^2 are in Afghanistan (Fig. 1). Its population is about 15,700,000, of which 78.5 percent is in the Pakistani province of Baluchistan, 17.7 percent in the Iranian province of Sistan and Baluchistan, and 3.8 percent in Afghanistan (Fig. 1).

Baluchistan has different climates due to its complex topography and vast area. According to De Martonne climate classification (De Martonne 1909), there are seven different climate classes in this territory. But since Baluchistan is located in the desert belt of the Northern Hemisphere, much of it is dominated by subtropical pressure cells. Consequently, much of it, except for the northeastern part, which is mountainous, has an arid and semi-arid climate (Fig. 2).

Given that the highlands in the northern latitudes of this territory are characterized by very cold winters and warm summers, and the lowlands in the lower latitudes with temperate winters and hotter summers, temporal and spatial changes of temperature and precipitation can be considered as the natural characteristics of this territory (Government of Balochistan 2019). The average annual temperature in this region varies between 15 °C and 40 °C, with the lowest average annual temperature in the northeast and the highest one on the southern coast (Fig. 3). The average annual precipitation in Baluchistan is approximately 137.4 mm. The lowest precipitation in Baluchistan occurs in the center with an average annual precipitation of approximately 50 mm and the highest precipitation occurs in the northeastern regions with an average annual precipitation of about 650 mm (Fig. 3).

In the present study, to investigate the relationship between vegetation dynamics and two climate variables of temperature and precipitation at different time lags in Baluchistan, two different databases were used:

(*i*) Satellite productions of vegetation indices.

(*ii*) The gridded temperature and precipitation data based on ground measurements.

The Normalized Different Vegetation Index (NDVI) is one of most important vegetation products of the MODIS sensor on Terra Satellite, which is suitable for monitoring the vegetation dynamics on lands on a global scale (Solano *et al*., 2010). This index is calculated from the surface reflectance in two red bands (0.6-0.7 µm) and near-infrared (0.1-7.1 µm) (Solano *et al*., 2010). MODIS NDVI 16-day composite products (MOD13A3), with 1 km spatial resolution, wereused in the present study. They were freely downloaded for a 17-year period (2000–2016) from the Earth Observing System (EOS) Data Gateway of the National Aeronautics and Space Administration (NASA). During the processing of data from these products, all corrections related to the reduction of the effects of atmospheric gases, aerosols and thin cirrus clouds (Vermote *et al*., 1997) have been made. Moreover, MODIS Reproject Tool (MRT) was used to convert downloaded MODIS NDVI images from the sinusoidal projection system to a geographic projection system. From these 16-day composite images, their monthly average images were obtained.

The second database related to monthly temperature and precipitation data was obtained for a 17-year period (2000-2016) from the Climate Research Unit (CRU) of the University of East Anglia. The research unit has widely prepared and published a large number of weather data sets with different temporal-spatial resolutions. The Climatic Research Unit Time series (CRU-TS) is a set of these data and its version 4.02 was prepared with 0.5 × 0.5 degree spatial resolution for the period 1901-2017 of all lands, except for the Antarctic (Harris *et al*., 2014).

Besides, validation of the gridded data of CRU precipitation and temperature was done using precipitation and temperature data obtained from five Zabol, Zahedan, Khash, Iranshahr, and Chabahar synoptic stations. The geographic locations of these five stations have been indicated in Fig. 1. To examine the performance of gridded precipitation and temperature data using precipitation and temperature data measured at meteorological stations, two different performance indices including Root Mean Square Error (RMSE), and Correlation Coefficient (R) were used [See Vandeput (2021) for mathematical basics of all these indices].

After providing the required databases, rescaling spatial resolution was the next stage. Considering the spatial resolution of 1 × 1 km of satellite image, the total number of pixels per image which has been studied within the boundaries of the study area amounted to 769,824 pixels. On the other hand, the total number of pixels in the CRU-TS climatic database was 767 pixels with the spatial resolution of 0.5 × 0.5 degree. At this stage, first, in the satellite images/products, all the pixels whose geographic coordinates matched the geographic coordinates of the gridded data were determined (767 pixels), and then the

