

Vegetation reening in Response to Ecological Restoration Programs in Shaanxi Province, China

Xinyu Dang*

Xi 'an International Studies University, Xi'an 710128, China

Abstract: Vegetation constitutes the structural backbone of terrestrial ecosystems, regulating carbon exchange, water cycling, and energy flux at regional scales. The Normalized Difference Vegetation Index (NDVI), derived from satellite remote sensing, provides a robust proxy for vegetation vitality and has been extensively adopted in long-term ecological monitoring. This study examines the spatio-temporal dynamics of vegetation coverage across Shaanxi Province, northwestern China, over the period 2000–2019, using MODIS MOD13C1 NDVI data. Growing-season (May–October) composites were generated via the Maximum Value Compositing (MVC) method, and pixel-wise temporal trends were quantified through ordinary least-squares regression. Results indicate: (1) spatially, vegetation coverage follows a pronounced south-to-north declining gradient, with high-coverage zones (NDVI > 0.6) concentrated along the southern Qinling foothills and northern Daba Mountains, representing approximately 32.85% of the provincial area; (2) temporally, provincial mean NDVI increased from 0.4488 in 2000 to 0.5405 in 2019, an overall gain of ~20.4%; (3) 98.07% of pixels exhibited positive trends, concentrated in central-southern Shaanbei where afforestation programs were intensively implemented, while declining trends (~1.93%) were confined to the Guanzhong urban agglomeration, attributable to cropland conversion and urban expansion. These findings offer a quantitative baseline for regional ecological assessment and policy evaluation in Shaanxi Province.

Keywords: NDVI; Vegetation Coverage; Spatio-temporal Dynamics; Shaanxi Province; MODIS; Trend Analysis.

1. Introduction

Vegetation regulates terrestrial biogeochemical cycles, underpins food-web structure, and modulates surface energy balance through albedo and evapotranspiration feedbacks [1]. Its sensitivity to both climatic forcing and anthropogenic disturbance makes it a widely adopted indicator of ecosystem condition and trajectory [2,3]. Understanding how vegetation cover has shifted over recent decades is therefore critical for diagnosing the ecological consequences of concurrent climate change and land-use transformation.

The Normalized Difference Vegetation Index remains the most widely used satellite-derived vegetation metric, capturing canopy greenness, leaf area, and photosynthetic capacity across spatial scales [4,5]. MODIS products, combining daily global coverage with well-characterized radiometric calibration, have become a standard platform for multi-decadal NDVI analyses. Despite a growing literature on vegetation dynamics in northern China, studies addressing Shaanxi Province—a transitional region spanning temperate steppe, warm-temperate loess terrain, and subtropical montane forest—remain comparatively limited in temporal scope and analytical rigor [10].

This study fills part of that gap by analysing 20 years (2000–2019) of MOD13C1 NDVI data for Shaanxi Province. Specific objectives are: (i) to characterise the spatial pattern of mean growing-season NDVI; (ii) to quantify interannual trends at provincial and pixel scales; and (iii) to discuss the dominant drivers of observed change, with reference to China's large-scale afforestation and ecological restoration programmes.

2. Study Area

Shaanxi Province (105°29'–111°15'E, 31°42'–39°35'N) occupies the central interior of China, straddling the middle

reach of the Yellow River basin. With a total area of 205,600 km², the province is administratively divided into ten prefecture-level cities. Terrain rises toward both the north and south, flanking the Guanzhong Plain: The Loess Plateau characterises the north, while the Qinba Mountains define the southern margin [6].

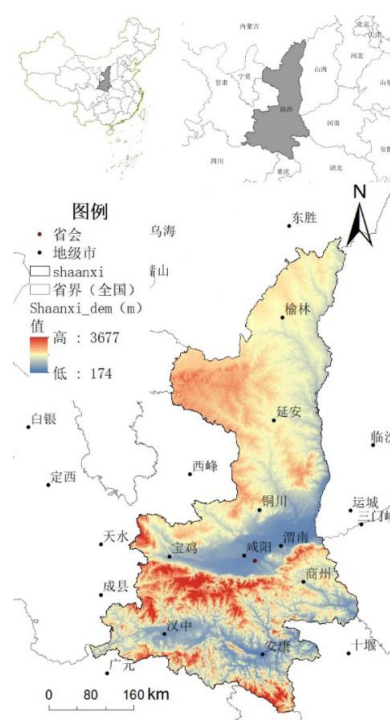


Fig. 1 Location of Shaanxi Province and its three sub-regions: Shaanbei (Loess Plateau), Guanzhong Plain, and Qinba Mountains (Qinling–Daba Mountain area). The black outline delineates the provincial administrative boundary.

