Spatio-temporal changes of vegetation coverage in Jingchuan County based on an analysis of TM imagery

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Abstract. Declines in vegetation coverage can have adverse effects on the environment. Analyses of vegetation cover change are particularly important in semi-arid areas, where the results of such work can help to guide soil and water conservation efforts. In this study, based on Thematic Mapper (TM) imagery of semi-arid Jingchuan County, China, from 1987 to 2015, the spatio-temporal trends in vegetation coverage were analyzed with the Normalized Difference Vegetation Index (NDVI). The results showed that the vegetation coverage in Jingchuan County was high (38%–58%), and the vegetation fraction showed an overall upward trend in most areas. In particular, the average vegetation coverage in the towns/townships of Feiyun, Gaoping, and Yaodian was higher than 50%, and these areas displayed obvious upward trends during the study period. The lowest average vegetation fraction of 38%–39% was detected in the towns/townships of Chengguan and Ruifeng; however, these areas also displayed upward trends during the study period. The vegetation coverage in the other towns/townships was in the range of 42%–49%. The increase in vegetation coverage in recent years was mainly due to the implementation of projects to convert farmland to forest and the development of orchards; notably, these are ashd slopes less than or equal to 2° over most of the terrain and the survival rate of vegetation after artificial planting was high. The Zhanglaosi farm, where the annual coverage was 48%, was one of the only places that showed a downward trend in vegetation coverage during the study period; this decrease could have been due to the loss of old orchard trees. Small areas along the river also displayed downward trends. The average vegetation coverage was different in areas with different slopes, and the coverage ranking from high to low for different slopes was as follows: 6°–15° (52% coverage), ≤2° (50% coverage), 2°–6° (47% coverage), >25° (42% coverage), 15°–25° (41% coverage). In regard to the interannual variation, the correlation between the vegetation coverage and climate factors was assessed. The annual vegetation coverage was found to be significantly related to the annual rainfall. In particular, the annual vegetation coverage tended to increase with increasing amounts of rainfall. The relationship between the vegetation and annual average temperature was also positive but not significant.

1. Introduction

Changes of vegetation coverage are an important indicator of the health of regional ecosystems and overall environmental quality, and such changes can have significant impacts on a region’s hydrology, ecology, and so forth [1]. With the development of remote sensing technology, measurements of
vegetation coverage have advanced from traditional ground measurements to remote sensing estimates that can cover larger spatial scales [2–4]. The methods used for remote sensing measurements of vegetation coverage can be divided into the following three types: regression model methods, vegetation index methods, and pixel decomposition model methods[5]. A regression model depends on the measured data of a specific region, and this method has many limitations in terms of its application. The vegetation indices are useful for large scale vegetation cover assessment, after being validated against in-situ observations (i.e., ground-truthing). Compared with regression model methods, the vegetation index methods have a higher universal significance [6].

This study used 24 Thematic Mapper(TM) and Operational Land Imager(OLI) images collected from 1987 to 2015 in Jingchuan County, China, to calculate the average vegetation coverage, and vegetation cover changes were analyzed by there gression trend analysis method to reveal the variation trends of the vegetation and to assess the effectiveness of ongoing artificial afforestation projects.

2. Materials and methods

2.1. Study area
Jingchuan County, which is part of Pingliang city in Gansu province, is located in the Longdong Loess Plateau (107°15ʹ–107°45ʹ E, 35°11ʹ–35°31ʹ N). The altitude of the county ranges from 930 to 1460 m. Jingchuan County belongs to the typical gully area of the Loess Plateau, and the terrain from the northwest to the southeast tilt area contains complex features such as undulating hills, ravines, mountains, plateaus, hills, gullies, and beams. The region has a typical continental monsoon climate with an average annual rainfall amount of 550 mm, and the average annual evaporation rate is two times more than the amount of precipitation. Soil erosion is a serious problem in this region. The main vegetation types forest steppe vegetation, which can be divided into natural vegetation areas and artificial vegetation areas. The majority of natural vegetation is sparse grasses. Other natural residual vegetation includes various thorns, wolf tooth, wolf berry, and so on. In this region, there are many kinds of exotic trees including poplar, willow, Robinia pseudoacacia, Sophora japonica, peach, apricot, pear, apple, cottonseed, and walnut. The area of Jingchuan County’s forest is 696 thousand hectares; the amount of forest coverage is 34.9%, and the forest volume is 1464 thousand cubic meters according to data collected in 2012 [7].

