Environmental Science and Pollution Research (2019) 26:28977–28992
https://doi.org/10.1007/s11356-019-06096-9

RESEARCH ARTICLE

Spatiotemporal variation and influencing factors of vegetation cover in the ecologically fragile areas of China from 2000 to 2015: a case study in Shaanxi Province

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Received: 18 March 2019 / Accepted: 26 July 2019 / Published online: 6 August 2019

Abstract

China's Loess Plateau region has a weak ecological environment, and the government has invested a considerable amount of money to repair the ecological environment. Vegetation plays an important role in the ecological environment. The Sen slope analysis and the Mann-Kendall trend test were used to analyze the trend and significance of vegetation coverage from 2000 to 2015. The vegetation coverage was analyzed to investigate the influence of land use types and conversion. The Pearson Correlation Test and qualitative analysis were utilized at the pixel and regional scales to investigate the influence of meteorological factors and topographical factors. The fluctuation of vegetation in Shaanxi was analyzed from 2000 to 2015. The impact of anthropogenic activities was investigated using residual trend analysis. Hurst exponent and H/S analysis were applied to investigate the potential future vegetation coverage trend. The vegetation coverage in Shaanxi Province improved from 2000 to 2015. In unchanged land use types, all types showed significant improvements expect for other construction land. In changed land use types, most of the land use types converted into urban land showed degradation. All the land use types converted into dry land, forest, and unused land showed improvements. Ecological protection has achieved great results. Precipitation and temperature partly affect vegetation coverage in Shaanxi. Gradients and elevation affected the distribution of vegetation coverage and human activities influenced land use type and the ecological environment. In the future, potential degradation risks still exist in the parts of Shaanxi Province.

Keywords Vegetation coverage · Spatiotemporal analysis · Land use type · Residual trends analysis · Hurst index

Introduction

Vegetation coverage is the percent value of area in a terrestrial vegetation unit area determined by vertical projection (Mu et al. 2013). The analysis of spatial-temporal variations or driving forces of vegetation coverage is widely applied at the scales of region, province, basin, national, and global (Liu et al. 2018a, b; Piao et al. 2003; Zhang et al. 2018; Zhu and Southworth 2013). Research on various aspects vegetation cover has gradually become a key focus in various aspects because it is an independent part of the socio-natural system and plays an important role in the water balance, carbon cycle, and energy flow (Huang and Xu 2016; Piao et al. 2003). Thus, it is important to investigate the variation in vegetation coverage and factors of driving on vegetation coverage change. The investigation can help researchers and policy makers to understand artificial or natural disturbance vegetation coverage then to protect the ecological environment.

Shaanxi is one of the most vulnerable and sensitive regions in China. In particular, soil erosion influences the development of the Shanbei Plateau region. Because of various ecological environments and complex topography, vegetation coverage is affected by different factors and presents various spatial distribution. It is necessary to investigate the vegetation coverage and its driving factors. However, few studies have

Responsible editor: Philippe Garrigues

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regarded Shaanxi as a study area or possessed a comprehensive understanding. Different land use types may have different effects on vegetation coverage and the conversion between different land types has different effects on vegetation coverage. Current studies have focused on precipitation and temperature, and have neglected the terrain and elevation factors that affect the distribution of vegetation and ecological policy (Deng et al. 2007). Meanwhile, it is crucial for Shaanxi to predict prospective vegetation cover, as these predictions provide governments with sufficient assistance in policy making. Since the implement of Ecological Construction Project in 1999, the government has invested a lot of money on afforestation. Thus, the period of our research is set from 2000 to 2015 to investigate the variation of vegetation coverage.

Remote sensing is an important technology used to monitor vegetation dynamic at diverse spatial-temporal scales. In particular, the Normalized Difference Vegetation Index (NDVI) is widely utilized for researchers to analyze vegetation coverage change. Because the NDVI data are acquired by the AVHRR GIMMS, SPOT VGT, and MODIS sensor, these data have the advantage of wide cover and successive time series (Fensholt et al. 2009; Gutman and Ignatov 1998; Yuan et al. 2013). Vegetation coverage dynamics are influenced by climate changes and human activities. In particular, temperature, and precipitation are dominant factors that drive variations in climate (Chu et al. 2019; He et al. 2015). Currently, many studies have focused on various regions of different countries to investigate vegetation coverage change and its influencing factors (Liu et al. 2018b; Pan et al. 2017). Nevertheless, topography is also an important constraint factor to affect vegetation coverage change (Fu et al. 2017; Peng et al. 2012). Meanwhile, the vegetation coverage is accelerated, i.e., increases or restrained based on human activities and policy (Ma et al. 2017). In terms of traditional methods, the linear regression is utilized to investigate the trend of inter-annual vegetation coverage (Baniya et al. 2018, Wei et al. 2018), and the *F* test is applied to test the significance of the vegetation coverage trend (Li et al. 2017). Many researchers have investigated the trend and its significance by Theil-Sen's median trend analysis and the Mann-Kendall test in recent years (Jiang et al. 2015b; Liu et al. 2016; Tian et al. 2017; Tong et al. 2018b). Regarding the correlation between various factors and vegetation coverage, most studies utilize Pearson's correlation test to investigate the coefficient and significance at the pixel scale (Wang et al. 2019).

Therefore, the objectives of our study were to (i) analyze the spatiotemporal variation in vegetation coverage using Sen's slope analysis and the Mann-Kendall trend test, (ii) analyze the factors influencing vegetation coverage, (iii) investigate change in vegetation coverage based on different land use types and their conversions, and (iv) predict the future change in vegetation coverage by the Hurst and H/S analysis.

Data and methods

Study area

Shaanxi Province is located in northwestern China and comprises 205800 km^2 (Fig. 1), including eight prefecture-level cities (Ankang city, Baoji city, Hanzhong city, Shangluo city, Tongchuan city, Weihai city, Yan'an city, and Yulin city). The geographic location of Shaanxi Province is between 31° 42′ N–39°35′ N and 105° 29′ E–111° 15′ E, which results in its various climates. Shaanxi Province is divided into three parts,

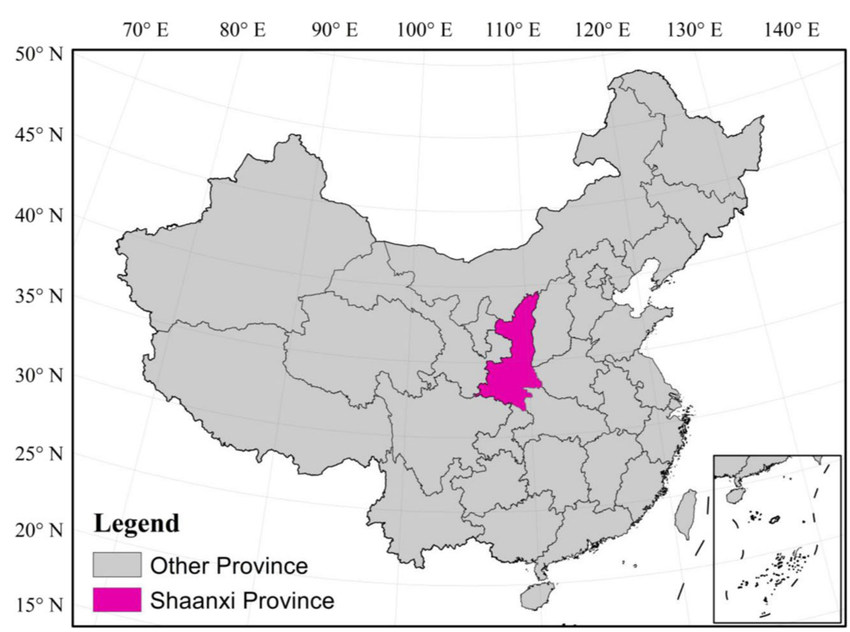

Fig. 1 The location of Shaanxi Province

i.e., Shanbei Plateau (SBP) region, Guanzhong Plain (GZP) region, and Qinling-Tapashan Mountainous (QTM) region by Beishan Mountains and Qinling Mountains (Wang and Li 2018). The elevation of Shaanxi Province ranges from nearly 350 to 3500 m and varied in different regions, with a mean elevation of approximately 1127 m. The annual average temperature ranges from 8 to 16 °C, with January temperatures ranging from − 11 to 3.5 °C and July temperatures ranging from 21 to 28 °C. The annual average precipitation is approximately 580 mm, most of which occurs from May to October (http://english.shaanxi.gov.cn) (Jiang et al. 2015a; Jiang et al. 2017).

Because of human activities and climate change, vegetation coverage has changed in recent years (Wang et al. 2013). The problem of soil and water loss is serious in Shaanxi Province and these problems are caused by urbanization and vegetation destruction. The Shaanxi government is taking specific measures to protect vegetation, especially in SBP which is one of the most serious ecologically damaged regions in China.

