Spatial and Temporal changes in the Normalized Difference Vegetation Index and its Response to Climate Change in Shaanxi Province, China

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Abstract. Vegetation largely reflects climatic changes. Monitoring of the dynamic changes of vegetation and its response to climate change plays an important role in our understanding of ecological changes in Shaanxi Province. Based on the GIMMS NDVI and air temperature and precipitation data of Shaanxi Province from 1982 to 2015, changes in the NDVI were studied. The NDVI in Shaanxi Province showed a significant linear increase from 1982 to 2015. Affected by a warming climate, increased precipitation, and the implementation of the “Grain for Green” project, the NDVI in northern Shaanxi showed a significant increase, while affected by climate warming and drying as well as human activities in central Shaanxi, it significantly decreased. This study provides a scientific basis for the adjustment of environmental protection policies in Shaanxi Province.

1. Introduction
Global environmental changes, in particular changes in land vegetation against the background of a warming climate, have recently received considerable attention. The impact of climate warming on vegetation changes differs among regions[1]. Vegetation in areas with high elevation and latitude is considered to be particularly sensitive to climate warming[2]. In addition, the temperature in semi-arid and arid regions has increased significantly in the last few decades, along with increasing surface evaporation[3].

Shaanxi Province is located in the eastern part of northwestern China and represents transition area from semi-arid and semi-humid climate to arid and semi-arid climate. It stretches from north to south and spans three the completely different landform types of the Loess Plateau, the Guanzhong Plain, and the Qinba Mountains, along with three climate zones, namely the temperate, the warm temperate, and the subtropical zones. This unique natural geographical location makes this area ideal for studying the changes in terrestrial vegetation under a changing climate.

Changes in the vegetation in Shaanxi are a result of both climate change and human activities[4]. The conversion of farmland to forest land and grassland started in 2000 and has caused a large area of sloping farmland on the Loess Plateau to be converted into forest land and grassland, resulting in improved vegetation conditions[5]. Affected by project implementation and socio-economic development, the farmland area has declined, while socio-economic income channels have increased. The family economic income structure is now inclined to non-agricultural income, resulting in...
dramatic farmland abandonment. The abandoned farmland is mainly converted into grassland, which further promotes the improvement of regional vegetation conditions[6-7]. Research on vegetation changes in Shaanxi Province and vegetation response to climate change is of great significance for the development and adjustment of policies regarding regional environmental protection.

2. Data and Methods

2.1. Data

(1) We used GIMMS NDVI data from 1982 to 2015, with a spatial resolution of 5 km and a temporal resolution of 15 d. The maximum value composition method was used to obtain annual series data of GIMMS NDVI. (2) Air temperature and precipitation interpolation data were downloaded from the Resource and Environment Data Cloud Platform of the Chinese Academy of Science (http://www.resdc.cn), with a resolution of 1 km. After resampling the air temperature and precipitation data to a resolution of 5 km, the correlation between NDVI and air temperature as well as precipitation data was analyzed.

2.2. Method

The study used the linear regression method and the F-test, with correlation coefficients and t-tests for analysis. The research methods have been described in detail elsewhere[8].

3. Results

3.1. Temporal change of NDVI

As seen in Figure 1, the average NDVI of Shaanxi Province from 1982 to 2015 was 0.6728, with 2007 as the boundary, and the average NDVI from 1982 to 2007 was 0.6601, which was about 1.89% lower than the average of 1982-2015. The average NDVI value in 2008-2015 was 0.7142, which is about 6.16% higher than the average value of 1982-2015. The average NDVI value for 2008-2015 was 0.045 (8.20%) higher than the average value for 1982-2015. During the study period, Shaanxi Province’s NDVI generally increased, with a linear increase rate reaching 0.002/a (P < 0.001), indicating that it will further increase in the future. Overall, Shaanxi Province’s NDVI has been increasing significantly since 2008, which may be related to the implementation of the national project “Returning Farmland to Forestland and Grassland”.

![Figure 1. Change of annual average NDVI in Shaanxi province during 1982-2015.](image-url)
3.2. Spatial change of NDVI

The change rates of the NDVI in Shaanxi Province from 1982 to 2015 and the F values were calculated. The change rate was divided into two increase and decrease, and the F value was partitioned into insignificant and significant according to the threshold value of 4.15. Finally, the classification results of the NDVI change rate and the F value were superimposed to obtain four classifications: significant increase, insignificant increase, insignificant decrease, and significant decrease (Fig. 2).