2.2. Remote sensing data
Remote sensing data used in this study consisted of Landsat5 imagery (1987–1988, 1991–2011) and Landsat8 imagery (2014–2015); these data were provided by the U.S. Geological Survey(USGS) (https://earthexplorer.usgs.gov/). Projection of the images was via WGS_1984_UTM_Zone_48N. Selection time of these images ranged from September to early October. These images that were used contained less than 10% cloud data (the images from 1989 to 1990 contained more than 25% cloud data and were excluded from the analysis). The images were downloaded and processed with various techniques including uniform color, mosaic, and clipping (to yield coordinate consistent data for administrative divisions of Jingchuan County) procedures; then, these data were applied to the methods described below.

2.3. Vegetation coverage model
There is a very significant linear correlation between vegetation coverage and the Normalized Difference Vegetation Index(NDVI), and the vegetation coverage information can be extracted directly by establishing a conversion relationship between the two[8,9]. The vegetation fraction is estimated by the Dimidiate Pixel Model. Assuming that the NDVI value of each pixel can be synthesized from two parts, namely, vegetation and soil, the formula is as follows:

$$\text{NDVI} = \text{NDVI}_{F_v} + \text{NDVI}_{S}(1 - F_v)$$

(1)
In the formula, NDVI, is the NDVI value of the vegetation part, NDVI_s is the NDVI value of the soil part, and F_ci is the vegetation fraction. During the actual calculation process, the maximum and minimum NDVI values of vegetation are used instead of the NDVI_s and NDVI_v, respectively.[10]

\[
F_{ci} = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}
\]  

(2)

As a result of the influence of noise that exists in the remote sensing imagery, overestimates or underestimates of NDVI values are possible. To avoid the occurrence of these errors in the NDVI_max and NDVI_min values, we cannot directly use the NDVI maximum values and minimum values of the collection; instead, confidence intervals of maximum and minimum values need to be assessed[11,12].

Regression was used to analyze the trend of vegetation change over the study period. Time t was used as the independent variable, and the annual NDVI and the year were analyzed to get the linear regression equation. By calculating the SLOPE from the equation below, we were able to analyze the trend of vegetation change; SLOPE <0 indicates that the degree of vegetation cover is decreasing, and SLOPE >0 indicates that the degree of vegetation coverage is increasing:

\[
SLOPE = \frac{n \times \sum_{i=1}^{n} i \times NDVI_i - \left( \sum_{i=1}^{n} i \right) \left( \sum_{i=1}^{n} NDVI_i \right)}{n \times \sum_{i=1}^{n} i^2 - \left( \sum_{i=1}^{n} i \right)^2}
\]  

(3)

SLOPE is computed from the linear equation of the regression slope. NDVI represents the average annual NDVI, and n indicates the number of years; is a value from 1 to n [13].

The SLOPE line reflects the changing trend of vegetation coverage for 1987–2015 in Jingchuan County. Positive slopes indicated that the vegetation coverage had increased, whereas negative slopes indicated that the vegetation coverage had decreased; the greater the absolute value of the slope, the greater the magnitude of the change in vegetation coverage.

2.4. Analysis of the correlation between the vegetation coverage and climate factors

The geographic system is a complex giant system composed of multiple elements. The change of one element in the system can inevitably cause changes in the other elements. The relationship between two specific variables can be studied by partial correlation analysis. Partial correlation analysis means that when two variables are related to a third variable at the same time, the influence of the third variable can be eliminated so that only the correlation between the other two variables can be studied[14].

In this study, the spatial analysis method based on pixels was used to analyze the partial correlation between the vegetation coverage and climatic factors (temperature and precipitation). First, the simple correlation coefficients were calculated, and then, the partial correlation coefficients were calculated.