Data source

The MODLT1D NDVI dataset, meteorological station dataset, elevation data, and the land use / cover dataset were used in the study. (i) The MODLT1D NDVI dataset was downloaded from the Geospatial Data Cloud (http://www.gscloud.cn) with a spatial resolution of 500 m × 500 m and a temporal resolution of one month. (ii) The information from 34 meteorological stations was used to analyze the correlation between meteorology (e.g., precipitation and temperature) and vegetation coverage. The monthly data was processed into yearly data and then interpolated to obtain precipitation and temperature by kriging with a spatial resolution of 500 m × 500 m. (iii) The land use cover data set was provided by the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) (http://www.resdc.cn). There are 26 types of land use cover classification and the dataset was reclassified into 11 types of land use cover classification. (iv) The Digital Elevation Model data was downloaded from the Geospatial Data Cloud (http://www.gscloud.cn). The slope data was calculated by Digital Elevation Model based on ArcGIS10.3. The gradient was classified based on "Technical Regulations for Survey of Land Use Status" and the elevation was classified by average division. (v) The afforestation data was collected from Statistical Yearbook of Shaanxi.

Processing method

Maximum value composites

The maximum value composites of the NDVI minimized the influence of clouds, sun angel, and atmospheric interference (Holben 1986; Stow et al. 2007). In this paper, monthly data were used to compose yearly data from 2000 to 2015 using the maximum value composites. The formula is shown as follows:

$$\mathrm{NDVI}_{\max} = \max(\mathrm{NDVI}_1 + \mathrm{NDVI}_2 + \mathrm{NDVI}_3 + \cdots + \mathrm{NDVI}_i), \quad (1)$$

where, i represents the month (May to October) and max is used to calculate the highest NDVI at the pixel scale.

Dimidiate pixel model

Assume that a pixel has two components, the surface covered by vegetation and the surface covered by bare soil. Calculate the processed NDVI value by using the pixels covered by the vegetation and the pixels completely covered by the bare soil. The model can effectively reduce the effects of solar elevation, cloud, atmospheric noise, and soil background. (Yang et al. 2015; Zhang et al. 2013).

$$\mathrm{NDVI} = \frac{\mathrm{NDVI}_i - \mathrm{NDVI}_{\mathrm{soil}}}{\mathrm{NDVI}_{\mathrm{veg}} - \mathrm{NDVI}_{\mathrm{soil}}}, \quad (2)$$

where $NDVI_{soil}$ represents the minimum value at 0.5% confidence, and $NDVI_{veg}$ represents the maximum value at 0.5% confidence.

Statistical methods

Sen's slope analysis and Mann-Kendall trend test

Sen's slope analysis and the Mann-Kendall (MK) trend test are nonparametric statistic tests (Liu et al. 2018b) that are applied in the long-time sequences of vegetation cover change (Gocic and Trajkovic 2013). Sen's Slope can effectively decrease the influence of outliers by fixing the shortage of the linear trend to improve accuracy (Fensholt et al. 2012). Sen's slope is used in this paper and its formula is as follows:

$$\theta = \mathrm{median}\left(\frac{\mathrm{NDVI}_i - \mathrm{NDVI}_j}{i-j}\right), \forall i < j, \quad (3)$$

where, $1 < i < j < n$ and n is the length of the sequence in research. $NDVI_i$ and $NDVI_j$ represent the vegetation in the times of i and j, respectively. θ shows the trend of vegetation change. When $\theta > 0$, it reflects an increasing trend in the time sequence. However, a decreasing trend was the opposite.

The Mann-Kendall trend test is widely used in hydrology and meteorology (Cao et al. 2014; Fensholt et al. 2012). The calculation is as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}\left(\mathrm{NDVI}_j - \mathrm{NDVI}_i\right), \quad (4)$$

$$\mathrm{sgn}\left(\mathrm{NDVI}_j - \mathrm{NDVI}_i\right) = \begin{cases} +1, \mathrm{NDVI}_j - \mathrm{NDVI}_i > 0 \\ 0, \mathrm{NDVI}_j - \mathrm{NDVI}_i = 0 \\ -1, \mathrm{NDVI}_j - \mathrm{NDVI}_i < 0 \end{cases}, \quad (5)$$

and

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}}, S > 0 \\ 0, S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}}, S < 0 \end{cases}, \quad (6)$$

where

$$VAR(S) = \frac{\left(n(n-1)(2n+5) - \sum_{p=1}^{q} t_p\left(t_p-1\right)\left(2t_p+5\right)\right)}{18}. \quad (7)$$

In this formula, n represents the length of the time sequence and t_p represents the number of data with identical NDVI values. When $Z > 1.96$ or $Z < -1.96$, the time sequence shows a significant change at the significance level of $\alpha < 0.05$. Otherwise, the time sequence shows non-significant change at the significance level of $\alpha > 0.05$.

Coefficient of variation

The coefficient of variation reflects the fluctuation degree of vegetation coverage (Tucker et al. 1991). The formula is as follows:

$$C_v = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(C_i - \overline{C}\right)^2}}{\overline{C}}. \quad (8)$$

In the formula, $\overline{C}$ is the average of vegetation from 2000 to 2015, C_i is the vegetation coverage in year i and n is the length of the time series. A larger C_v reveals higher fluctuations for the pixel of vegetation coverage. Meanwhile, a lower C_v shows a lower fluctuation for vegetation coverage. In this study, the values of fluctuation are divided into five classifications: lower fluctuation ($C_v \leq 0.04$), low fluctuation ($0.04 < C_v \leq 0.07$), moderate fluctuation ($0.07 < C_v \leq 0.16$), high fluctuation ($0.16 < C_v \leq 0.28$), and higher fluctuation ($C_v > 0.28$).

Residual trends analysis

Vegetation coverage is affected not only by precipitation and temperature but also by anthropogenic activities (Liang et al. 2012). The Multiple linear regression was adopted to fit the vegetation coverage and meteorological factors and to calculate the predicted value. Using the true value from remote sensing and the predicted value, the residual trend can be calculated from 2000 to 2015. When the pixel shows a significant trend, anthropogenic activities are the dominant factor. Otherwise, the meteorological factor plays a major role. The formula is as follows (Jiao et al. 2017):

$$\mathrm{NDVI}_{\mathrm{est}} = k_1 P + k_2 T + b, \quad (9)$$

$$\varepsilon = \mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{est}}, \quad (10)$$

and

$$\varepsilon = mt + n. \quad (11)$$

In the formula, P is the value of the precipitation factor, T is the value of the temperature factor, and k_1 and k_2 are the coefficients of the equation. NDVI represents the true value of remote sensing and $\mathrm{NDVI}_{\mathrm{est}}$ represents the estimated vegetation coverage. ε is the residual value of the vegetation coverage from 2000 to 2015 at the pixel scale, and t represents the year. Equation (11) is used to fit time sequence and residual value. When $m > 0$, anthropogenic activities have had a positive impact on vegetation coverage in recent years. Otherwise, anthropogenic activities have had a negative impact.

Hurst exponent and H/S analysis

The Hurst index is a statistical method used to analyze long-term time sequence correlations (Tong et al. 2018a).

First, calculate the mean time sequence:

$$\overline{NDVI}_{(q)} = \frac{1}{q}\sum_{i=1}^{q} NDVI_{(q)} \quad q = 1, 2, 3, \cdots, n. \quad (12)$$

The accumulated deviation is calculated as follows:

$$X_{(t,q)} = \sum_{i=1}^{t}\left(NDVI_{(t)} - \overline{NDVI}_{(q)}\right) \quad 1 \leq t \leq q. \quad (13)$$

The extreme deviation is calculated as follows:

$$R_{(q)} = \max_{1\leq t\leq q} X_{(t,q)} - \min_{1\leq t\leq q} X_{(t,q)} \quad q = 1, 2, 3, \cdots, n. \quad (14)$$

The standard deviation is calculated as follows:

$$S_{(q)} = \left[\frac{1}{q}\sum_{t=1}^{q}\left(NDVI_{(t)} - NDVI_{(q)}\right)^2\right]^{\frac{1}{2}} \quad q = 1, 2, 3, \cdots, n. \quad (15)$$

The Hurst index is calculated as follows:

$$\frac{R_{(q)}}{S_{(q)}} = (cq)^H. \quad (16)$$

where the Hurst exponent H can be calculated by fitting. When $H = 0.5$, the time series reveals no changes. When $H > 0.5$, the time series reveals a continuous trend and the future is consistent with the past. When $H < 0.5$, the time series reveals an opposite trend compared with that of the past.

Correlation analysis

The Pearson correlation test was utilized to describe the relationship between two variables (Li et al. 2018). In this study, vegetation coverage and meteorological factors were analyzed by using the Pearson correlation test. The formula is shown as follow:

$$R = \frac{\sum_{i=1}^{n}\left(x_i - \overline{x}\right)\left(y_i - \overline{y}\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2 \sum_{i=1}^{n}\left(y_i - \overline{y}\right)^2}}. \quad (17)$$

In this formula, x_i represents the value of vegetation coverage for the i year, and y_i represents the value of precipitation or temperature for the i year. R is the correlation between two factors. When $R > 0$, the two factors have a positive correlation. Otherwise, the two factors have a negative correlation. Meanwhile, the two factors are tested for significance to determine the significance level of the correlation coefficient.

