Dynamic Assessment on the Landscape Patterns and Spatio-temporal Change in the mainstream of Tarim River

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Abstract. The Tarim River (TR), as the longest inland river at an arid area in China, is a typical regions of vegetation variation research and plays a crucial role in the sustainable development of regional ecological environment. In this paper, the newest dataset of MODND1M NDVI, at a resolution of 500m, were applied to calculate vegetation index in growing season during the period 2000-2015. Using a vegetation coverage index, a trend line analysis, and the local spatial autocorrelation analysis, this paper investigated the landscape patterns and spatio-temporal variation of vegetation coverage at regional and pixel scales over mainstream of the Tarim River, Xinjiang. The results showed that (1) The bare land area on both sides of Tarim River appeared to have a fluctuated downward trend and there were two obvious valley values in 2005 and 2012. (2) Spatially, the vegetation coverage improved areas is mostly distributed in upstream and the degraded areas is mainly distributed in the left bank of midstream and the end of Tarim River during 2000-2005. (3) The local spatial auto-correlation analysis revealed that vegetation coverage was spatially positive autocorrelated and spatial concentrated. The high-high self-related areas are mainly distributed in upstream, where vegetation cover are relatively good, and the low-low self-related areas are mostly with lower vegetation cover in the lower reaches of Tarim River.

1. Introduction
Vegetation is the connection of atmosphere, soil, water as well as other elements and plays a notably essential role in whole ecosystem stability [1]. The variations of vegetation distribution and its composition affect the balance of regional ecosystems [2]. The majority of the research has focused on examining trends of vegetation in the Normalized Difference Vegetation Index (NDVI)[3]. Nowadays there are various categories of NDVI datasets available: MODIS NDVI, AVHRR NDVI, SPOT VGT NDVI, and TM NDVI [4]. The time sequence of each remote sensing product is different, but they are all calculated from the spectral reflectance measured in the visible and infrared bands of a satellite sensor, and provide an indication of photosynthetically active vegetation [5].

Recently, much attention has been paid to the issues of vegetation dynamics in arid areas in China [6-8]. Dai et al.[8] investigated the spatio-temporal variation of NDVI over northwest China from 1982 to
2006, and evaluated the NDVI increase responses to large-scale ecological construction projects in northwest China at the slope of less than 25°. Cao et al.[7] reported that the response of 10-day NDVI to temperature was more significant than that to precipitation in Xinjiang, while the decrease of annual precipitation was the main factor resulting in the fluctuation of vegetation coverage. Currently, studies on the vegetation coverage in arid area of Tarim River mainly concentrate on the lower reaches of TR [9-11]. Wu et al.[9] presented a study about land cover changes on the section of the Tarim River between Qiala and Taitema Lake, and concluded that the total amount of land cover change between 1988 and 2000 is small, however, the areas of urban or waters were expanded. Wang et al.[11] analyzed the spatial and temporal changes of vegetation coverage in the lower reaches of TR by extracting Landsat TM datasets during 2006-2011, and suggested that the dominant factor of vegetation growth and recovery in the area is groundwater.

However, up to date there are very few studies reported on the landscape patterns and spatio-temporal change in the mainstream of TR by the newest dataset of MODIS/NDVI at the basin. Therefore, based on the NDVI data from 2000 to 2015, the primary objective of this study is to detect the vegetation information due to ecological water transport at the TR. In order to characterize the spatio-temporal variation of vegetation in growing season, a vegetation coverage index (fc) was calculated and ENVI 5.1 and ArcGIS10.1 software were applied. Trend line analysis method combined with spatial autocorrelation analysis method were contribute to the understanding of current condition of landscape improvement and spatial aggregation of vegetation cover. Hopefully, knowledge of the characteristics of landscape patterns and spatio-temporal changed will help aid in generalizing the results of vegetation’s collective changes in this region and maintaining ecological construction achievements.

