Temporal and Spatial Variation Characteristics of Natural Woodland in the Upper Reaches of the Tarim River in Recent 25 Years

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Abstract. Natural woodland is highly prized in the Tarim River Basin for its great ecological, economic and social benefits, and it occupies an important position in the "The Belt and Road" strategy, but influenced by the natural environment changes and human activities, the natural woodland has changed in some way. So we implemented the dynamic monitoring of land use and natural woodland in the upper reach of the Tarim River and analyzed their changes, based upon the Landsat remote sensing images of 1990-2015. The results showed that: (1) From 1990 to 2015, the land use degree in the study area showed a significantly increasing trend, yet the land use degree and development intensity stayed in a relatively low level between two counterparts of the natural and agricultural land use. (2) In the past 25 years, the natural woodland area reached higher level in the middle terms (1995-2005), while remained lower at both ends. Additionally, the dynamic changes had a high increase speed during 1990-1995 as well as had a high decrease speed during 2005-2010. (3) The transfer features of natural woodland from 1990 to 2015 was: natural woodland were mainly changed into farmland, and the newly increased natural woodland mainly came from grassland and saline alkali land.

1. Introduction
March 27, 2015, China National Development and Reform Commission, the Ministry of Foreign Affairs and the Ministry of Commerce jointly issued the 《Vision and Actions on Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road》in Hainan, the Boao forum for Asia, marking the "The Belt and Road" strategy had entered the comprehensive construction phase.
Xinjiang autonomous region, as a core area of the Silk Road Economic Zone in western China, has an important port to center and southern Asian countries (such as Pakistan, Afghanistan, and Tajikistan). The Tarim River Basin (TRB), as one part of Xinjiang, with large population plays a significant role in regional economic activities and ecological function and environment protection[1]. However, owing to the influence of natural environment changes and human activities, ecological environment problems such as the shortage of water resources, desert riparian forest degradation and land desertification have presented increasingly serious situation in the region during recent years. The TRB thus faces the challenges on the deterioration of ecological environment. The natural woodland, as the main body of riparian vegetation along the TRB, is very significant for the stability and healthy development of ecological environment in the basin.

In recent years, many researches on the woodland of TRB have been down, i.e., the relationship between woodland soil properties and vegetation[2-4], Populus euphratica’s individual and population characteristics[5-6], groundwater and vegetation changes under multiple ecological water transfer in the lower reach of the Tarim River[7-9], and the simulation of water consumption and transpiration of woodland based on relevant models[10-12].

With the advantages of high timeliness, large range and low cost, remote sensing technology has been widely used. Many scholars at home and abroad thus have carried out a series of research on LUCC (Land-Use and Land-Cover Change) in TRB by using this technology. By using the Landsat8 OLI remote sensing images and measured LAI (Leaf Area Index) data, Zhu Xuchao et al. established a LAI estimation model to estimate the LAI of riparian forest along the lower reach of the Tarim River[13]. With the help of satellite remote sensing and GIS (Geographic Information System) technologies, Bai Yuan et al. adopted the buffer gradient method to analyze the horizontal distribution structure of desert riparian forest along the Tarim River[14]. Based on nearly 40 years of Landsat remote sensing images and field survey data, Chen Haiyan and Chen Yaning analyzed the temporal and spatial variation of the vegetation zone with which the main body was desert riparian forest along the Tarim River[15]. The results showed that the vegetation coverage degree along the Tarim River presented a tendency of rise, being faster in the upstream and slower in the midstream, while the downstream presented a downward trend; In terms of the different levels of the vegetation coverage, the area of the low vegetation coverage zone reflected the desert riparian forest showed a decreasing trend, and the area of the high vegetation coverage zone reflected the farmland and artificial vegetation area showed an increasing trend.

There were a lot of researches about woodland in the TRB. However, influenced by the zero flow on the lower reach of the Tarim River, more researches focused on the lower reach, and the UTR as the core area of the TRB drew less attention. Therefore, in this study, we selected the Upper reach of the Tarim River (UTR) as a study area, and implemented the dynamic monitoring of land use and natural woodland along the UTR and analyzed their changes, based upon the Landsat TM/ETM+/OLI remote sensing images of 1990-2015. In this way, we hope that our study can provide help for scientific research and ecological environment conservation and government decision making in this region.