Results

Temporal variation in vegetation coverage

Figure 2 shows an increasing trend of the interannual vegetation coverage from 2000 to 2015 in Shaanxi. In the 16 years, the trend increased significantly with a rate of 0.00878 year^{-1}. The maximum vegetation coverage occurs in 2013 (0.7576) and the minimum vegetation coverage occurs in 2000 (0.6073).

The vegetation coverage change trend is given from 2000–2015 and shows the there was a significant change. Overall, the vegetation coverage is greater in the south than in the north; however, the GZP region in Shaanxi Province has shown low vegetation coverage.

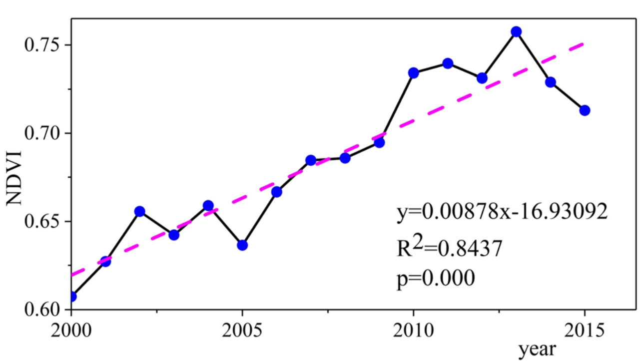

Fig. 2 Interannual variation of NDVI and trends in Shaanxi

The trends of the annual vegetation coverage index in the SBP region, GZP region, and QTM region are presented in Fig. 3. The vegetation coverage of the QTM region is greater than that of the SBP region and GZP region, while SBP region shows the lowest vegetation cover in Shaanxi Province. In the SBP region, the vegetation coverage displays an unstable rising trend at an average of 0.0134 year^{-1}, and the range is from 0.3472 (2000) to 0.5948 (2013). In the GZP region, the vegetation coverage increases at 0.0065 year^{-1} on average and the range is from 0.7005 (2001) to 0.8168 (2013). In the QTM region, the vegetation coverage maintains steady growth at an average of 0.0051 year^{-1} and its range is from 0.8353 (2000) to 0.9088 (2015).The vegetation coverage in southern Shaanxi is higher than that in northern Shaanxi (Fig. 4a). The greatest vegetation coverage is mainly found in southern Shaanxi, while the poorest vegetation coverage is found in the northwest. From north to south, the vegetation coverage is divided into four levels, i.e., from great to poor: QTM region > GZP region > southern SBP region > northern SBP region.

Spatial variations and NDVI trend in Shaanxi

The spatial vegetation coverage in Shaanxi reflects the change in heterogeneity from 2000 to 2015 (Fig. 4b and Table 1). There are 90.29% pixels (approximately 131179.25 km^2) that demonstrate an increasing trend that is far greater than the number of pixels with a decreasing trend; specifically, 55.14% of study area reflects significant improvement and 35.15% reflects slight improvement. Moreover, the areas with slight degradation and significant degradation, with values of 8.57% and 1.14%, respectively, are mainly in northern Xi'an city, Qishan County, Fengxiang County, Chencang County of Baoji, southern Xianyang city, southern Tongchuan city, Yuyang District and Dingbian County of Yulin city, and Dali County of Weinan city which are mostly rapidly developing urban areas.

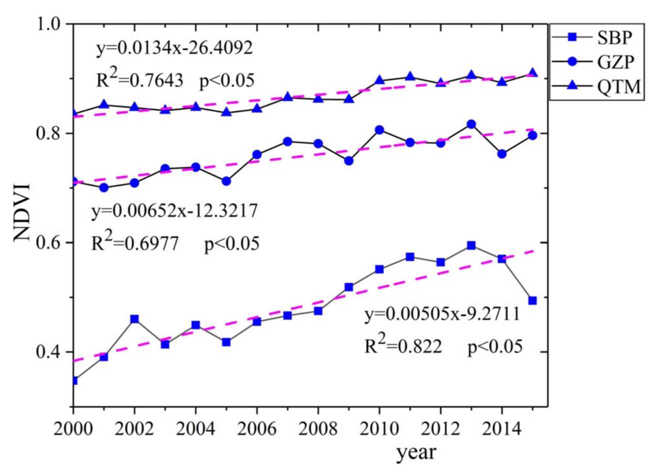

Fig. 3 The average vegetation coverage in three regions from 2000 to 2015

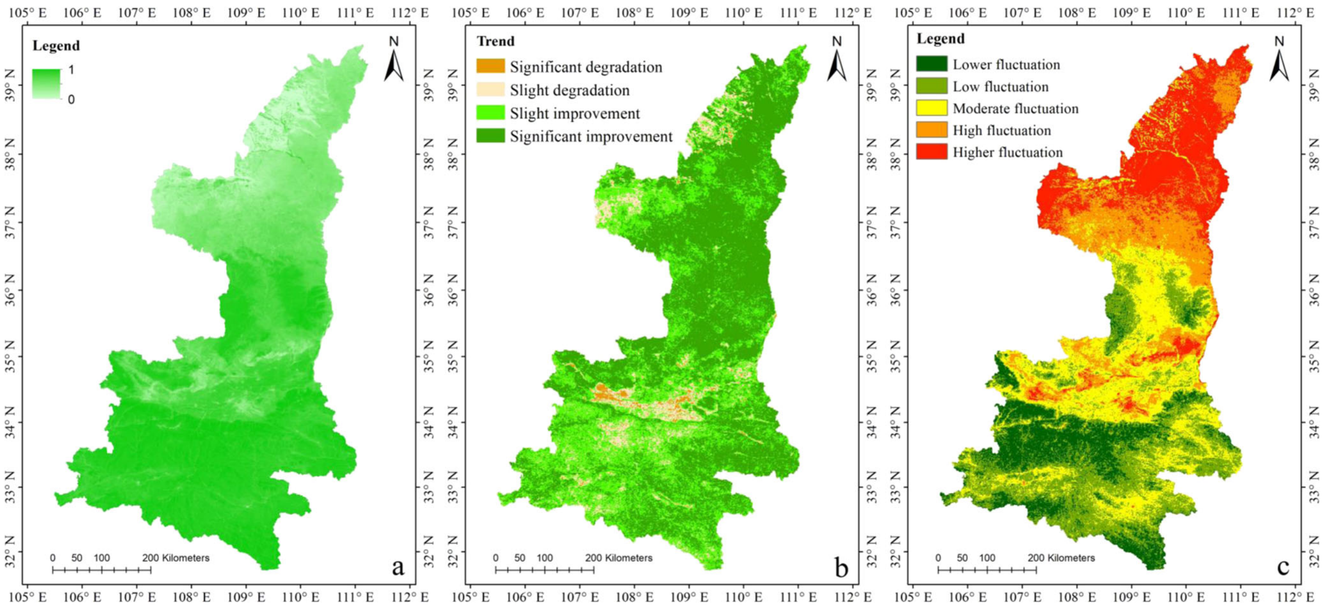

Fig. 4 Vegetation coverage in Shaanxi from 2000 to 2015. **a** The annual average NDVI. **b** The vegetation coverage trend. **c** The fluctuation of vegetation coverage

Fluctuation of vegetation coverage in Shaanxi

The fluctuation of vegetation coverage in the north is higher than that in the south, and the rank from 2000 to 2015 is as follows: SBP region > GZP region > QTM region from (Fig. 4c). In particular, vulnerable ecotones exhibit dramatic fluctuations, and rapidly developing areas exhibit high fluctuations. In the QTM region, the vegetation coverage had a low fluctuation.