2. Materials and methods

2.1. Study area

The Tarim River is a typical inland river located in the south of Xinjiang, China, between 39°30′~41°35′ N and 81°51′~88°30′ E. The mainstream of TR begins from the junction of Akesu River, Yarkant River and Hotan River and empties to the Taitema Lake [12], with a total area of 1.02 million km2. The length of its mainstream is 1321km, which is divided into three sections according to the geomorphic features. The length of upstream is 495km, from Xiaojiake to Yingbazha; the middle reaches is from Yingbazha to Qiala (398km); while the lower reaches is from Qiala to Taitema Lake (428km). The mainstream of the TR belongs to an extremely continental arid climate, which is characterized by scare precipitation less than 70mm and high evapotranspiration beyond 1000mm per year. Due to over-exploitation of water resources, the amount of runoff flow reaching to the downstream of the TR has decreased considerably. As a result, several channel sections have dried up especially in the reaches below the Daxihaizi Reservoir, leading to desertification of land, sharply decreased of Populus euphratica forest areas, and degradation of ecosystem. The “Green Corridor” is on the verge of destruction.

2.2. Data sources and processing

Data used in this study are as follows: (1) The MODIS NDVI dataset was derived from the MODIS composed product in China from 2000 through 2015 in growing season, with 500m * 500m spatial resolution and 30 days temporal resolution, which was downloaded from the geospatial data cloud (http://www.gscloud.cn/). The MODND1M dataset has already been processed by radiometric correction, cloud mask, atmospheric correction and geometric correction. (2) Daily flow of TR from January 2000 to December 2015 measured by Alar and Xinquman hydrological stations were obtained from Tarim River Basin Management Bureau of China.
2.3. Methods

2.3.1. Calculation and classification of vegetation coverage. MODIS1M images were obtained for August from 2000 to 2015. This series correspond to the best season of vegetation coverage when plant is the most flourish of the year and vegetation restoration can be easily distinguished. According to the Dimidiate Pixel Model, the NDVI value of the pixel is composed of the green vegetation information and the bare soil information. Vegetation coverage, as an important indicator of plant, it is often used to monitor changes in vegetation. Considering that there is a markedly linear correlation between vegetation coverage and NDVI, the following equation was used to calculate the MODND1M data of vegetation coverage in the study area:

\[
f_c = \frac{\text{NDVI}_{\text{veg}} - \text{NDVI}_{\text{soil}}}{\text{NDVI}_{\text{soil}} - \text{NDVI}_{\text{soil}}}
\]

Where NDVI is the value of each pixel, NDVI_{soil} is the value of bare soil area, NDVI_{veg} is the values for complete cover areas of vegetation.

2.3.2. Trend line analysis. Trend line analysis can analyze the change trend of each grid point, and calculate the change rate of vegetation coverage on time scale. This statistic is defined as follows:

\[
\theta_{\text{slope}} = \frac{\sum_{i=1}^{n} i * f_k - \sum_{i=1}^{n} \sum_{j=1}^{n} f_k}{n \sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2}
\]

Where, \(\theta_{\text{slope}}\) refers the slope trend of the linear regression of one variable equation. \(n\) represents the monitoring years, \(f_k\) is the vegetation cover value in monitoring month for the specified year. The inter-annual variation of the vegetation cover trend line is characterized by the correlation coefficient between vegetation coverage sequence and time series. When the \(\theta_{\text{slope}}\) is greater than 0, the annual vegetation coverage value is increased, by contrast, the vegetation coverage is decreased.