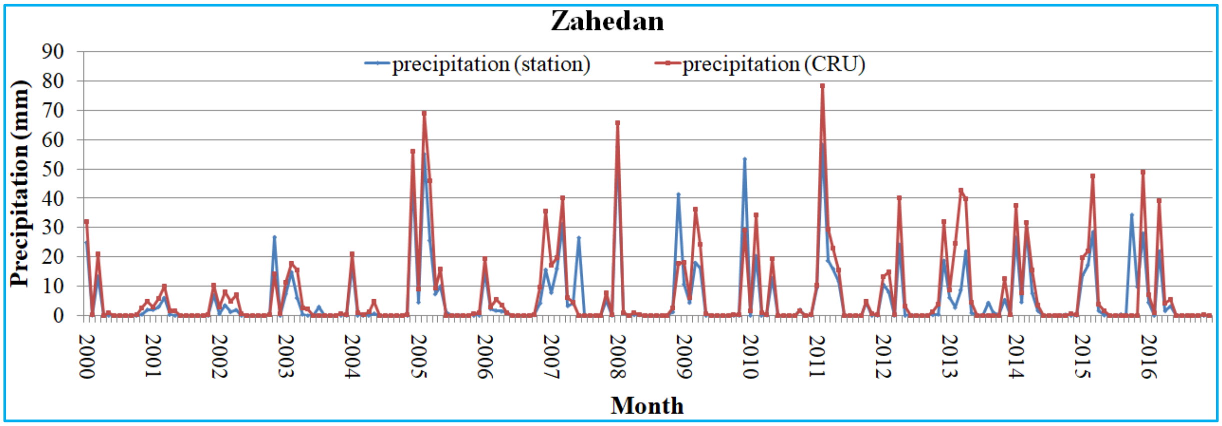

Fig. 4. Graph of monthly time series of precipitation related to the Zahedan meteorological station and the gridded CRU TS 4.02 precipitation data for the period 2000-2016

TABLE 1

Classes of the Pearson product-moment correlation coefficient values (Asakereh 2012)

Correlation Classes	Correlation Values
Positive(direct) Strong Correlation	0.7 - 1
Positive (direct) Moderate Correlation	0.3 - 0.69
Positive (direct) Weak Correlation	0 - 0.29
Negative (inverse) Weak Correlation	-0.29 - 0
Negative (inverse) Moderate Correlation	-0.69 - -0.3
Negative (inverse) Strong Correlation	-1 - -0.7

TABLE 2

Statistical indicators of performance of CRU gridded precipitation data with meteorological stations precipitation data (Root Mean Square Error (RMSE) and Correlation Coefficient (R))

Station	RMSE	R
Zahedan	7.124	**0.88**
Khash	16.290	**0.82**
Zabol	8.591	**0.79**
Iranshahr	7.324	**0.88**
Chabahr	21.680	**0.51**

maximum values of NDVI were extracted on the 0.5 × 0.5 degree areas considering these pixels as centres. In this way, both spatial resolution and geographic coordinates of both databases became identical. In the following, the Pearson product-moment correlation coefficient (Bates and Watts, 1988) was used to examine the relationship between vegetation dynamics and two climate variables of temperature and precipitation simultaneously, as well as at three (one-, two and three-month) time lags. Finally, to more properly interpret the results of the correlation analysis, the classification presented in Table 1 has been used.

3. Results

3.1. *Spatial-temporal distribution of temperature and precipitation in Baluchistan*

At first, to investigate the accuracy of the gridded CRU TS 4.02 data, they were compared with the data from five meteorological stations with complete and reliable data. To this end, five Zabol, Zahedan, Khash, Iranshahr and Chabahar stations were selected as the sample. The geographic locations of these five stations have been indicated in Fig. 2. The results of the analysis of correlation between monthly precipitation data from these five stations and the nearest gridded CRU TS 4.02 points to them for the period 2000-2016 showed that correlation coefficient values were 0.88, 0.82, 0.79, 0.72 and 0.51 and belonged to Zahedan, Khash, Zabol, Iranshahr and Chahbahar stations, respectively. It should be noted that all of these coefficients were significant at the probability level of $\alpha = 0.05$ (Table 2). The results of the RMSE performance index indicate that the gridded precipitation data corresponding to the Chabahar station (21.680) and that of the Zahedan station (7.124) have the highest and lowest error rates, respectively. The error rate of other gridded points corresponding to other stations ranged between these two bounds (Table 2). Therefore, according to the results of performance indices and considering the turbulent nature of precipitation in arid and semi-arid regions, the gridded CRU TS 4.02

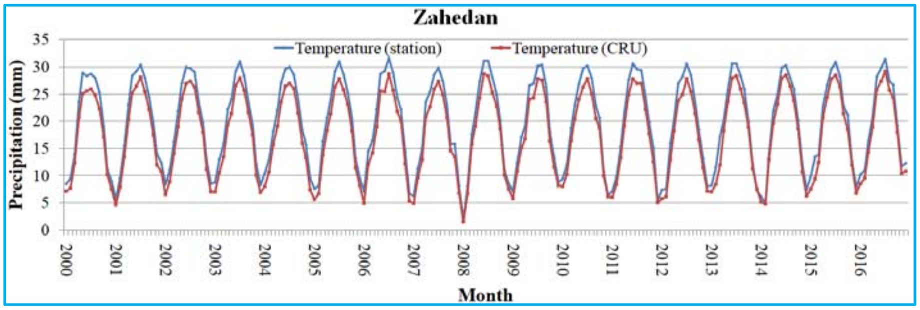

Fig. 5. Graph of monthly time series of temperature related to the Zahedan meteorological station and the gridded CRU TS 4.02 temperature data for the period 2000-2016