Vegetation coverage change in various land use types

Vegetation coverage for unchanged land use types

From 2000 to 2015, most of the area still retained the original land use type (Fig. 5). In addition to construction land, the other ten land use types showed a significant increasing trend. In paddy fields, the vegetation coverage of most areas displayed an increasing trend in Shaanxi (Fig. 6a). The decreasing vegetation coverage is mostly found in the area around cities. However, in the other places, the vegetation coverage shows an increasing trend. The increasing trends found in most of the area in Shaanxi and the areas with decreasing trend were typically found around rapidly developing regions (Fig. 6b). In the forest, vegetation coverage with degradation is mainly distributed in the southern QTM region,

Table 1 The area and proportion for different trends in Shaanxi Province of China

Trend	Pixel number	Area (km^2)	Proportion (%)
Significant degradation	6621	1655.25	1.14
Slight degradation	49831	12457.75	8.57
Slight improvement	204280	51070	35.15
Significant improvement	320437	80109.25	55.14

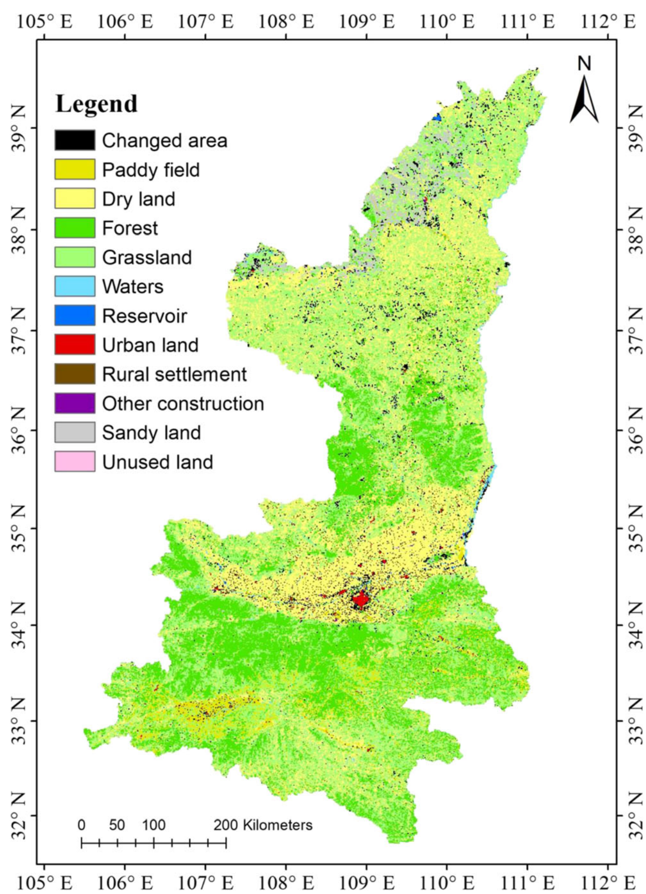

Fig. 5 The changed and unchanged land use types in Shaanxi from 2000 to 2015

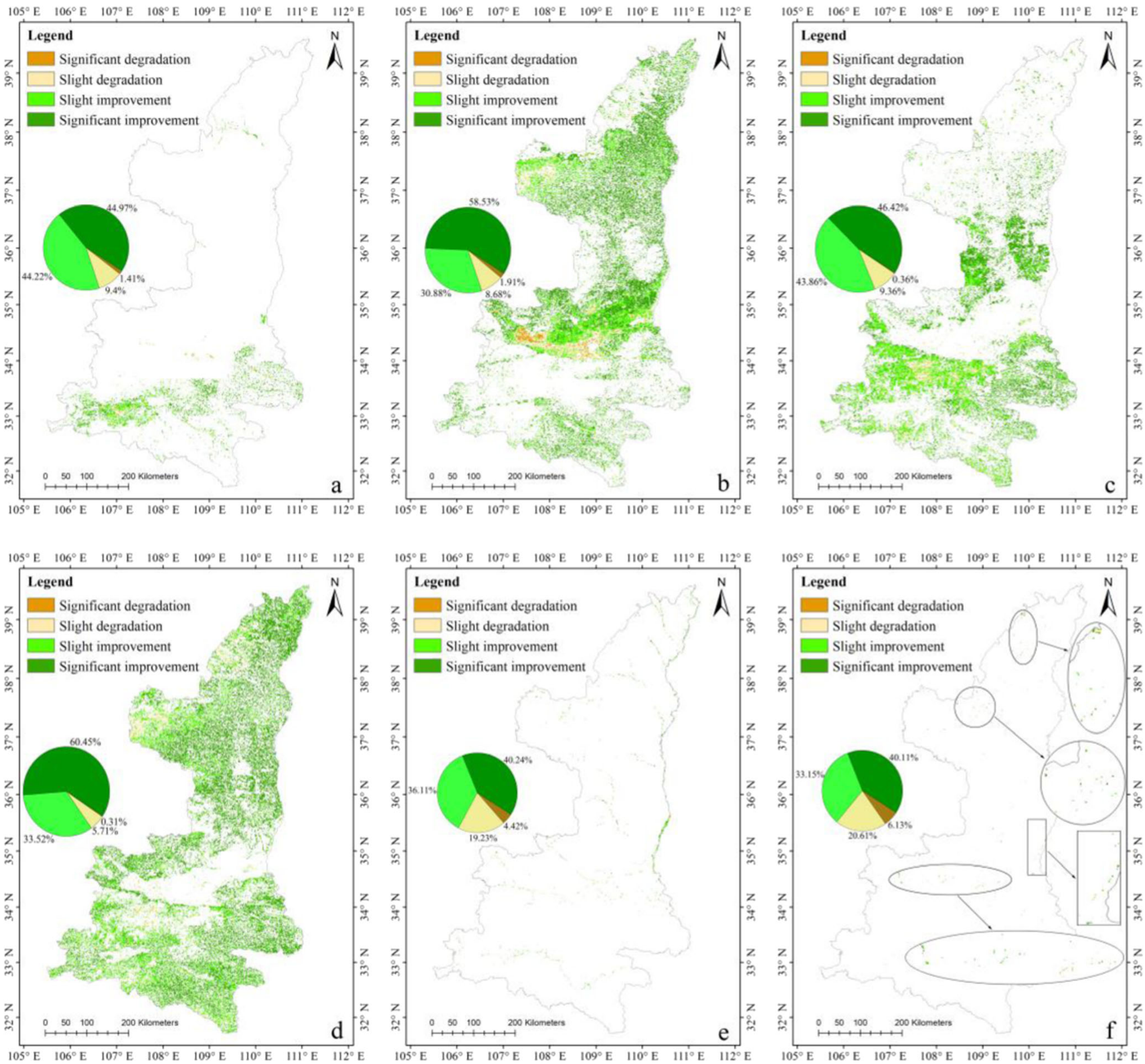

Fig. 6 The change in vegetation coverage in paddy field (**a**), cropland (**b**), forest (**c**), grassland (**d**), waters (**e**), and reservoir (**f**)

and most of the area displays the improvements in vegetation coverage in Shaanxi (Fig. 6c). In grasslands, 93.97% of Shaanxi showed improvement (Fig. 6d), and the area of degradation was mainly distributed in the northern part of the SBP region and in part of the QTM region. In waters and reservoirs (Fig. 6e, f), the vegetation coverage mainly shows signs of improvement and only part of the area presents signs of degradation. Meanwhile, in urban land, rural settlement, and other construction (Fig. 7a–c), the area with an increasing trend is larger than the area with a decreasing trend. For sandy land, more than half of the area is significantly improved and only 1.94% of the area is significantly degraded in the northern SBP region (Fig. 8a). In unused land (Fig. 8b), most of the area shows an increasing trend.

Vegetation coverage for changed land use types

The land use types that underwent transitions from 2000 to 2015 with different areas are shown in Table 2. The area of unchanged land use type accounts for a large proportion and the area of changed land use type accounts for a small proportion. Table 3 reveals that the average vegetation coverage varies under different land use types. Every land use type that was transferred into dry land showed a significant improvement, except for paddy fields which showed only slight improvements. All land use types that were transferred into forest and grassland revealed significant improvements. Expect for grassland, other land use types that were transferred into urban land revealed degradation. For urban land, all land use

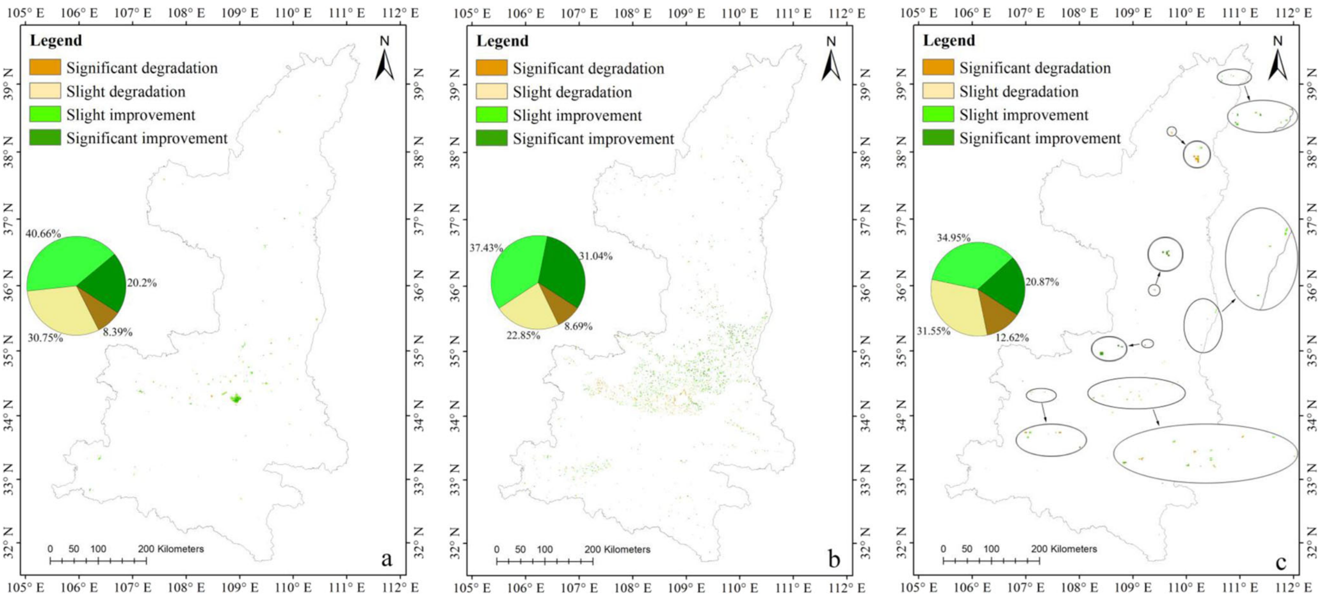

Fig. 7 The change in vegetation coverage in urban land (**a**), rural settlement (**b**), and other construction (**c**)

types showed degradation. Specifically, dry land and forest transferred into rural settlement revealed significant improvements. All land use types transferred into unused land showed improvements.