2.3.3. Spatial autocorrelation analysis. The local spatial autocorrelation analysis method was conducted to discuss the spatial distribution and aggregation degree of vegetation coverage, global spatial autocorrelation statistics, for instance, the Moran’s I and local indicators of spatial associations (LISA) were developed [13]. The local Moran’s I values are calculated as follows[14]:

\[
I_i = \frac{(x_i - \bar{x}) \sum_j W_{ij} (x_j - \bar{x})}{S^2 \sum_j W_{ij}}
\]

\[
S^2 = \frac{1}{N} \sum_i (x_i - \bar{x})^2; \quad \bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i
\]

Where \(x_i\) and \(x_j\) are the observation value in i and j positions, \(\bar{x}\) is the mean value, \(W_{ij}\) is the weighting matrix of the adjacent relations of position i and j. The Moran’s I ranges from -1 to 1, generally, negative values represent negative correlation, which means the spatial aggregation decreases gradually; I is equal
to 0 if the observation values are independent and random distributed; and it is > 0 which represents positive correlation while spatial features tend to aggregate.

3. Results and Discussion

3.1. Temporal variation of the vegetation coverage in growing season

Figure 1 shows the temporal variation characteristics of the vegetation coverage in growing season for 16 years from 2000 to 2015 in the mainstream of TR. As shown in this figure, the bare land area on both sides of the TR was gradually reduced after the ecological water diversion in 2000, since the early stage of water transportation in 2003, the area of bare land declined rapidly. After that, the proportion of bare land area shows a minor change, but it was obviously less than the background years from 2000 to 2002. There are two obvious valley values in the line chart, respectively, in 2005 and 2012, and the corresponding bare land area ratios are 41.47% and 36.49%. As for the tendency, the area of low coverage desert vegetation experienced different stages of change and showed different periodic features. The fluctuation from 2000 through 2004 years is very small, while the proportion of low coverage vegetation area soared to 26% in 2005. Besides, the values tend to be stable from 2005 to 2011, and the wave crest occurred in 2013 of 16 years accounted for 27.93%. In addition, the variations of high coverage desert vegetation area did not show a significant trend, while it can be seen that 7.53% to 9.84% areas belong to this rank. Furthermore, the area of oasis agricultural area exhibited minor rise variations, especially after 2010, the proportion of oasis agriculture area remained above 26.67%, and the areas reached its peak in 2013 with a vegetation coverage values above 0.35 accounted for 28.58%.

Figure 1. Temporal variation of vegetation cover types in growing season from 2000 to 2015 over the mainstream of TR (Note: vegetation coverage was classified into four ranks: bare land (fc < 0.1), low coverage area (0.1< fc < 0.25), high coverage area (0.25< fc < 0.35) and oasis agricultural area (fc > 0.35).)
3.2. Spatial variation of the vegetation coverage in growing season

The trend line analysis method is used to reflect the spatial characteristics of vegetation of each raster grid[11]. Figure 2 is the spatial distribution map of $\theta_{slope}$, which shows the vegetation cover condition changes over Tarim River during 2000 to 2015. The variation trends of vegetation coverage were analyzed on 6 categories. As suggested by Fig.2 (a), during 2000 to 2006, the area showing slight and severe degradation accounts for and is mainly distributed in the middle and upper reaches of TR, the vast majority of the area remains unchanged and dispersed, the area with slight improvement is primarily scattered in downstream along the river. As shown in Fig.2 (b) from 2006 through 2012, the vegetation coverage in the mainstream of TR has improved markedly and these areas are largely located in upstream and midstream, which are mainly obviously improvement and slight improvement, respectively. The vegetation cover on the right bank of the downstream has a certain degree of degradation, but stability area is still the dominant trend. Fig.2 (c) is the spatial distribution map of during recent 16 years (2000-2015), the area showing improvement above slight is mostly distributed in upstream, while the area with slight degradation is mainly distributed in the left bank of midstream and the end of TR.