2. Data and methodology

2.1 Study area
The TRB is the largest inland river basin in China, which is located in southern Xinjiang (between 73°10′ E-94°05′ E longitude and 34°55′ N-43°48′ N latitude) with an area of about 102,000 km²[16]. The Tarim River is composed of four tributaries and one main stream, and has a length of 1,321 km divided into three sections (upper, middle, and lower reach). The upper reach is from Alaer to Yingbaza, and the river length is 495 km; the middle reach is from Yingbaza to Kala with the river length of 398 km; the lower reach is from Kala to Taitema Lake with the river length of 428 km, but 321 km of the lower reach currently has been drying up[17]. The Tarim River was surrounded by the Taklimakan Desert in the northeast, and the river basin is a continental warm temperate extreme arid climate with the annual average temperature in 10.7 °C and the average precipitation in 17.4-42.8 mm[14]. The zonal vegetation in the area affected by the arid desert climate is temperate and semi-shrub, populous is the main part of the desert riparian forest that mainly distributed in the floodplain and on both sides of the lower terraces.

The study area contains the upper reach region of the Tarim River with a buffer at width of 12.6×2 km. It crossed the Akesu and Bayingolin Mongol Autonomous prefectures, being across six county-level administrative units, i.e., Akesu City, Xinhe County, Shaya County, Kuche County, Luntai County, and Weli County, with an area of 7747 km². The main land use types in this area are woodland, grassland, farmland, and sand.

2.2 Data source

The land use classification data of the study area during 1990-2015 were derived from the historical Landsat TM/ETM+/OLI remote sensing images (Table 2), which were acquired from the website of Geospatial Data Cloud (http://www.gscloud.cn/) and Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences (http://www.radi.ac.cn/). The data of each study year includes five images, and the time of image mainly are concentrated in August with high vegetation coverage, where the available and cloud-free image will be selected.

2.3 Data processing

Firstly, this paper pre-processed the remote sensing images by the software of ENVI5.1, including layer stacking, clipping, and band matching, then obtained the synthetic images that contained the data of band and spectral indices such as NDVI (Normalized Difference Vegetation Index), NDBI (Normalized Difference Building Index) and MNDWI (Modified Normalized Difference Water Index). Secondly, the region of interest was selected by using the Google Earth software (version 7.1). Thirdly, the decision tree classifier that is a distributed model based on cart algorithm was used to classify the synthetic images, and get the land use classification data which had a total of nine categories included farmland (including artificial woodland), natural woodland, grassland, waters, beach land, residential land, sand, saline alkali land and swamps. Finally, verified classification data by GF-1 PMS (a spatial resolution of 2 m), the results demonstrated that the accuracies of land use classification data (2015) with the overall accuracy of 87.74% and kappa coefficient of 0.84. Eventually there are six periods of land use classification data used in the analysis of this study.
Figure 1. Location (A) and scope (B) of the study area

Table 2. Attributes of the Landsat TM/ETM+/OLI images used in the study

| Year of study | Satellite | Sensor | Data imaging time | Spatial resolution /m | Time resolution /day |
|---------------|-----------|--------|-------------------|-----------------------|---------------------|
| 1990          | Landsat5  | TM     | 1992.09.26        | 1990.10.23            | 144/31              |
|               |           |        | 1992.04.10        | 1989.08.08            | 144/32              |
|               |           |        | 1990.08.02        |                       |                     |
| 1995          | Landsat5  | TM     | 1996.09.21        | 1995.11.06            | 145/31              |
|               |           |        | 1995.05.05        | 1996.08.27            | 145/32              |
|               |           |        | 1994.08.13        |                       |                     |
| 2000          | Landsat7  | ETM+   | 2000.08.07        | 2000.08.07            | 146/32              |
|               |           |        | 2000.05.10        | 2001.09.02            | 146/32              |
|               |           |        | 2000.08.05        |                       |                     |
| 2005          | Landsat7  | ETM+   | 2005.08.21        | 2005.08.21            |                     |
|               |           |        | 2005.05.08        | 2005.09.13            |                     |
|               |           |        | 2005.07.18        |                       |                     |
| 2010          | Landsat5  | TM     | 2010.08.11        | 2010.08.11            |                     |
|               |           |        | 2010.08.02        | 2010.08.02            |                     |
|               |           |        | 2010.08.06        |                       |                     |
| 2015          | Landsat8  | OLI    | 2015.07.24        | 2015.07.24            |                     |
|               |           |        | 2015.07.15        |                       |                     |
|               |           |        | 2015.07.22        |                       |                     |

2.4 Models and methods

In order to research the land use situation, especially the temporal and spatial change of natural woodland, we analyzed the land use degree, the area variation and transfer features of natural woodland using the following models (Table 3). The land use degree index calculation formula is used to calculate the land use degree index, which is worked out by Liu Jiuyuan et al.[18-19]. The land use degree index can be used to quantitatively reveal the comprehensive land use level, and has an important role in reflecting the change of land use degree. Besides, for the purpose of showing the intensity of land use change, this paper respectively used the single land use dynamic degree and the comprehensive land use dynamic degree index to analyze the dynamic change of natural woodland and all land use types[20]. Finally, the transfer matrix was used to analyze the transfer features of natural woodland and other land use types for the sake of making clear the natural woodland’s transfer source and destination[20].