Influencing factors of vegetation coverage change

Meteorological factors

The vegetation coverage is influenced by temperature and precipitation (Bao et al. 2007). In general, the vegetation coverage is more significantly positively correlated with precipitation than with temperature (Fig. 9), at 9.65% (13990.25 km^2) and 1.34% (1956.5 km^2), respectively (Table 4). For the temperature factor, the area with a negative correlation which was mainly located in the SBP region, accounted for 53.26% (77221 km^2), and the area with a positive correlation accounted for 46.74% (67765.25 km^2). The significantly negative correlation was mainly distributed in west of Yulin city, west of Xianyang city, the junction of Baoji city, Xi'an city, and west of Hanzhong city.

For precipitation factors, the SBP region showed a positive correlation with vegetation coverage. This result may be

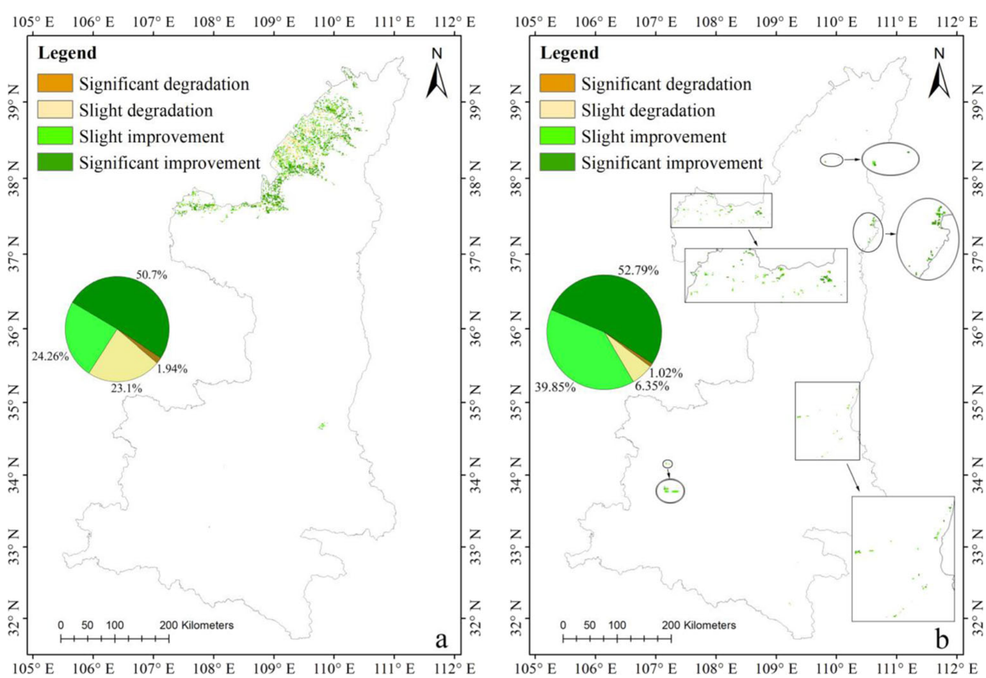

Fig. 8 The change in vegetation coverage change in sandy land (**a**) and unused land (**b**)

Table 2 Land use transfer matrix in Shaanxi Province from 2000 to 2015 (unit km^2)

Land use type	Paddy field	Dry land	Forest	Grassland	Waters	Reservoir	Urban land	Rural settlement	Other construction	Sandy land	Unused land	Total area (2000)
Paddy field	8205	9	9	12	6	8	16	52	22	0	2	8341
Dry land	5	60972	758	761	129	32	249	298	288	1	33	63526
Forest	2	48	46332	54	4	3	22	8	17	9	30	46529
Grassland	3	252	580	76300	22	19	9	14	259	34	62	77554
Waters	5	75	6	23	1443	21	0	3	6	0	1	1583
Reservoir	0	5	2	5	19	251	2	0	0	0	0	284
Urban land	0	0	0	0	0	0	540	0	0	0	0	540
Rural settlement	0	2	0	2	0	0	40	2335	1	0	0	2380
Other construction	0	0	0	1	0	0	1	0	141	0	0	143
Sandy land	1	106	9	126	1	3	0	0	83	4222	13	4564
Unused land	0	9	1	2	1	4	0	0	6	0	259	282
Total area (2015)	8221	61478	47697	77286	1625	341	879	2710	823	4266	400	205726

explained by the SBP region belonging to the area of water and soil erosion and the arid region. Vegetation growth requires water, soil, organic matter, and light. Higher temperatures accelerate the evaporation of water and more rainfall promotes the growth of vegetation. Thus, temperature has a negative effect on vegetation coverage. The area with a significantly negative correlation was mainly located in Ankang city, east of Hanzhong city, east of Baoji city, south of Xianyang city, north of Xi'an city, and southeast of Shangluo city.

Topographical factors influencing vegetation coverage

The vegetation coverage of different gradients was as follows: less than 2° < 2–6° < 6–15° < 15–25° < more than 25° (Fig. 10a, Table 5, and Fig. 11). The 6–15° area had the fastest increase in vegetation coverage, and Table 5 reveals that the area with 6–15° had the greatest increased proportion of vegetation coverage. Nevertheless, the region with more than 25° showed the slowest increase compared with that of the other gradients.

The vegetation coverage of different elevations revealed the following: 1000–1500 m < 1500–2000 m < 500–1000 m < less than 500 m < greater than 2000 m (Fig. 10b, Table 6, and Fig. 12). The area with 1000–1500 m showed the fastest increase in vegetation coverage and the area greater than 2000 m showed the slowest increase in vegetation coverage. Meanwhile, the area with 1000–1500 m has the greatest increased proportion of vegetation coverage.

Table 3 The vegetation coverage change in changed land use types

Land use type and transfer	Paddy field	Dry land	Forest	Grassland	Waters	Reservoir	Urban land	Rural settlement	Other construction	Sandy land	Unused land
Paddy field	None	SLI	SII	SII	SLI	SLD	SID	SLD	SLD	None	SII
Dry land	SLI	None	SII	SII	SLD	SLI	SID	SII	SLD	SLD	SLI
Forest	SII	SII	None	SII	SLI	SLI	SLD	SII	SLD	SLI	SII
Grassland	SLD	SII	SII	None	SII	SII	SII	SLI	SII	SII	SLI
Waters	SII	SII	SII	SII	None	SID	None	SLI	SLI	None	SII
Reservoir	None	SII	SII	SII	SII	None	SLD	None	None	None	None
Urban land	None	None	None	None	None	None	None	SLI	None	None	None
Rural settlement	None	SII	None	SII	None	None	SID	None	SLI	None	None
Other construction	None	None	None	SII	None	None	SID	None	None	None	None
Sandy land	SLI	SII	SII	SII	SLI	SLI	None	None	SII	None	SII
Unused land	None	SII	SII	SII	SLI	SII	None	None	SII	None	None

None, unchanged area or no transfer; *SII*, significant improvement; *SLI*, slight improvement; *SLD*, slight degradation; *SID*, significant degradation