Climate shifts systematically from temperate semi-arid conditions in the north (mean annual precipitation ~400 mm)

to north-subtropical humid conditions in the south (~1,200 mm), creating one of China's most pronounced intra-provincial ecological gradients. Northern soils, heavily disturbed by wind and water erosion at the Mu Us Desert margin, are particularly susceptible to vegetation degradation [7].

3. Data Sources and Methods

3.1. Data Sources

NDVI data were sourced from the MODIS MOD13C1 Version 6 product (NASA EOSDIS, <https://ladsweb.modaps.eosdis.nasa.gov/>), which provides 16-day composite NDVI at 0.05° (~5.6 km) spatial resolution. The full 2000–2019 archive was downloaded and processed in MATLAB. Quality-flagged pixels were masked using the embedded quality-assurance (QA) layer prior to compositing. Growing-season monthly maxima (May–October) were assembled via the Maximum Value Compositing method (see Section 3.2.1). Provincial administrative boundaries were obtained from the Resource and Environment Science and Data Center, Chinese Academy of Sciences (<https://www.resdc.cn/>).

3.2. Methods

3.2.1. Maximum Value Compositing (MVC)

To suppress residual cloud contamination and atmospheric noise, monthly NDVI composites were generated by retaining the highest valid 16-day value within each calendar month:

$$NDVI_{ij} = \max(NDVI_{iab}) \quad (1)$$

where $NDVI_{ij}$ is the maximum composite value for pixel i in month j ; $NDVI_{iab}$ is the 16-day value for period b of month a in year i . Annual growing-season means were then computed as:

$$NDVI_i = (1/n) \times \sum_{(j=5 \rightarrow 10)} NDVI_{ij} \quad (2)$$

where n is the total number of valid pixels and the summation spans growing-season months (May = 5 to October = 10).

3.2.2. Trend Analysis

Pixel-wise temporal trends were estimated by fitting an ordinary least-squares (OLS) regression of annual mean growing-season NDVI against year:

$$\text{slope} = [n \times \sum(i \times NDVI_i) - \sum i \times \sum NDVI_i] / [n \times \sum i^2 - (\sum i)^2] \quad (3)$$

A positive slope indicates vegetation greening; a negative slope indicates browning. Statistical significance was not evaluated in this study due to the relatively short time series ($n = 20$); caution is therefore warranted when interpreting pixel-level trend magnitudes.

4. Results and Analysis

4.1. Spatial Pattern of Mean NDVI

The 20-year mean growing-season NDVI map (Fig. 2) reveals a clear south-to-north negative gradient, consistent with the precipitation and temperature gradients that characterise the province. This gradient broadly reflects the transition from the subtropical humid Qinba Mountain zone in the south through the warm-temperate Guanzhong Plain in the middle to the semi-arid Loess Plateau in the north. Across the province, four distinct vegetation coverage zones can be identified based on NDVI magnitude.

Sparse-vegetation zones ($NDVI < 0.2$) cover only 2.51% of the provincial area and are located predominantly in the wind-eroded grassland and desert-grassland transition belt of

northern Shaanbei, in the vicinity of the Mu Us Desert margin. These areas are characterised by sandy substrates, limited precipitation ($< 350 \text{ mm yr}^{-1}$), and historically intensive land disturbance, all of which constrain vegetation establishment and canopy closure.

Low-to-moderate coverage zones ($NDVI 0.2\text{--}0.4$) account for a further portion of the Loess Plateau, where sparse scrubland, degraded grassland, and dryland agriculture coexist. Moderate coverage zones ($NDVI 0.4\text{--}0.6$) prevail across the Guanzhong Plain, reflecting a spatially heterogeneous mosaic of irrigated winter wheat and maize croplands, peri-urban greenspace, and orchard land along the Wei River valley.