3. Results and discussion

3.1 Change of land use degree

The area proportion of each land use type were extracted from the land use classification data of 1990-2015, then calculated the land use degree index by the land use degree index calculation formula, as shown in Figure 4.
Table 3. Formula of calculating index

| Calculation index                  | Calculating formula                                                                 | Variable introduction                                                                 |
|-----------------------------------|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Land use degree index             | \( K = 100 \times \sum_{i=1}^{n} (A_{i} \times C_{i}) \)                            | where: \( K \) = land use degree index; \( A_{i} \) = land use degree grading index of \( i \) type; \( C_{i} \) = area proportion of \( i \) type; \( n \) = number of land use type. |
| Single land use dynamic degree    | \( L = \frac{(U_{b} - U_{a})}{U_{a}} \times \frac{1}{T} \times 100\% \)             | where: \( L \) = single land use dynamic degree; \( U_{b} \) = area of land use type at the beginning; \( U_{a} \) = area of land use type at the end; \( T \) = length of study period; |
| Comprehensive land use dynamic degree | \( LC = \frac{\sum_{i=1}^{n} \Delta LU_{i-j}}{2 \sum_{j=1}^{i-1} LU_{j}} \times \frac{1}{T} \times 100\% \) | where: \( LC \) = comprehensive land use dynamic degree; \( LU_{i} \) = area of \( i \) type in the early stage of the study; \( \Delta LU_{i-j} \) = absolute value of the area of \( i \) type to non \( i \) type (\( j \) type). |

Figure 4. Variation tendency of the natural woodland area (B) and land use degree index (A) in the study area from 1990 to 2015.

From Figure 4, the land use degree index showed a gradually increasing trend from 176.05 in 1990 to 205.20 in 2015, in particular, the period of 2005-2010 decreased with a small amplitude. The fastest growing period of land use degree index was 2000-2005 with the value increased from 187 to 198.54. In the other periods, the change value from high to low was 7.95 of 2010-2015, 6.81 of 1990-1995, and 3.69 of 1995-2000. During the past 25 years, the most intense change period of land use degree was 2000-2015 with a high amplitude and unfixed change direction.

On the other hand, the maximum land use degree index in all years was 205.2, i.e., just half size of the limit value (namely, 400)[18-19], and the average land use degree index was 191.3 in a low level. It showed that the land use degree and development intensity stayed in a relatively low level between two counterparts of the natural and agricultural land use.

By comparing it with the change of the natural woodland, the land use degree index increased slowly (1995-2000) or decreased (2005-2010) comparatively with the decrease of the natural woodland in the
corresponding periods, which indicated that the change of land use degree was to a certain extent affected by the change of natural woodland.

3.2 Dynamic change of natural woodland

The area and conversion area of each land use type were extracted from the land use classification data of 1990-2015, and the single land use dynamic degree of natural woodland and comprehensive land use dynamic degree were calculated by the single and comprehensive land use dynamic degree formula, as shown in Figure 5.

Figure 5. Variation tendency of the natural woodland area (C) and land use dynamic degree (A and B) in the study area between 1990 and 2015. (Note: CDD is the comprehensive dynamic degree, SDD is the single dynamic degree, NWA is the natural woodland area).

Figure 5 shows the natural woodland area of study area in the last 25 years, and the maximum and minimum value was respectively 2585km$^2$ in 2005 and 2026km$^2$ in 2010. Besides, the area of natural woodland in 1995 and 2000 is at the same high level as in 2005, and in 1990 and 2015 at the same low level as in 2010. From 1990 to 2015, the overall trend of natural woodland area in the study area increased firstly and then decreased with a total increase value of 59km$^2$.

We can discover the dynamic change of natural woodland from Figure 5, the results shows three increase periods and two reduction periods, and the increase periods was 1990-1995, 2000-2005 and 2010-2015, as well as the reduction periods was 1995-2000 and 2005-2010. Among them, the fastest increasing period was 1990-1995 with a positive dynamic degree of 3.5% and the area increased by 360km2, while the period of 2005-2010 was turned out to be the fastest decreasing period with a negative dynamic degree of -4.3% and the area decreased by 559km$^2$. Variation range of the remaining three periods were small, and their single dynamic degree of natural woodland respectively were 1.9% during 2000-2005, 0.7% during 2010-2015, and 0.3% during 1995-2000.