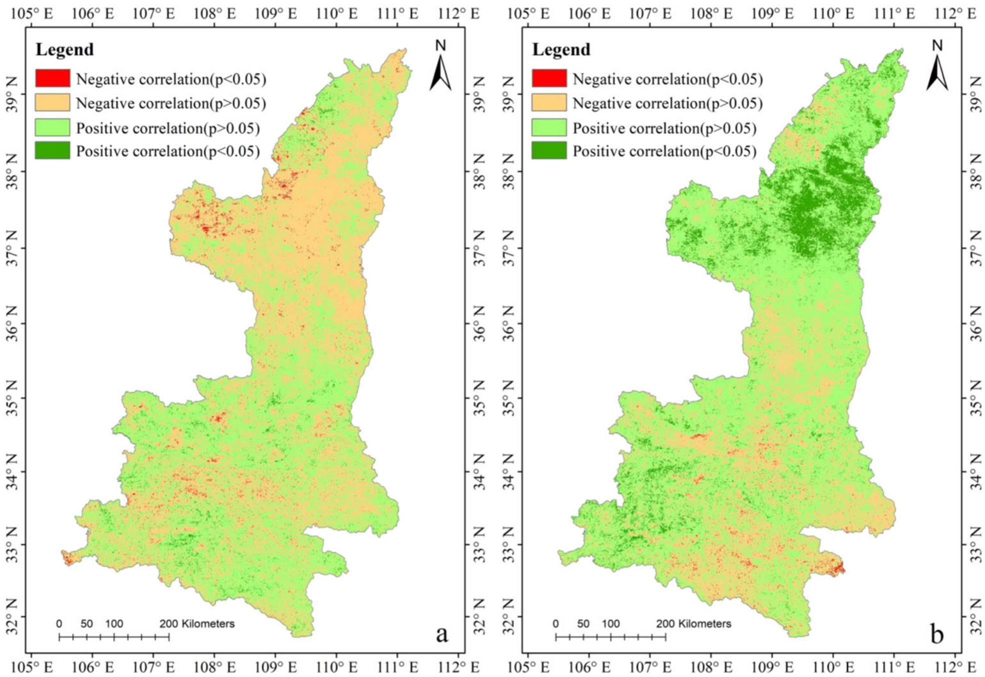

Fig. 9 The correlation between vegetation coverage and temperature (**a**) and precipitation (**b**)

Human activities factor influencing vegetation coverage

Anthropogenic activities play an important role in Shaanxi, and influence land use type and vegetation growth. The study used multiple linear regression to fit vegetation coverage and climate factors (e.g., temperature and precipitation) at the pixel scale. Then, the predicted vegetation coverage value was subtracted from the true value to fit its trend. Furthermore, the trend was divided into four classifications: significant decrease, insignificant decrease, insignificant increase, and significant increase. The influence of human activities is indicated in Fig. 13.

Residual trends of vegetation coverage with significant decrease were mainly located in Hu County, Chang'an District, Weiyang District, and Gaoling County of Xi'an city; Wugong County, Xingping County, Qindu District, and Weicheng District of Xianyang city; Chencang District, Fengxiang County, Long County, and Fufeng County of Baoji city; Yuyang District, Dingbian County, and Jingbian County of Yulin city; and Liuba County, Mian County, Hantai District, Nanzheng County, Chenggu County, Yang County, and Lueyang County of Hanzhong city. The result shows the overall area is not only influenced by climate factors but also affected by anthropogenic activities.

Residual trends with significant increases were found in Yan'an city, eastern Yulin city, northwestern Baoji city, northern Xianyang city, eastern Tongchuan city, northern Weinan city, and southeastern Shangluo city. Anthropogenic activities had positive impacts on vegetation coverage changes in the area from 2000 to 2015. The SBP region is an ecologically fragile zone in the Loess Plateau and the government takes measures to protect it. Meanwhile, the result showed that the cultivated area was positively affected. Grain is one of the most important essentials for human survival and the crop requires many resources, including water, chemical fertilizer, and manpower. Thus, anthropogenic activities result in the area showing a positive trend.

The correlation between average vegetation coverage and cumulative afforestation is shown in Fig. 14. The afforestation affected average vegetation coverage positively ($R^2 = 0.919$, $p < 0.01$) in Shaanxi Province.

Prediction trend of vegetation coverage

The trend of future vegetation coverage is shown in Fig. 15. Shaanxi is divided into five classifications: (1) consistent decreasing trend (Hurst > 0.5 and significant degradation), (2) potential

Table 4 The area and proportion for correlation between vegetation coverage and meteorological factors

Type	Temperature		Precipitation	
	Area	Proportion (%)	Area	Proportion (%)
Positive correlation ($p > 0.05$)	65808.75	45.39	90290.25	62.28
Negative correlation ($p > 0.05$)	75602	52.14	39906.75	27.52
Negative correlation ($p < 0.05$)	1619	1.12	799	0.55
Positive correlation ($p < 0.05$)	1956.5	1.35	13990.25	9.65

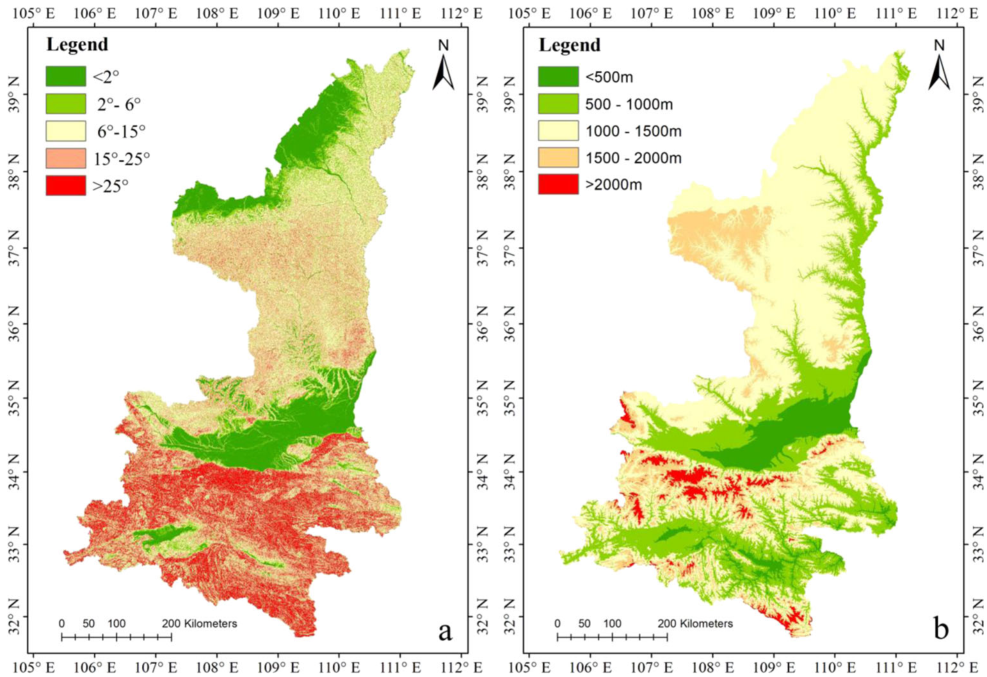

Fig. 10 Elevation (**a**) and gradient (**b**) distribution

increasing trend (Hurst < 0.5 and significant degradation), (3) non-significant change (slight improvement or degradation), (4) potential decreasing trend (Hurst < 0.5 and significant improvement), (5) consistent increasing trend (Hurst > 0.5 and significant improvement). A potential increasing trend was primarily located in urban developing areas (Fig. 14). The result showed that the potential decreasing trend occupied the area of the high gradients and the consistent increasing trend was located in the SBP region and part of the QTM region.

Discussion

General vegetation coverage variation

Although urbanization encroaches on some cropland, forest, and grassland, which leads to poor vegetation coverage, the vegetation coverage of Shaanxi and its region generally showed a significant increase from 2000 to 2015. Because of land use management, vegetation coverage is increasing in China (Chen et al. 2019). Shaanxi is a province of China, and it shows an increasing trend. High fluctuations were observed in northern Shaanxi, especially in the SBP region, which showed a significantly positive correlation with precipitation and revealed that the SBP region is vulnerable. This vulnerability may be attributed to soil erosion, which affects the growth of vegetation, and the government vigorously promotes afforestation (Pelak et al. 2016). Natural negative effects (e.g., water shortages) and human disturbance interacted continuously from 2000 to 2015 (Zheng et al. 2019). Thus, the SBP region shows high fluctuations.

Vegetation coverage variation in various land use types

In unchanged land use types, only other construction showed slight improvements and other land use types revealed significant improvement. For dry land, although most of the area

Table 5 The vegetation coverage change trend at different gradients

Trend	< 2°		2–6°		6–15°		15–25°		> 25°	
	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)
Significant degradation	1325.75	5.75	163.75	0.96	61.5	0.14	48.5	0.12	53.5	0.25
Slight degradation	5310.5	23.03	1337.25	7.82	1824.5	4.14	2008.75	5.03	1960	9.29
Slight improvement	8568	37.15	5360.5	31.36	12748	28.94	14227.5	35.59	10159.75	48.18
Significant improvement	7858.75	34.08	10232.25	59.86	29409.5	66.77	23689.5	59.26	8914.75	42.27