Dense vegetation zones ($NDVI > 0.6$) are concentrated along two physiographic corridors: the southern Qinling foothills (Mian County–Liuba–Taibai South–Foping–Yang County–Ningshan–Zhenan–Xunyang–Baihe) and the northern Daba Mountains (Nanzheng–Zhenba–Ziyang–Langao–Pingli–Zhenping)[10], collectively accounting for approximately 32.85% of the province. These areas receive the highest precipitation in the province ($> 800 \text{ mm yr}^{-1}$), benefit from relatively undisturbed mixed broadleaf-conifer and subtropical evergreen forest cover, and are buffered from agricultural encroachment by steep terrain. The strong physiographic control on vegetation distribution underscores the importance of elevation-mediated moisture availability, soil development, and historical land-use history as co-drivers of the observed spatial pattern.

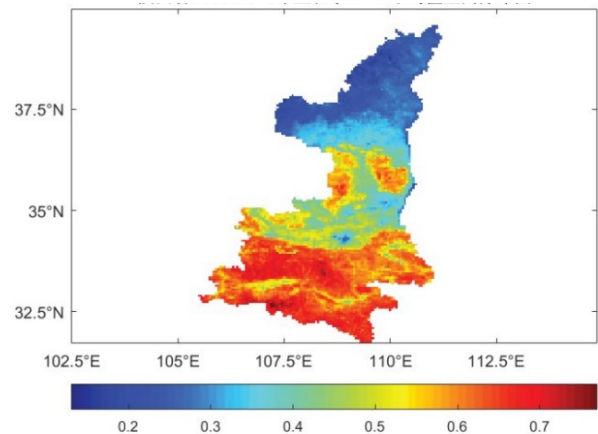


Fig. 2 Spatial distribution of mean growing-season NDVI in Shaanxi Province over 2000–2019. NDVI values are classified into four coverage categories: sparse (< 0.2), low-to-moderate ($0.2\text{--}0.4$), moderate ($0.4\text{--}0.6$), and dense (> 0.6). Black lines indicate prefecture-level city boundaries.

4.2. Temporal Trends in NDVI

Provincial mean growing-season NDVI increased monotonically from 0.4488 in 2000 to 0.5405 in 2019 (Fig. 3), an absolute gain of 0.0917 and a relative increase of approximately 20.4% over the study period. The mean annual rate of increase was approximately 0.0046 yr^{-1} , corresponding to a proportional greening rate of roughly $1.0\% \text{ yr}^{-1}$ relative to the 2000 baseline.

Year-to-year variability was superimposed on the positive long-term trend. The lowest annual mean was recorded in 2001 ($NDVI = 0.4402$), consistent with the dry, anomalously warm conditions widely documented across northwest China in that year, while the highest value occurred in 2019 ($NDVI = 0.5405$). Notable short-term fluctuations—including a moderate dip around 2007–2008 and a steeper recovery from

2012 onward—likely reflect interannual precipitation variability at the regional scale. Despite these fluctuations, the overriding positive trajectory is robust over the full 20-year window.

The upward trend temporally coincides with the phased implementation of China's Grain-for-Green Programme (initiated 1999), the Three-North Shelterbelt expansion (), and targeted desertification control in northern Shaanxi [11]. The Grain-for-Green Programme alone converted millions of hectares of cropland on steep slopes across the Loess Plateau to terraced farmland, grassland, or woodland, providing a direct mechanism for NDVI increase in central-southern Shaanbei. The temporal alignment between policy rollout and the observed NDVI trajectory strongly suggests that policy-driven land-use change, rather than precipitation trends alone, constitutes a primary driver of regional greening.

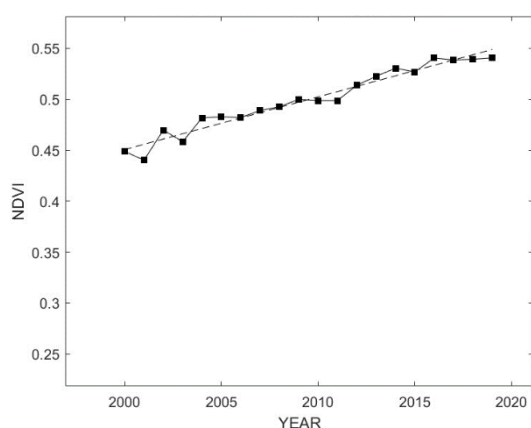


Fig. 3 Interannual variation of mean growing-season NDVI in Shaanxi Province, 2000–2019. The grey dashed line represents the linear trend estimated by ordinary least-squares regression (slope = 0.0046 yr^{-1}). Open circles denote annual mean values.