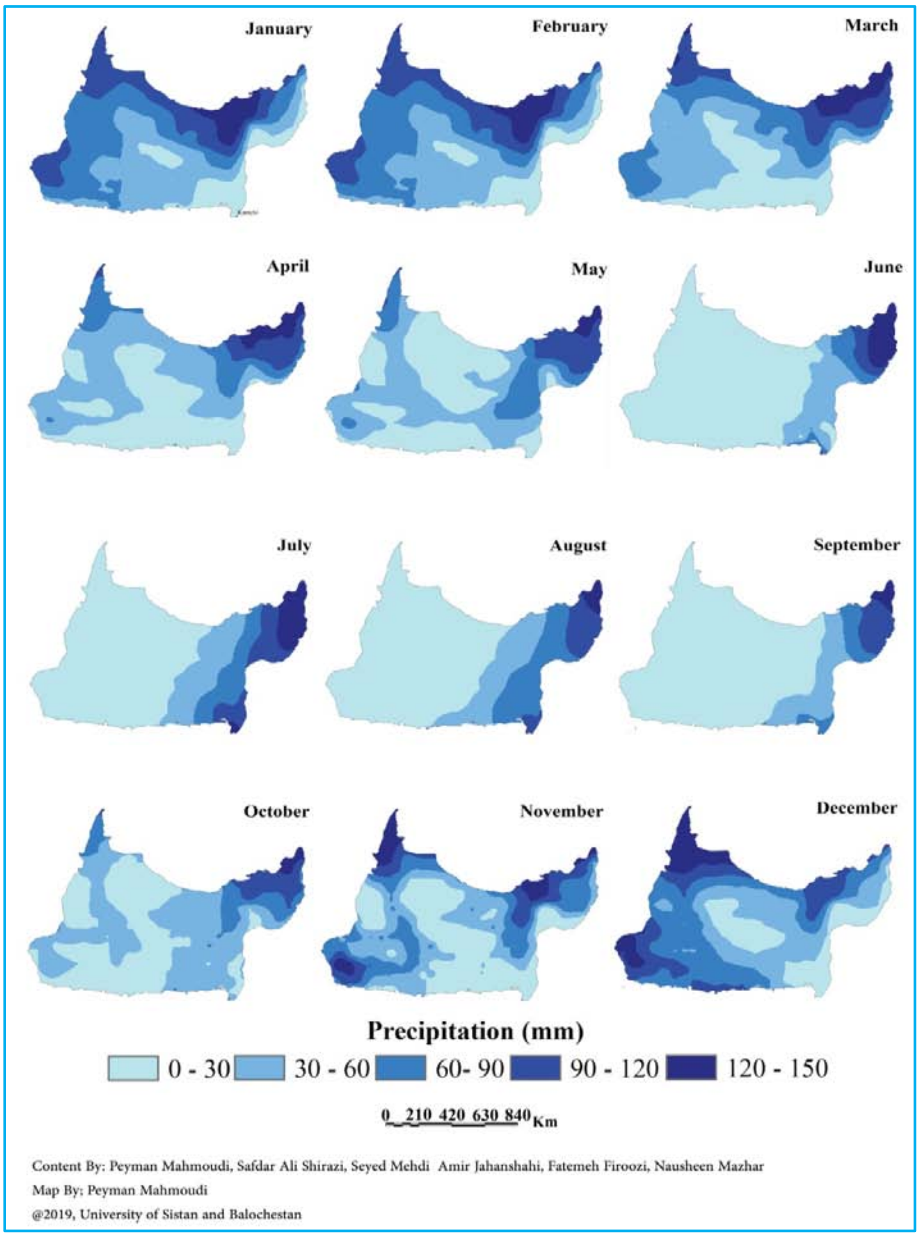

Fig. 6. The monthly precipitation maps in Baluchistan derived from the gridded data taken from the Climate Research Unit (CRU) of the University of East Anglia for the statistical period of 1987-2016