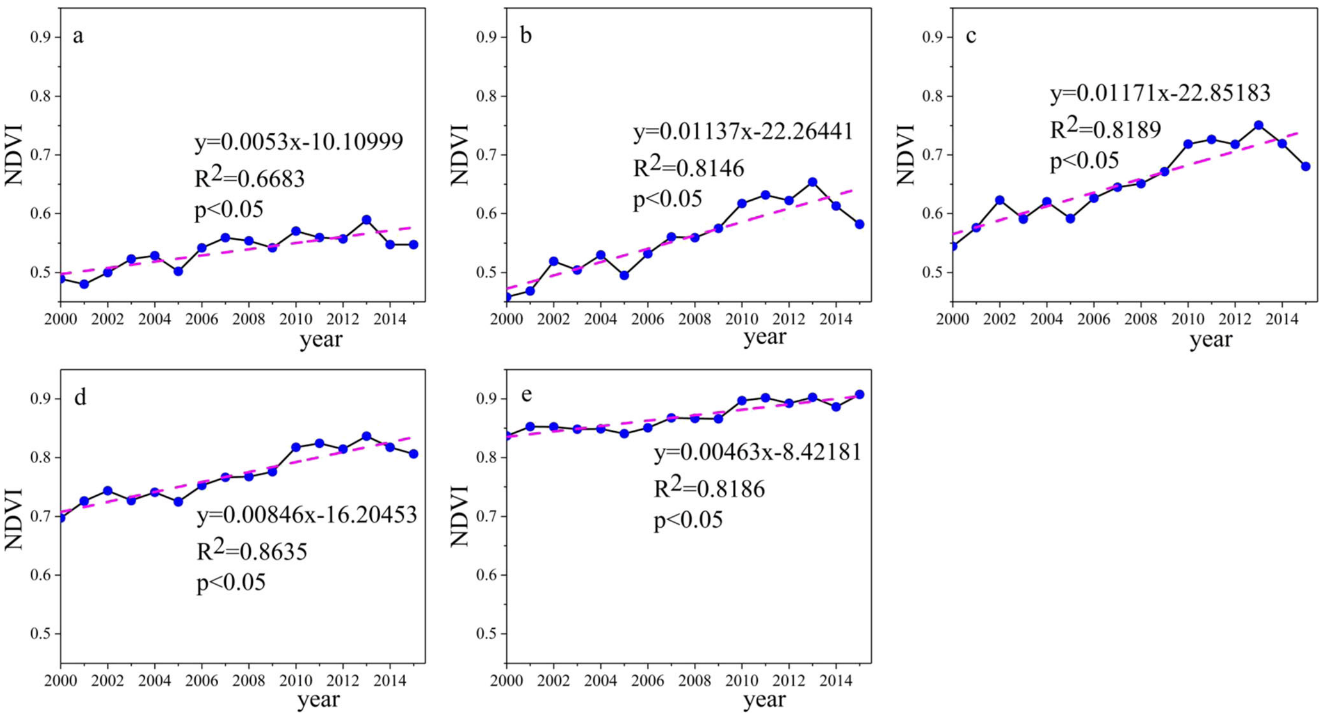

Fig. 11 The variation in vegetation coverage at different gradients. **a** Less than 2°. **b** 2–6°. **c** 6–15°. **d** 15–25°. **e** Greater than 25°

presented improvements, the part of the area located in the region with less than 2° and around the rapid urban development zone showed slight degradation and even significant improvements. Residual analysis showed the area is mainly affected by anthropogenic activities. This result may be attributed to the behavior of leaving land idle in the area (Liang et al. 2002). Meanwhile, the intensification of cropland is being improved because of increasing capital and labor inputs (Wang et al. 2015). Grain is the most important factor to ensure food security, and it requires a great deal of fertilizer, irrigation, land, and mechanized equipment (Sun et al. 2015). Thus, there have been improvements in the vegetation coverage of dry land.

The area of forest revealed improvements and a very small portion showed degradation. The area with degradation was found in areas greater than 25° and higher than 2000 m, because soil erosion is closely correlated with gradient (Ban et al. 2017). Based on ecological protection policy, the government adopts a series of measures to prevent the soil erosion(Zhao et al. 2019). Thus, most of the area has shown improvements. Meanwhile, grassland is the main land use type in the region, and grassland which has shown improvement is influenced by soil erosion (Gao et al. 2018). The area of grassland with degradation is consistent with that of forest in terms of space.

For urban land, 60.84% of the area shows improvements. This result is attributed to urban greening policy which has continuously advanced in recent years (Ren et al. 2018). Meanwhile, 68.47% of rural settlements have presented improvements and 31.53% have revealed degradation. Because of hollow villages, the vegetation coverage in part of a rural settlement decreases gradually. The old rural settlement is the part that still remains (Li and Wu 2017). Additionally, crops in the yards of rural settlements that lack human inputs have resulted in decreasing vegetation coverage in recent years.

Table 6 The vegetation coverage change trend at different elevations

Trend	< 500 m		500–1000 m		1000–1500 m		1500–2000 m		> 2000 m	
	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)
Significant degradation	625	5.93	691.25	1.79	228.75	0.31	39.25	0.21	68.75	1.95
Slight degradation	2568.5	24.35	2166.25	5.62	3523.75	4.77	3010	16.12	1172.5	33.18
Slight improvement	4444.5	42.14	12380.5	32.11	21401.75	28.94	10769.5	57.67	2067.5	58.51
Significant improvement	2909.25	27.58	23322.75	60.48	48788.75	65.98	4854.25	26.00	224.75	6.36

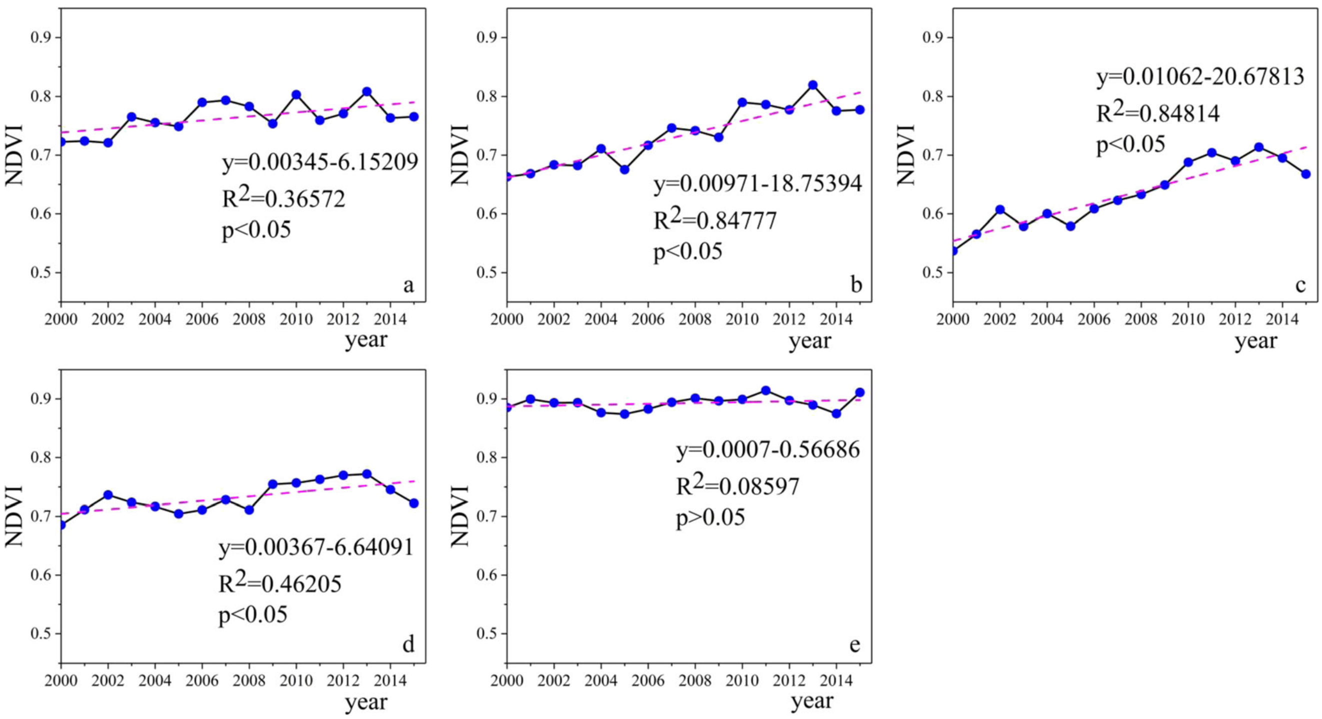

Fig. 12 The variation in vegetation coverage at different elevations. **a** < 500 m. **b** 500–1000 m. **c** 1000–1500 m. **d** 1500–2000 m. **e** > 2000 m