4.3. Spatial Distribution of NDVI Trends

Pixel-wise OLS trend analysis (Fig. 4) provides a spatially disaggregated view of vegetation change over the study period. A total of 98.07% of pixels across the province displayed positive slopes, indicating widespread and geographically pervasive vegetation greening. The strongest positive trends—with slope values exceeding $0.010 \text{ NDVI units yr}^{-1}$ —are concentrated in central-southern Shaanbei, particularly on the Loess Plateau south of Yanan and in the transition zone between the plateau and the Guanzhong Plain. This spatial pattern closely mirrors the geographic focus of afforestation and revegetation efforts under the Grain-for-Green Programme, where slope-cropland conversion and active tree and grass planting have been most intensively implemented since 1999. Moderate positive trends (0.004 – $0.008 \text{ NDVI yr}^{-1}$) are broadly distributed across the rest of the province, including the Guanzhong Plain and the Qinba Mountain areas, reflecting incremental improvements in vegetation condition under both policy-driven management and generally favourable climatic conditions over the period.

Negative trends affect approximately 1.93% of provincial pixels, with a distinctly clustered spatial distribution. The majority of declining pixels are concentrated in the Guanzhong urban core, particularly within the administrative districts of Xian, Weinan, Fuping, and Huyi. These areas have undergone rapid impervious surface expansion over the study period, as documented in satellite-based urban land-cover products, leading to progressive displacement of both irrigated cropland and remnant patches of natural vegetation

by built-up land. Secondary clusters of declining pixels are also observed in selected peri-urban areas of Hanzhong and Ankang prefectures in southern Shaanxi, where urban growth along valley floors has encroached on fertile agricultural land. Taken together, the spatial pattern of negative trends is strongly consistent with the known trajectory of urbanisation in Shaanxi Province and highlights the competing pressures of ecological restoration and urban expansion on provincial-scale vegetation dynamics.

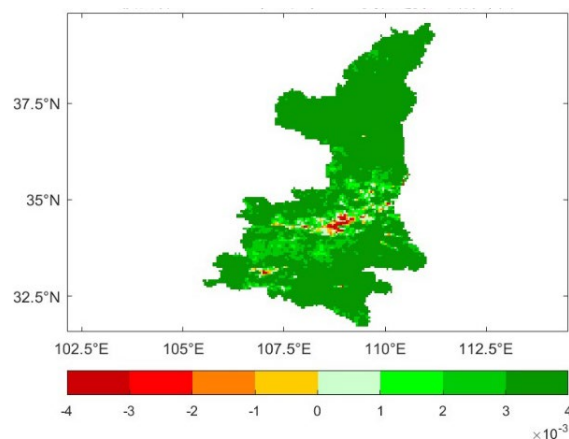


Fig. 4 Spatial distribution of pixel-wise NDVI trend slopes (NDVI units yr^{-1}) in Shaanxi Province over 2000–2019, derived from ordinary least-squares regression. Positive values (green) indicate greening; negative values (red/brown) indicate browning. Black lines indicate prefecture-level city boundaries.

5. Discussion

5.1. Dominant Drivers of Vegetation Greening

The near-ubiquitous increase in growing-season NDVI observed across Shaanxi Province between 2000 and 2019 is consistent with the broader regional greening trend documented across northern China and the Loess Plateau over the same period [2,10]. While multiple drivers—including changes in temperature, precipitation, and atmospheric CO_2 concentration—may contribute to vegetation greening at the global scale, the geographic concentration of the strongest NDVI gains in central-southern Shaanbei strongly implicates policy-driven afforestation as the primary proximate driver in this province.

The Grain-for-Green Programme, launched in 1999 and substantially expanded after 2002, required farmers on slopes steeper than 25° to convert cultivated land to woodland or grassland in exchange for grain and cash subsidies. By the mid-2010s, the programme had restored or afforested several million hectares on the Shaanxi section of the Loess Plateau alone [11]. The temporal and spatial coincidence between the most intensive programme implementation areas and the highest observed NDVI slopes provides strong circumstantial evidence for a policy-vegetation feedback. This interpretation is broadly corroborated by prior studies reporting significant NDVI increases across the Loess Plateau attributable to afforestation under Grain-for-Green [10,11].