3. Analysis and results

3.1. Spatial distribution characteristics of vegetation coverage in the forest land
Figure 1 shows a map of the annual average vegetation fraction in Jingchuan County from 1987 to 2015, and Table 1 provides specific data on the average annual vegetation fraction of Jingchuan County from 1987 to 2015. It can be seen from Figure 1 and Table 1 that the regional vegetation coverage was high as a whole, and the towns/townships of Feiyun, Gaoping, and Yaodian had coverage values amounting to more than 50%, which is consistent with the actual local situation in which there are numerous forested lands in these areas. For Yudu, Fentai, Danyang, Zhanglaosi farm, and Jingming, the coverage ranged from 47% to 49%, and for Libao, Honghe, TaiPing, Luohan Dong, and Yucun, the coverage ranged from 42%–44%. The minimum vegetation coverage values of 38%–39% on land were detected in Chengguan and Ruifeng, and these low values can be attributed to regional economic development and the expansion of construction land. Areas with river water had a value of 0.
Figure 1. Average annual vegetation coverage of Jingchuan County for 1987–2015.

Table 1. Average annual vegetation coverage of towns located in Jingchuan County for 1987–2015.

| Name    | Coverage (%) | Name    | Coverage (%) | Name    | Coverage (%) |
|---------|--------------|---------|--------------|---------|--------------|
| Feiyun  | 58.3960      | Dangyuan| 48.2251      | Taiping | 43.5256      |
| Gaoping | 53.0895      | Zhanglaosi | 48.2172 | Luohandong | 43.1247      |
| Yaodian| 52.0072      | Jingming | 47.1435      | Yucun   | 42.0918      |
| Yudu   | 48.8745      | Libao   | 44.1184      | Ruifeng | 38.6179      |
| Fengtai| 48.7784      | Honghe  | 43.7660      | Chengguan | 38.0907    |

3.2. Interannual temporal and spatial variation of the vegetation cover

Figure 2. Changes and trends of NDVI in Jingchuan County for 1987–2015.
From 1987 to 2015, the trend of vegetation coverage in Jingchuan County is growth (Figure 2), and the territory wide average SLOPE index was 0.00427. Among these areas, places with decreasing coverage were mainly detected along the Jinghe River, which is where construction land is present. Decreasing trends were also detected at Zhanglaosi farm and in various areas with forestry resources, the latter of which was due to the conversion of land into arable land.

According to the SLOPE statistics for the administrative divisions shown in Table 2, vegetation coverage in Feiyun grew the fastest followed by that of Gaoping. Of these administrative units, Zhanglaosi farm was the only place where decreases in vegetation coverage were detected; all other towns/townships showed increases in coverage.

### Table 2. SLOPE values of all towns in Jingchuan County for 1987–2015.

| Name       | SLOPE | Name       | SLOPE | Name       | SLOPE |
|------------|-------|------------|-------|------------|-------|
| Feiyun     | 0.006278 | Taiping    | 0.004723 | Libao      | 0.003229 |
| Gaoping    | 0.005876 | Yudu       | 0.004435 | Chengguan  | 0.002991 |
| Honghe     | 0.005832 | Jingming   | 0.003865 | Yucun      | 0.002515 |
| Yaodian    | 0.00541  | Fengtai    | 0.003685 | Ruifeng    | 0.002403 |
| Dangyu     | 0.005212 | Luohandong  | 0.003616 | Zhanglaosi | -0.00028 |

#### 3.3. Vegetation coverage over terrain with different slopes

Annual vegetation coverage and SLOPE data for different terrain slope classes in Jingchuan County are shown in Table 3. The results show that the average vegetation coverage was ranked from high to low over slopes of 6°–15°, ≤2°, 2°–6°, >25°, and 15°–25°; the slope vegetation coverage in the 6°–15° area was the highest, and the slope vegetation coverage in the 15°–25° area was the lowest. During 1987–2015 in Jingchuan County, the vegetation coverage growth trend as indicated by the SLOPE data was ranked from high to low over slopes of ≤2°, 6°–15°, 2°–6°, 15°–25°, and >25°; in general, the vegetation coverage increase was very slow. Many of the increases in vegetation growth were likely the result of artificial afforestation projects that have been implemented in Jingchuan County over the past nearly 30 years. Water resources in the low slope region were high, and this could have contributed to the robust vegetation with high survivorship rates and the high SLOPE data.