![Figure 2](image_url)

**Figure 2.** Spatial distribution of vegetation coverage change in growing season over the mainstream of TR (Note: a. Average vegetation coverage change from 2000 to 2006; b. Average vegetation coverage change from 2006 to 2012; c. Average vegetation coverage change from 2000 to 2015)

3.3. Local spatial autocorrelation analysis of vegetation coverage

The average vegetation coverage in TR during 2000 to 2015 was carried out by local spatial autocorrelation analysis (Figure 3). The calculation of the local spatial autocorrelation of vegetation index and the mapping of LISA map are more conducive to understand the local spatial aggregation patterns and regularity of vegetation coverage. In this manner, the grid is resampled with 0.05*0.05 degrees, one can view the average vegetation index value of each grid for 16 years, and calculating
Moran’s I scatter plot of local spatial autocorrelation of vegetation coverage spatial association index in GeoDa software. The local Moran ’s I value of the mainstream of Tarim is 0.73, which is remarkable at the level of $\alpha$=0.05 (Figure 3). It shows that the spatial distribution of vegetation coverage in the mainstream of TR is not completely random, rather, it shows a positive spatial correlation significantly on the whole and the vegetation coverage is aggregated.

Figure 3. Moran’s I scatter plot of local spatial autocorrelation of vegetation coverage

![Moran’s I scatter plot of local spatial autocorrelation of vegetation coverage](image)

Figure 4. The LISA cluster map of vegetation coverage over the mainstream of TR

![LISA Cluster Map](image)

Figure 5. The LISA significance map of vegetation cover over the mainstream of TR

![LISA Significance Map](image)
4. Conclusion

By combining the Moran scatter diagram with the LISA significance level, the LISA concentration map (Figure 4) and the significance horizontal distribution map (Figure 5) of the vegetation coverage are drawn. In Figure 4, the grey region indicates that the spatial autocorrelation is not significant. In the upper reaches of TR, it is closely related with the characteristic of high-high autocorrelation. At the same time, in the downstream of Tarim, especially the right bank, the vegetation coverage was low-low correlation and showed zonal distribution. Here the "high" and "low" is relative to the mean value of the grid, high-high autocorrelation results of vegetation coverage of local spatial autocorrelation analysis showed that the vegetation cover is relatively good, and there is an association between their annual average vegetation cover. Low-low autocorrelation results show that vegetation coverage in this area is poor, and they have little influence on each other. Figure 5 shows that the distribution was not significant in most of the middle reaches of TR, which was coloured grep in map, other regions have reached a significant level of 5%.

NDVI is an essential index for learning vegetation’s dynamic variation and its distribution and composition are closely related to ecological environment, especially in arid area. In this study, NDVI time series data in 2000-2015 were obtained based on MODND1M dataset at a resolution of 500m. The spatio-temporal variation characteristics of vegetation cover in the mainstream of Tarim River was analyzed using trend line analysis and the local spatial autocorrelation analysis methods. The main conclusions are as follows:

(1) Temporally, the bare land area on both sides of the TR was rapidly reduced since the early stage of water diversion in 2003. The area of oasis agricultural area exhibited rise variations, and the wave crests occurred in 2011 (28.50%) and 2013 (28.58%). The area proportion of high coverage desert vegetation is between 7.53%-9.84%.

(2) Spatially, regarding the variation in trends of the vegetation coverage, the areas with improved vegetation coverage were far greater than the degraded areas in the mainstream of TR during 2006-2012. The trends of the vegetation coverage vary greatly and even reverse between 2000-2006 and 2006-2012. The vegetation coverage in 2000-2015 exhibited great changes, however, the vegetation cover improved areas is mostly distributed in upstream and the degraded areas is mainly distributed in the left bank of midstream and the end of TR.

(3) Through the establishing of the Moran Index, the spatial autocorrelation of vegetation distribution was reflected in TR. The Moran Index extracted from the results was 0.73, which indicates that there is significant spatial autocorrelation in the distribution of vegetation.

(4) The increasing trend of vegetation coverage during 2000-2015 over the mainstream of TR was mainly caused by the increasing flow from the headstreams. At the same time, people began to implement ecological water diversion from Bosten Lake to the lower reaches of TR fifteen times since 2000, which has alleviated the fragile ecosystem in some extent. Though the driving forces associated with vegetation variations have been explored, quantitative analysis of vegetation variations caused by ecological water transport needs further study.

Acknowledgments

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