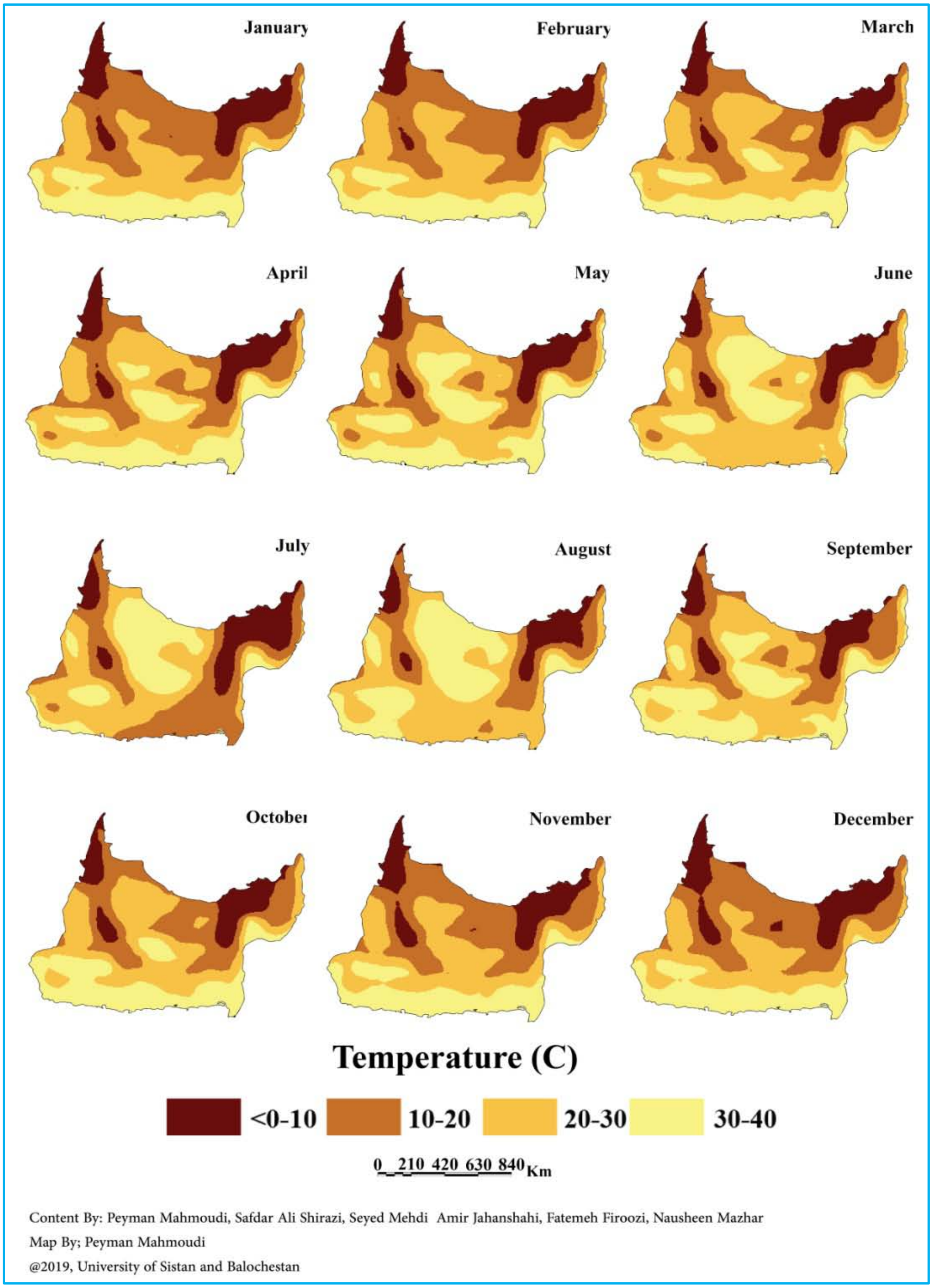

Fig. 7. Monthly temperature maps of Baluchistan derived from the gridded data taken from the Climate Research Unit (CRU) of the University of East Anglia for the statistical period of 1987-2016

precipitation data could be used for this region, which lacks a regular network of meteorological stations, with relative confidence. To better compare station data with gridded precipitation data, changes in monthly time series