### Table 3. Annual vegetation coverage and SLOPE for each terrain slope class in Jingchuan County.

| Terrain slope classes | Annual vegetation coverage (%) | SLOPE | Range | Area rate (%) |
|-----------------------|--------------------------------|-------|-------|--------------|
| 1                     | 50.1818                        | 0.005034 | ≤2°   | 24.8305      |
| 2                     | 47.3358                        | 0.004549 | 2°–6° | 16.3356      |
| 3                     | 51.7396                        | 0.004783 | 6°–15°| 24.6592      |
| 4                     | 40.8020                        | 0.002691 | 15°–25°| 10.3335     |
| 5                     | 41.4961                        | 0.002533 | >25°   | 23.8412      |

#### 3.4. Analysis of the correlation between the vegetation coverage and climate factors

The partial correlation coefficients between the 1987–2011 vegetation coverage (VC) and annual average temperature and annual rainfall were calculated with SPSS software. The correlation coefficients between the vegetation coverage and annual average temperature and annual rainfall in the study area were 0.034 and 0.553, respectively. These results indicate that the vegetation coverage was more closely related to the annual rainfall in Jingchuan County than the average annual temperature.

Vegetation growth can be affected by temperature, precipitation, and other climatic conditions. With the remote sensing time series, the relationship between vegetation coverage and annual temperature changes in Jingchuan County for the years 1987–2011 was analyzed. As shown in Figure 3, the correlation between vegetation coverage and temperature of the current year was not significant (ρ = -0.0720), but the data were consistent with the trend in temperature change in the following year, which indicates that the vegetation coverage may have had an influence on the temperature of the following year. The relationship between vegetation coverage and annual
precipitation in Jingchuan County for the years 1987–2011 was also analyzed. As shown in Figure 4, it was found that the correlation between vegetation coverage and precipitation during the study period was significant ($\rho=0.5554$), and the vegetation tended to increase with the increases in precipitation of the current year. These results indicate that the vegetation coverage was affected by the availability of water.

![Figure 3. Changes of vegetation coverage and annual average temperature in Jingchuan County for 1987–2011.](image)

![Figure 4. Changes of vegetation coverage and annual precipitation in Jingchuan County for 1987–2011.](image)

4. Discussion and conclusion
This study analyzed a long time series (1987 to 2015) of remote sensing data on vegetation coverage in an area of the Longdong Loess Plateau in China to discern the temporal and spatial variations in vegetation coverage. The result shows that vegetation coverage was high; and there was an upward trend in the vegetation coverage in most areas of Jingchuan County.

The increases in vegetation coverage were likely related the implementation of projects to return farmland to forestland and an increase in the number of orchard trees. A decrease in the vegetation coverage was detected at Zhanglaosi farm, where the annual coverage was 48%, and this was one of only a few places that showed a downward trend in vegetation coverage during the study period; this decrease could have been due to the loss of old orchard trees. Small areas along the river where construction land was present also displayed downward trends.

The average annual vegetation coverage differed for lands with different slopes, and the areas with a slope of $6^\circ$–$15^\circ$ had the highest vegetation coverage (52%), whereas the areas with a slope of $15^\circ$–$25^\circ$ had the lowest vegetation coverage (41%). The growth trend of vegetation coverage in areas with a slope less than $2^\circ$ was the most obvious, and the slowest growth occurred in areas with a slope of more than $25^\circ$. 
The relationships between the annual vegetation coverage and the annual average temperature and rainfall in Jingchuan County from 1987 to 2011 were analyzed. The vegetation coverage in the study area was greatly influenced by the rainfall, whereby the annual vegetation coverage increased with increases in precipitation. However, no significant relationship was detected between the vegetation coverage and temperature. It is possible that the growth in vegetation coverage in a particular year affected the temperature of the subsequent year.

This paper did not fully examine the influence of meteorological factors on the changes in vegetation coverage, and future research in this regard would be useful to undertake. For example, we only used remote sensing data from the end of September and the beginning of October of each year in the analysis, and the examination of data from other seasons and times could reveal other interesting relationships. Another important research direction would be to investigate how vegetation coverage can help to alleviate urban heat and improve micro climates and human thermal comfort.

Acknowledgement
This research was supported by the Fund for Less Developed Regions of the National Natural Science Foundation of China (Grant No. 41461112 & Grant No.31660235) and the International Cooperation Project of the Gansu Provincial Science and Technology Bureau (Grant No. 1504WKCA006).

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