By comparing the single land use dynamic degree of natural woodland with the comprehensive land use dynamic degree, they both had significant values in the first and fourth periods, which indicated that the overall land use change was somehow influenced by the change of natural woodland.
3.3 Transfer features of natural woodland

The transfer matrix was constructed by the land use classification data of 1990 and 2015, as described in Figure 6 and Figure 7. Figure 6 shows that there were vast areas of natural woodland on both sides of the Tarim River, being no change during the last 25 years, but large areas of natural woodland changed into farmland not far from the river, and moreover, there were a lot of newly increased natural woodland at the borders between oasis and desert.

The transfer data of natural woodland with other land use types are mentioned in the Figure 7. From 1990 to 2015, a total of 846 km$^2$ natural woodland changed into the non-natural woodland, of which about 44.8% transferred into farmland with an area of 379 km$^2$. Furthermore, the grassland and waters were turned out to be the second and third, respectively transferred out of 337 km$^2$ and 71 km$^2$, accounted for 48.22% of all transfer area. Moreover, the transfer area of the rest types did not exceed 20 km$^2$, and the roll out percentage did not exceed 2%.

Besides, there were 904 km$^2$ newly increased natural woodland derived from the other land use types that are mainly grassland with an area of 502 km$^2$ being more than half of the total transfer area. The saline alkali land, sand and waters in the following three, and the transfer area were 114 km$^2$, 103 km$^2$ and 83 km$^2$, accounted for 33.18% of the total transfer area. The remaining four categories accounted for only 11.39%, and no changes had occurred on residential land.

It can be known that there were no obvious changes on the natural woodland area with only increased 59 km$^2$ in the past 25 years. However, the transfers between natural woodland and other land use types were remarkable, mainly were the natural woodland changed into farmland and the newly increased natural woodland came from grassland, saline alkali land and sand.

![Figure 6. The spatial distribution of different change of natural woodland in the study area from 1990 to 2015.](image)

3.4 Driving forces of changes

From 1990 to 2015, the land use degree of the study area showed a significantly increasing trend, which was mainly caused by the expansion of farmland and residential land with a high land use degree grading index (Figure 8), while the influence by the other land use types was not remarkable. In addition, the overall land use degree was low between the natural and agricultural land use level, and the reason was that there were a high ratio of the land use types with a low land use degree
grading index, such as natural woodland, grassland, sand and saline alkali land (Figure 9).

In the past 25 years, the natural woodland area in the study area reached higher level in the middle terms (1995-2005), while remained lower at both ends, and the overall natural woodland area increased 59km². It was influenced by natural factors in early stages, and later by the impact of human activities. The increasing farmland and residential land squeezed the living space of the natural woodland (Figure 8), which made the natural woodland area of 2005-2015 tended to decrease. On the other hand, the dynamic changes of natural woodland in 1990-1995 and 2005-2010 were the most dramatic, which increased significantly in 1990-1995, and 2005-2010 for a substantial reduction.

![Figure 7](image).

**Figure 7.** The transition area (A) and percentage (B and C) of natural woodland in the study area from 1990 to 2015.

![Figure 8](image).

**Figure 8.** Variation tendency of the residential land area (A) and farmland area (B) in the study area from 1990 to 2015.
Figure 9. The proportion of each land use type in the study area

The transfer features of natural woodland mainly were natural woodland turned to farmland while grassland and saline alkali land turned to natural woodland during the last 25 years. Influenced by the agricultural and economic development, a large number of original natural woodland had been developed into farmland and residential land, therefore natural woodland tended to develop outward under the artificial squeeze. So there was a large part of the grassland and saline alkali land (which is located at the border between oasis and desert) transferred to natural woodland. However, there were no changes of vast areas of natural woodland on both sides of the Tarim River in the past 25 years, because it is difficult to develop in the region along the river, and the natural woodland along the river has very important value of ecology, economy and sociology so as to be protected by the government.

4. Uncertainty analyses

Data is the basis of the research, and the long-term temporal LUCC analysis usually requires the utilization of multi-temporal and multi-sensor images, which may incur problems such as unmatched image parameters. In order to minimize the impacts of inconsistency among images, we chose the Landsat TM/ETM+/OLI series data as the data source and ensured its imaging time mainly concentrated in August with high vegetation coverage. But influenced by the seasonal rivers, missing of some data and the uncertainty of interpretation, the consistency of the data was not high enough, so there was some difference between the research results and the actual level.

5. Conclusions

In this study, we quantitatively analyzed the dynamic change of the natural woodland over UTR in recently 25 years. This study indicated that the natural woodland had an intense change, especially the transition changes as to grassland and farmland. The changes were significantly influenced by human activities, particularly on the agriculture activity. The results of this study can offer an useful insight on reasonable land use, and provide available information to the policy makers so as to make scientific decision, and promote the implementation of the “The Belt and Road” strategy and regional ecological environment conservation and socio-economic sustainable development.

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