Beyond afforestation, the Three-North Shelterbelt Programme has also contributed to greening in northern Shaanbei through the establishment of windbreak forest networks that stabilise sandy soils, reduce wind erosion, and create micro-environments that facilitate natural vegetation colonisation. The complementary role of precipitation must also be acknowledged: several studies have documented a

modest positive precipitation trend over the Loess Plateau during the 2000s, which would have enhanced the effectiveness of planted vegetation by improving soil moisture conditions and reducing mortality of newly established seedlings [2,3].

5.2. Urbanisation-Driven Browning in the Guanzhong Plain

The spatially coherent cluster of negative NDVI trends in the Guanzhong urban agglomeration—centred on Xian and extending into Weinan and adjacent districts—reflects the well-documented process of urban expansion-induced vegetation loss. Xian is one of the fastest-growing cities in inland China, with its built-up area approximately doubling between 2000 and 2015 according to national land-use survey data. The conversion of high-productivity irrigated cropland (which yields high NDVI during the growing season) to impervious surfaces represents the primary pathway through which urbanisation suppresses NDVI in this context.

Notably, the fraction of declining pixels (~1.93%) is small relative to the overall provincial area, suggesting that the ecological restoration gains achieved through afforestation substantially outweigh the vegetation losses attributable to urban expansion at the provincial scale. However, at the local scale, the ecological consequences of cropland conversion may be significant, as it represents the permanent loss of productive agricultural and green-space land in China's densest intra-provincial urban corridor. Future monitoring should therefore distinguish between the NDVI trajectories of natural vegetation, managed forest, and cropland to provide a more nuanced assessment of land-cover quality change.

5.3. Limitations and Uncertainties

Several limitations warrant consideration when interpreting the results of this study. First, the spatial resolution of the MOD13C1 product (0.05°, ~5.6 km) is relatively coarse for detecting fine-scale intra-urban vegetation dynamics or assessing the heterogeneous mosaic of restored and degraded patches within the Loess Plateau transition zone. Mixed-pixel effects may attenuate observed NDVI signals in areas of rapid land-cover change at sub-pixel scales.

Second, the absence of formal statistical significance testing for the pixel-wise OLS trends (see Section 3.2.2) means that some of the reported trend slopes—particularly those in pixels with high year-to-year variability relative to the long-term trend magnitude—may not be statistically distinguishable from zero at conventional confidence levels. Future analyses should incorporate Mann–Kendall significance tests or bootstrap-based confidence intervals to quantify trend uncertainty.

Third, this study does not explicitly disentangle the relative contributions of climate variability and human activities to observed NDVI trends. Partial correlation analysis, residual trend analysis, or attribution modelling approaches—coupling NDVI time series with gridded precipitation, temperature, and land-use change datasets—would allow a more rigorous separation of climatic and anthropogenic drivers. Such attribution analyses represent a clear priority for future work in this region.

Finally, the study period ends in 2019, and substantial ecological restoration activity has continued in Shaanxi Province through the 2020s. Extending the analysis to include more recent years, ideally using higher-resolution imagery

from the Landsat or Sentinel-2 archives, would provide a complete and more current picture of vegetation dynamics in the province.

5.4. Implications for Regional Ecological Policy

The findings of this study carry several implications for ongoing ecological management in Shaanxi Province. The robust and widespread NDVI increase observed over 2000–2019 suggests that the large-scale ecological restoration programmes implemented since the late 1990s have achieved measurable landscape-scale greening outcomes within two decades, lending empirical support to the continuation and consolidation of these initiatives.

However, the co-occurrence of vegetation greening with intensive afforestation raises questions about the hydrological sustainability of large-scale tree planting in a semi-arid environment. Several studies have reported declining streamflow and soil moisture in afforested catchments on the Loess Plateau, attributed to the high-water consumption of densely planted trees relative to the natural grassland and sparse shrubland they replaced. Ensuring that vegetation restoration achieves durable ecological co-benefits—including improved soil carbon sequestration, biodiversity, and water yield—rather than simply maximising NDVI will require more ecologically informed species selection and planting density management in future restoration phases.