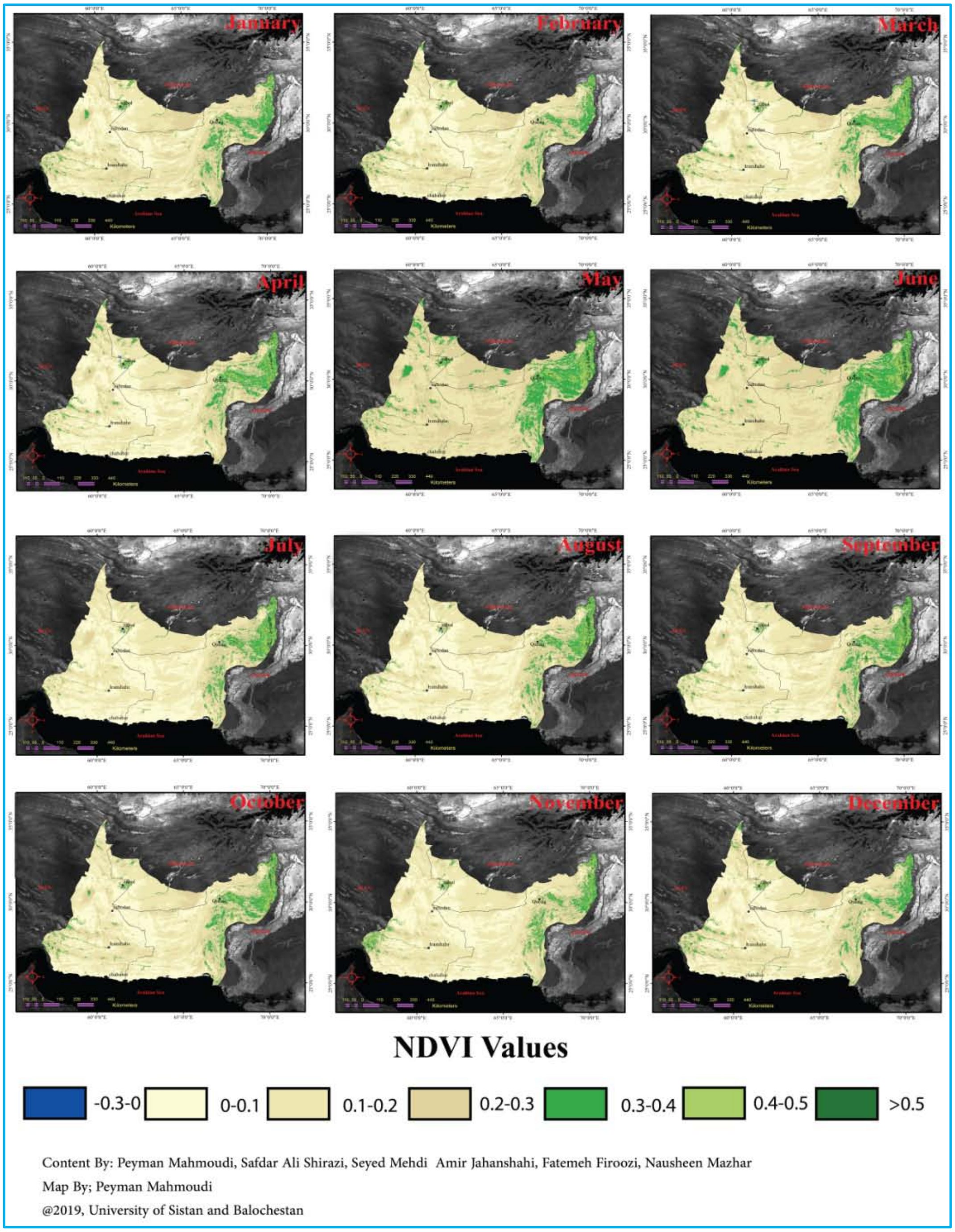

Fig. 8. Baluchistan vegetation dynamics map (2015) on a monthly scale

of precipitation related to the Zahedan meteorological station and the gridded precipitation data have been presented in the graph in Fig. 4.

Comparing the monthly average temperature of selected stations with the gridded CRU TS 4.02 temperature data, showed a very good match between them. The correlation coefficients for all of them were higher than 0.98 (Table 2). The results of the RMSE performance index further revealed that gridded temperature data corresponding to the Khash station (5.151) and that of the Zahedan station (2.266) have the

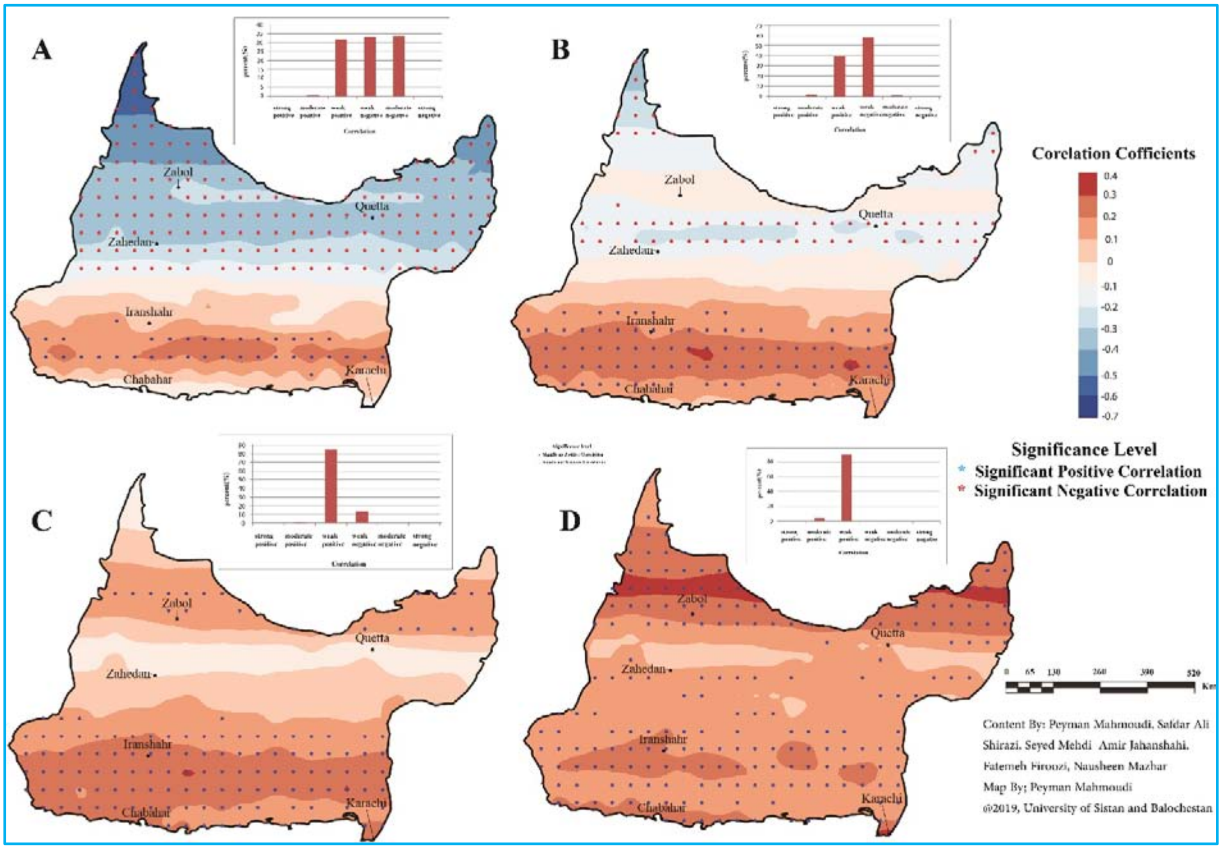

Fig. 9. Maps of correlation coefficients between temperature and NDVI for Baluchistan occupied by Iran, Pakistan and Afghanistan in Southwest Asia. A: Simultaneous relationship, B: One-month lag, C: 2-month lag, D: 3-month lag