From 1982 to 2015, the NDVI in Shaanxi Province mainly increased (including significant increase and insignificant increase), accounting for 82.48% of the total area of Shaanxi Province. Of this, the significant increase was relatively high, reaching 62.55%, mainly concentrated in the Yulin area, the northern and central Yan’an area, the southeast of the Guanzhong Plain, and in Ankang and Shangluo of the Qinling Mountains. The increase in the NDVI indicates that the condition of the vegetation in these areas improved from 1982 to 2015. This improvement in the northern Shaanxi Province was closely related to the implementation of the project “Returning Farmland to Forestland and Grassland”, while the improvement in the southern Shaanxi Province may be related to the implementation of various environmental policies such as mountain closures and grazing bans. The NDVI reduction areas (including significant and insignificant reduction) accounted for 17.52% of the total area of Shaanxi Province, with areas experiencing a significant reduction accounting for 5.68%, reflecting the overall improvement of vegetation during the study period. Areas with significantly decreasing NDVI values showed a more scattered distribution and were concentrated on the Guanzhong Plain, extending northward into the Yan’an territory and southwestward into the Hanzhong territory. Significantly reduced drivers may be related to human activities. With the rapid economic and social development from 1982 to 2015, a series of human activities, such as urban expansion, farmland reduction, and the construction of roads and railways, considerably changed the underlying surface condition, resulting in
poor vegetation conditions on the Guanzhong Plain, which was the region with the most intense human activities in Shaanxi Province (Fig. 2).

3.3. Relationship between NDVI and precipitation, air temperature
The correlation coefficient of the NDVI and the precipitation in Shaanxi Province from 1982 to 2015 were calculated, and the threshold (0.3494) was used to divide the correlation coefficient into five different categories: significant negative correlation (< -0.3494), insignificant negative correlation (-0.3494-0), no correlation (0, generally not available), insignificant positive correlation (0-0.3494), and significant positive correlation (> 0.3494).
Figure 3. Spatial distribution of correlation between annual average NDVI and precipitation (a), air temperature (c), and change rate of precipitation (b) and air temperature (d) in Shaanxi Province during 1982-2015.

There was a positive correlation between NDVI and precipitation, with significant positive correlations accounting for 19.65% of the total area of Shanxi Province, concentrated in the southern Yulin area and the Yan’an area in the north of the province (Fig. 3a). From 1982 to 2015, annual precipitation and annual average air temperature increased, with a trend toward a warmer and wetter
climate. The annual precipitation increase rate was 14.49–27.07 mm/a (Fig. 3b), and the annual air temperature increase rate was 0.39–0.46℃/a, providing favorable conditions for vegetation development. The negative correlation between NDVI and precipitation accounted for 22.9%, although the proportion of significant negative correlations was low (0.25%). Overall, and increase in precipitation during this period resulted in improved vegetation conditions in Shaanxi Province.

The parameters NDVI and air temperature were mainly positively correlated, accounting for 75.82% of the total area of Shaanxi Province, with a significant positive correlation in 22.55% of the area, concentrated in the northern and southern marginal areas of Shaanxi Province (Fig. 3c). These areas became warmer and wetter from 1982 to 2015, based on the increased air temperature and increased precipitation (Fig. 3d). Negative correlations between NDVI and air temperature accounted for 24.18%, while significant negative correlations were only observed for 3.96% of the study area, concentrated in the Guanzhong Plain in central Shaanxi Province, especially in the vicinity of Xi’an, the capital of Shaanxi Province.

From 1982 to 2015, the NDVI increased significantly in the north and southeast of Shaanxi Province, while it decreased significantly in the middle and southwest. The average air temperature increased during the study period, while precipitation increased in the northern and southwestern marginal areas and decreased in large areas in the central and southern regions of Shaanxi Province (Figs. 2 and 3). It can be assumed that the increase in the NDVI in northern Shaanxi was related to climate warming and humidification, while the significant increase in the NDVI in the southeast was related to climate warming and drying. In addition, the implementation of the project “Returning Farmland to Forestland and Grassland” also played an important role in improving vegetation in northern Shaanxi. The decline in the NDVI in the central and southern regions was related to the warmer and drier climate, while the decline in the central Guanzhong Plain can be linked to human activities such as urban expansion.

4. Conclusions
Using GIMMS, NDVI, air temperature, and precipitation data from Shaanxi Province during 1982-2015, the NDVI change trend and its relationship with air temperature and precipitation were analyzed. Based on the results, the NDVI in Shaanxi Province increased significantly linearly from 1982 to 2015, in particular from 2008 to 2015. The significant increase mainly occurred in the northern and southeastern parts of Shaanxi Province. In the northern regions, this development was related to the implementation of the “Returning Farmland to Forestland and Grassland” policy, as well as to a warmer and drier climate. In the southern areas, it was a result of a warmer and drier climate. The areas with a significant reduction in NDVI were concentrated in the central and southern regions. On the central Guanzhong Plain, this was related to climate warming and drying as well as to human activities, while in the southern region, climate warming, accompanied by decreased precipitation, played an important role. This study provides a scientific basis for the adjustment of ecological protection policies in Shaanxi Province, China.

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