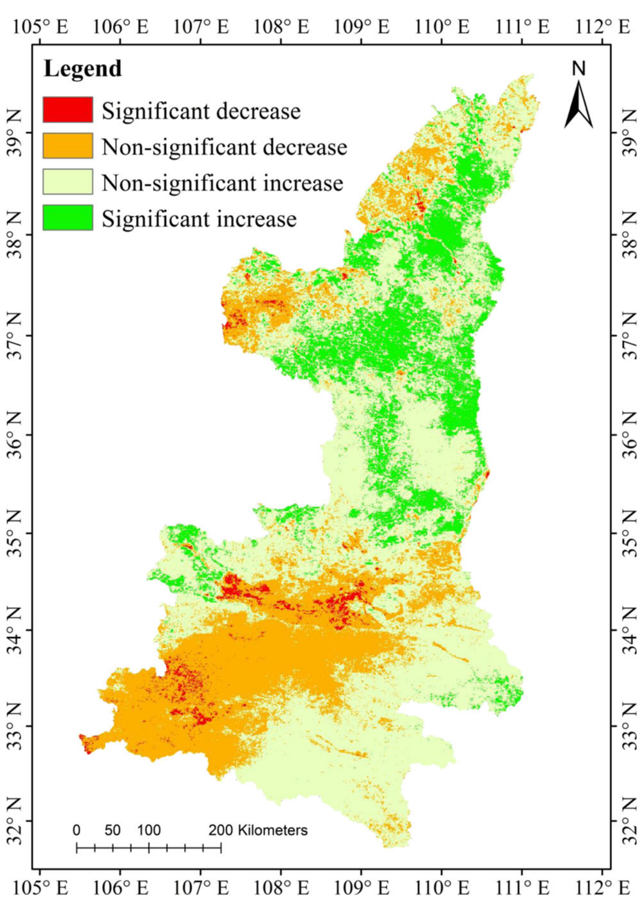

Fig. 13 The influence of human activities on vegetation coverage variation

In changed land use types, all land types converted to grassland showed a trend of significant improvement. With the government continuing to increase the intensity of ecological protection, many land types have been remodeled into the most suitable category. Thus, vegetation coverage has increased significantly from 2000 to 2015. Specifically, as the treatment of sandy land becomes grassland, vegetation coverage increases gradually.

Most of the land use types transferred into urban land show degradation and are mainly located in the areas that are less than 2°. This result is attributed to the development of urban land, which encroaches on the areas with higher vegetation coverage, and the locations of urban are chosen mainly in

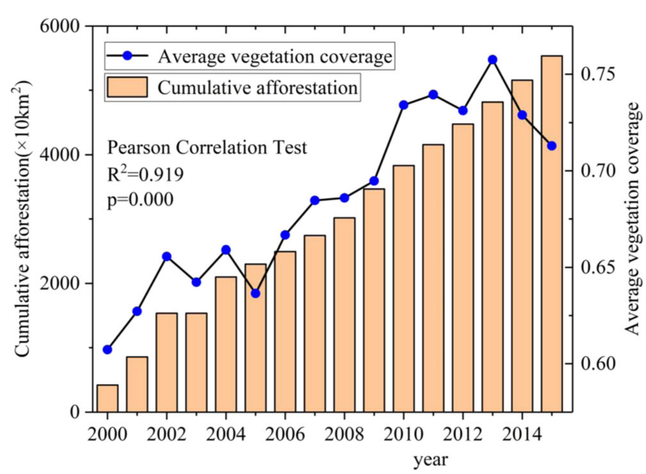

Fig. 14 The correlation between cumulative afforestation and average vegetation coverage

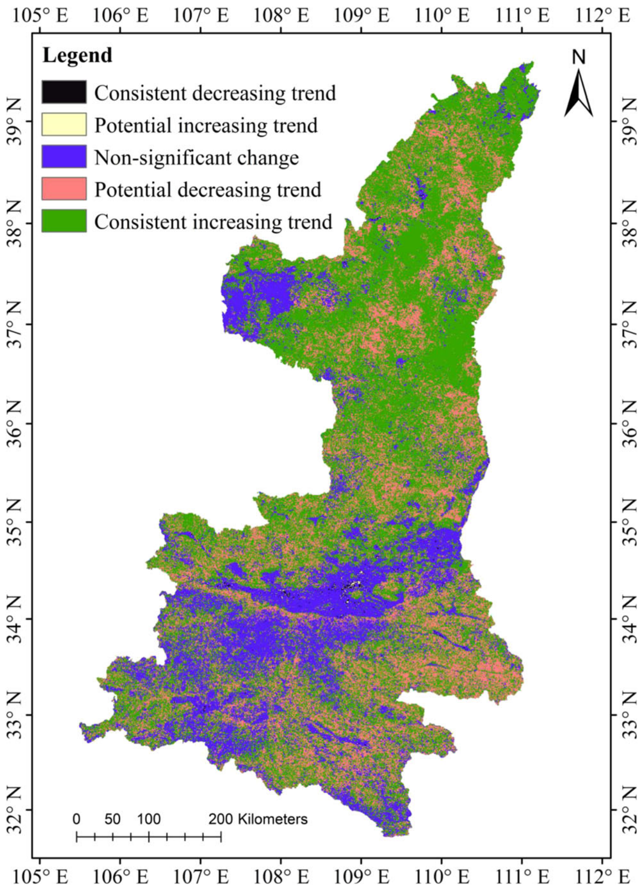

Fig. 15 The future variation in vegetation coverage in Shaanxi

areas with gentle inclines and low elevation, which makes it easier for construction and dwelling of buildings and communities (Liu et al. 2009b). With the continuous forwarding policy of the Grain for Green Project, the part of the area with 6–15° is not suitable for cultivating crops or for converting into forest and grassland (Liu et al. 2019). Thus, the results show that vegetation coverage is significantly improved because of land use type conversion.

Although the land was in a state of ruin before the land was converted to unused land, the vegetation coverage has been increasing due to the lack of human disturbance.

Factors of vegetation coverage variation

The area with a low gradient in southern Shaanxi shows a negative correlation with precipitation and a positive correlation with temperature. First, the area with a lower gradient is more frequently influenced by human activities that affect vegetation growth (Huang et al. 2019). Second, compared with the Shaanxi region as a whole, the area is more likely to experience floods and waterlogging. Illumination accelerates the evaporation of surface water which has positive effects and precipitation has an inhibitory effect (Liu et al. 2012). Thus, precipitation and temperature have different effects on vegetation coverage, respectively.

Anthropogenic activities including afforestation and intensive crop planting affect the growth conditions of vegetation and change the vegetation coverage trend under natural condition (Gao et al. 2018). Thus, anthropogenic activities have a positive effect on the area. The SBP region shows that anthropogenic activities have had a positive impact from 2000 to 2015. The Ecological Construction Project was implemented to restrain and diminish the soil erosion area (Gao et al. 2017). The government has invested a lot of money in afforestation. The result shows that afforestation has a significant positive impact on vegetation coverage. The ecological policy plays an important role in the ecological environment. Meanwhile, unnatural disturbances have a negative effect on the survival of mankind. The area that is influenced by anthropogenic activities is mainly found in the rapidly developing region. It is essential for the GZP region with 0–2° to develop urban construction and promote economic growth (Huang et al. 2019).

As the slope increases, the area gradually becomes unsuitable for the production of humans, and the vegetation coverage gradually increases (Hu and Xia 2019). Nevertheless, in terms of the rates of increase, 1000–1500 m and 6–15° are the most suitable areas for vegetation growth. The vegetation coverage in areas greater than 15° is less than that in areas with 6–15° because the 6–15° region's own vegetation coverage leads to a lower rate of increase (Liu and Fu 2013). Additionally, areas that are less than 6° are more affected by negative human activities.

Prediction of future vegetation coverage change

The results of potential increasing trend may be explained by rapid urban development that encroaches on cropland and ecological land, but the government and policy makers have increasingly focused on urban landscapes which play a great role in the construction of ecological cities and sponge cities (Li et al. 2019). The SBP region is influenced by anthropogenic activities and it needs to be maintained consistently. Although most of the SBP region shows a consistent increasing trend, vegetation coverage in the part of the areas with a high gradient has the risk of degradation (Liu et al. 2009a).

Therefore, the trend of vegetation coverage shows diversity in the local and regional scales, and precipitation, temperature, gradient, and elevation act together to affect the changes in spatial and temporal vegetation coverage changes (Peng et al. 2017). Different land types and their land use types have different changes in vegetation coverage. Previous research has only focused on overall vegetation coverage variation and the impact of precipitation and temperature factors. This study summarizes vegetation coverage variation in different land use types and identifies correlations with topographic factors and meteorological factors. The gradient and elevation both influence land use policy and anthropogenic activities. The study will provide a useful reference for ecological protection and land use plans.

Conclusions

This study analyzed the spatiotemporal variation of vegetation coverage based on different land use types and their conversion patterns. Meanwhile, the study investigates the meteorological and topographical factors that affect vegetation coverage. Shaanxi and its SBP region, GZP region, and QTM region all showed significant increases. Because of human activities and natural disturbance, vegetation coverage in the north is more unstable than that in the south. In unchanged land use types, all types showed significant improvements expect for other construction. In changed land use types, most of the conversions into urban land showed degradation. Conversions into dry land, forest, and unused land showed improvements. Ecological protection efforts have achieved great results. The area affected by precipitation in Shaanxi is larger than that affected by temperature, and the northern Shaanxi area is significantly affected by precipitation. Gradients and elevation affect the distribution of vegetation coverage and human activities which influence land use types and the ecological environment. In the future, potential degradation risks still exist in the parts of Shaanxi.

Funding information This research was financially supported by the National Key Research and Development Program of China (2017YFF0206804) and the Fundamental Research Funds for the Central Universities of China (2652018045).

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