In the Guanzhong urban agglomeration, the negative NDVI trends signal an ongoing need to integrate green infrastructure planning into urban development frameworks. Policies that mandate urban green space standards, promote peri-urban forest belt preservation, and incentivise the greening of road corridors and public spaces could partially offset the NDVI loss associated with impervious surface expansion. Coordinating these urban greening efforts with provincial-level ecological restoration targets would contribute to a more spatially balanced and ecologically resilient landscape in Shaanxi Province.

6. Conclusions

(1) Mean growing-season NDVI in Shaanxi Province exhibits a pronounced south-to-north declining gradient. High-coverage zones (NDVI > 0.6) account for ~32.85% of the provincial area, concentrated along the southern Qinling and northern Daba mountain corridors, while low-coverage zones (NDVI < 0.2) occupy only 2.51% of the area in northern Shaanbei.

(2) Provincial mean NDVI increased from 0.4488 to 0.5405 between 2000 and 2019 (~20.4% gain), a trend temporally aligned with large-scale ecological restoration programmes including the Grain-for-Green, Three-North Shelterbelt, and desertification control initiatives.

(3) Positive NDVI trends characterise 98.07% of the province; negative trends (~1.93%) are confined to the Guanzhong urban agglomeration, where rapid impervious surface expansion has converted cropland and natural vegetation.

This study is limited by the coarse spatial resolution of MOD13C1 (0.05°), which constrains the detection of fine-scale intra-urban vegetation change. Future work should integrate higher-resolution imagery (e.g., Landsat or Sentinel-2) and attribution modelling to disentangle climatic and anthropogenic contributions to observed NDVI trends.

Acknowledgements

The authors gratefully acknowledge NASA's EOSDIS for providing MOD13C1 products and the Resource and Environment Science and Data Center, Chinese Academy of Sciences, for the administrative boundary dataset.

References

- [1] Liu W B, Cai T J, Ju C Y, et al. Vegetation change and its response to climate in Heilongjiang Province from 1981 to 2003 [J]. *Scientia Silvae Sinicae*, 2010, 46(06): 154-160.
- [2] Chen J H, Wu K, Hu Z M, et al. Spatio-temporal variability of vegetation sensitivity on the Qinghai-Tibet Plateau during the growing season, 2000-2021 [J]. *Acta Ecologica Sinica*, 2023, 43(10): 4054-4065.
- [3] Jin Y S, Jin K, Wang F, et al. Influence of climate change and human activities on NDVI variation in China's eastern coastal region [J]. *Environmental Science*, 2023, 44(06): 3329-3342.
- [4] Mao D H, Wang Z M, Luo L, et al. NDVI variation and its correlation with temperature and precipitation in Northeast China based on MODIS and AVHRR data [J]. *Remote Sensing Technology and Application*, 2012, 27(01): 77-85.
- [5] Wang Q, Zhang B, Dai S P, et al. Vegetation coverage dynamics in the Three-North Shelterbelt Program area based on GIMMS AVHRR NDVI [J]. *Resources Science*, 2011, 33(08): 1613-1620.
- [6] Zhu B C, Li T S, Zhu X Q, et al. Ecological protection importance assessment based on ecological network optimisation: A case study of Shaanxi Province [J]. *Journal of Agricultural Resources and Environment*, 2023, 40(06): 1480-1493.
- [7] Chen X Y, Li T S, Zhu X Q, et al. Land desertification sensitivity evaluation based on field survey and remote sensing interpretation: A case study of Shaanxi Province [J]. *Arid Land Geography*, 2023, 46(11): 1813-1825.
- [8] Yang S W, Dong B, Sheng S W, et al. Vegetation coverage change and driving factors in Shengjin Lake Nature Reserve [J]. *Journal of Northwest A&F University (Natural Science Edition)*, 2016, 44(08): 177-184.
- [9] Liu Y, Li Y, Cui C X, et al. Assessment of MODIS MOD13Q1 for desertification monitoring in northern Xinjiang [J]. *Acta Prataculturae Sinica*, 2010, 19(03): 14-21.
- [10] Li X, Wang X K, Liu X H, et al. Spatio-temporal variation of vegetation NDVI and climatic drivers in Shaanxi Province, 2000-2020 [J]. *Research of Soil and Water Conservation*, 2024, 31(02): 443-453.
- [11] Cui X L, Zhao J, Bai H Y, et al. Vegetation coverage change in Shaanxi Province based on MODIS NDVI [J]. *Journal of Northwest A&F University (Natural Science Edition)*, 2013, 41(05): 87-93.