TABLE 3

Statistical indicators of performance of CRU gridded temperature data with meteorological stations temperature data (Root Mean Square Error (RMSE) and Correlation Coefficient (R))

Station	RMSE	R
Zahedan	2.266	**0.99**
Khash	5.181	**0.98**
Zabol	2.732	**0.99**
Iranshahr	2.421	**0.99**
Chabahr	2.921	**0.98**

highest and lowest error rate, respectively (Table 2). These performance indices indicated that these data could be used for the case study in complete confidence. The reason for the higher correlation coefficients obtained for the temperature as compared with those obtained for precipitation is that it is easier to interpolate thetemperature compared to precipitation. In Fig. 5, differences in monthly time series of temperature related to the Zahedan meteorological station and the gridded CRU TS 4.02 temperature data have been presented in the graph. In this graph, the matching of these two time series is clear.

According to the results of the analysis of the correlation between the gridded temperature and precipitation data and the temperature and precipitation data obtained from meteorological stations, temporal and spatial distribution of temperature and precipitation were considered on a monthly scale. The temporal and spatial distribution of precipitation and temperature in Baluchistan is very heterogeneous due to its geographical location, complex topography, and its expanse. The monthly precipitation maps derived from the gridded data taken from the Climate Research Unit (CRU) of the University of East Anglia show that in this territory, the high-precipitation core, in most months, is found in the northeastern mountainous regions, and precipitation minimum core is observed in the desert areas in the center of Baluchistan (Fig. 6). In most of the relatively warm months of the year (June, July, August, September and October), a large part of Baluchistan (center and west) has

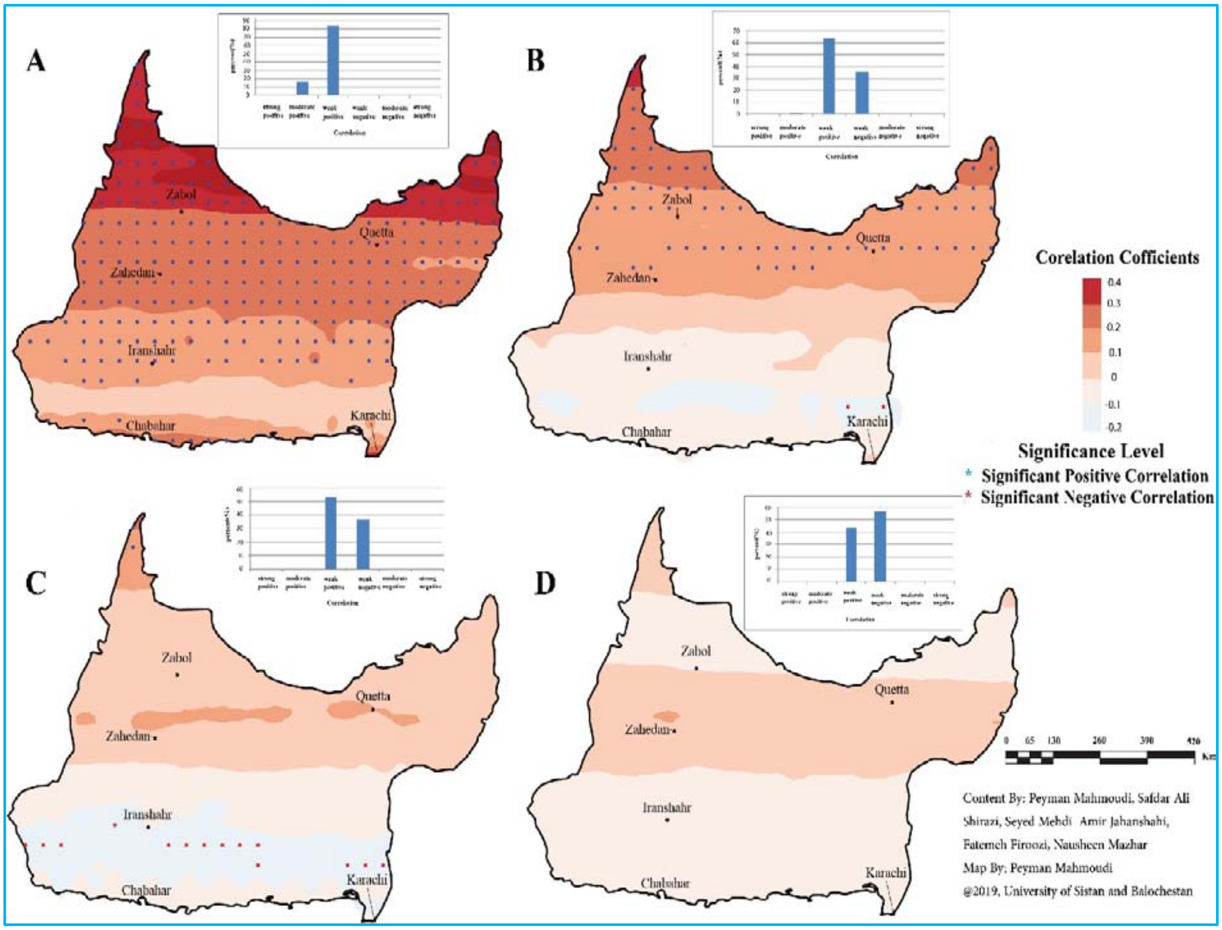

Fig. 10. Maps of correlation coefficients between precipitation and NDVI for Baluchistan occupied by Iran, Pakistan and Afghanistan in Southwest Asia. A: Simultaneous relationship, B: One-month lag, C: 2-month lag, D: 3-month lag

the low precipitation, but the eastern parts, due to the influence of monsoon low pressure, receive more precipitation. In this territory, most precipitations occur in winter, which can be due to the entry of western winds into the area.

But temporal and spatial variations of the temperature on a monthly scale show a more stable condition as compared to precipitation. According to the temperature maps derived from the gridded data taken from the Climate Research Unit (CRU) of the University of East Anglia, it is observed that the arrangement of temperature lines in this is a function of latitude and elevation. The lowest average monthly temperature cores, for the entire 12 months, could be observed in the northeastern and northwestern mountainous regions, and western highlands of this territory. But the highest temperature cores are found in lower latitudes and adjacent to the Oman and Arabian Seas, as well as inland drylands (Fig. 7).

3.2. *Analysis of correlation between vegetation dynamics and two variables of temperature and precipitation in Baluchistan*

Baluchistan's vegetation dynamic maps prepared on a monthly scale for 17 years clearly showed the intra- and inter-annual variations of vegetation in this land. Given a large number of images (204 images), only the vegetation dynamics maps related to 2015 have been shown as an example in Fig. 8. In this figure, the intra-annual variations of vegetation are observed. Comparing these images with the monthly precipitation maps (Fig. 6) and monthly temperature maps (Fig. 7) of Baluchistan provides very useful information about the relationship between vegetation dynamics and the two climate variables of temperature and precipitation. According to this figure, it is observed that vegetation density, especially in the eastern parts of Baluchistan, reaches its maximum in May, June and July and its decreasing trend is visible in other months (Fig. 8).

The results of the analysis of the correlation between the mean monthly temperature and NDVI at different time lags showed that in the simultaneous relationship, NDVI of the northern half of Baluchistan (Above 28° North latitude) had a negative correlation with temperature while NDVI of the southern half (Lower than 28° North latitudes) had a positive correlation with it [Fig. 9(a)]. The correlations related to the northern half were much stronger than those related to the southern half. All the correlations related to the northern half, especially from the latitude of approximately 29 degrees north and higher, have been classified as moderate correlations (0.3 - 0.7) and all of which were significant at $\alpha = 0.05$ (on the maps, those areas with significant correlations are shown with colored solid circles, red circles indicate a significant positive correlation and blue circles indicate a significant negative correlation). In the northern half, the negative correlations are related to the NDVIs of humid and semi-humid climates, while in the southern half, the positive correlations are related to the NDVIs of arid and semi-arid climates. In general, about 67.7 percent of the vegetation dynamics in Baluchistan had a negative correlation with the temperature, of which 33.7 percent belonged to the weak coefficient class and 34 percent to the moderate coefficient class [Fig. 9(a)].

However, in the one-, two-, and three-month lags, the results were very different from those obtained in the simultaneous relationship. In the one-month lag, in the northern half, the correlation coefficients between temperature and NDVI drastically decreased, so that in this time lag, a weak correlation (positive and negative) was observed in about 59.9 percent of the area, and there were no moderate correlations. Then, for this reason, their statistically significant level drops sharply in such a way that the points with a statistically significant correlation at the level of $\alpha = 0.05$ has decreased to less than half compared to the simultaneous relationship. But in the southern half, which is mostly affected by the tropical atmospheric systems, the correlation coefficients between the temperature and NDVI, in addition to the increase, had a spatial expansion, so that 39.9 percent of the area had a weak correlation and 1.6 percent also had a moderate correlation [Fig. 9(b)]. This increase in the value of the correlation coefficient has also increased their level of significance in such a way that these points are remarkable with a statistically significant correlation at the level of $\alpha = 0.05$.

In two- and three-month lags [Figs. 9(c&d)], for the total area of Baluchistan, the correlation between temperature and NDVI has been positive. In a two-month lag, 86 percent of its area and in 3-month lag, about 100 percent of its area had a positive correlation and most of them were in the weak positive correlation class [Figs. 9(c&d)]. In terms of statistical significance, it is observed that their correlation coefficient was significant at the level of $\alpha = 0.05$ in the two-month delay of the southern half and in the three-month delay of the largest area of Baluchistan with the exception of its central regions.

The analysis of the correlation between precipitation and NDVI in Baluchistan showed very different situations compared to temperature. In the simultaneous relationship, it is observed that in a large part of Baluchistan, the correlation between precipitation and NDVI was positive and significant at $\alpha = 0.05$ [Fig. 10(a)]. In this simultaneous relationship, no negative correlation was observed. 86.6 percent of points had a weak positive correlation with precipitation and 16.4% of them had a moderate positive correlation. Most of the moderate positive correlations have been observed in the northeastern and northwestern parts with humid and semi-humid climates (Fig. 2).

In a one-month lag, there were more different relationships between precipitation and NDVI. Moderate positive correlations actually reached their minimum value of 0.4 in this lag. In this lag, 64 percent of NDVI had a weak positive correlation and 35.6 percent had a weak negative correlation with precipitation. Only the correlations related to the northeastern and northwestern parts of Baluchistan were significant at $\alpha = 0.05$ [Fig. 10(b)].

In the two- and three-month lags, the correlation between precipitation and NDVI practically reached its lowest value. In a two-month lag, 53 percent and 47 percent of NDVI had a weak positive correlation and a weak negative correlation with precipitation. In this lag, only the correlations related to some parts of the southern half, which were negative, were significant at $\alpha = 0.05$ [Fig. 10(c)]. In the three-month lag, the correlation between precipitation and NDVI reached its lowest value and no significant correlation was observed at $\alpha = 0.05$ [Fig. 10(d)]. In other words, in the two and three-month lags, the relationship between precipitation and vegetation dynamics in Baluchistan practically gets to the lowest amount.

4. Discussion

Climatic variables are always one of the most important factors affecting the temporal-spatial dynamics of ecosystems on all local, regional and global scales, and the topic has always been a matter of interest to researchers in the field of climate, ecology, agriculture and remote sensing. In the present study, the relationship between temperature and precipitation variables with the vegetation dynamics in one of the arid and semi-arid regions of the world, *i.e*., Baluchistan, and shared by the three countries of Iran, Pakistan, and Afghanistan, was investigated. Due to the wide area of this land and lack of a regular and a dense network of weather stations, the gridded temperature and precipitation data from the Climate Research Unit (CRU) of the University of East Anglia, called CRU TS 4.02, were used. In addition, the normalized difference vegetation index (NDVI) obtained from the MODIS sensor of the TERRA satellite was used. The results of the analysis of correlation between the average monthly temperature and NDVI at different time lags indicated that the NDVIs of humid and semi-humid climates in the northern half of Baluchistan simultaneously reacted to temperature changes, while the NDVI of the arid and semi-arid climates in the southern half of Baluchistan climatic reacted to them at one-month lag. This result was consistent with the results of a study by Firozi *et al*., (2018). In their study, they have analyzed the correlations between temperature and NDVI for three months of April, May and June April for the Sistan Plain, with the centrality of Zabol, in the northwest of Baluchistan, at different time lags. Also the results presented for the simultaneous relationship were consistent with the results of a study by Los *et al*., (2001). In their study, they considered the availability of moisture as a factor limiting the plant growth. Therefore, considering the climatic and environmental conditions in Baluchistan, this factor can also play a key role in this region.

But the results of the analysis of the correlation between the total monthly precipitation and the monthly NDVI showed that the relationship between NDVI and precipitation was simultaneous, that is the precipitation of each month had the greatest effect on the NDVI on the same month. Although many studies in the world have confirmed the relationship between precipitation and NDVI at one- or two-month lag (Nicholson and Farrar, 1994; Richards and Poccard, 1998; Alwesabi, 2012), in present study, it was observed that the vegetation dynamics simultaneously reacted to precipitation changes and in more humid climates in the northeastern and northwestern parts, it reacted to precipitation changes at a one-month lag. The simultaneous reaction of NDVI to precipitation changes can be due to the relative dryness of the Baluchistan territory, and its reaction at one-month lag, especially in the northern half, can be due to the different composition and structure of vegetation in this part of Baluchistan. Shrublands, croplands, and grasslands are the most important and dominant types of vegetation on this land. Shrublands in the eastern and northern half and croplands and grasslands in southwestern Baluchistan, have also included the highest spatial concentration. Therefore, the differences existing in vegetation types in various parts of Baluchistan may be an important reason for their different responses to rainfall variability at different time lags. The results of the present study were consistent with the results of the study by Firozi, *et al*., (2018). Both of these studies on the Sistan plain in the northwest of Baluchistan with the centrality of Baluchistan showed a moderate positive correlation. However, the difference between the two studies in method and objective, which were not very similar to each other, should also be considered.

5. **Conclusion**

The results of the analysis of a correlation between the mean temperature and monthly NDVI in different time lags indicated that in the humid and semi-humid regions in the northern half of Baluchistan, NDVI simultaneously reacted to temperature variations, while in the arid and semi-arid regions in the southern half of Baluchistan, NDVI had a one-month time lag with temperature. However, the results of the analysis of a correlation between precipitation and monthly NDVI in different time lags indicated that NDVI simultaneously reacted to precipitation variations, that is precipitation of each month had the greatest effect on the NDVI of the same month.

In the results obtained, also there were uncertainties that must be taken into account in the analysis. Some of these uncertainties relate to the nature of gridded data and the amount of error occurring during the interpolation of data, while some other certainties relate to various factors such as seasonal variations in atmospheric water vapor, atmospheric aerosol changes and large areas of bare soil in arid and semi-arid regions that can make changes in the NDVI values while these factors have no relationship with active vegetation.

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