Spatiotemporal dynamics of climate and agricultural landscape patterns in Xinjiang, China (2000-2015)

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Abstract. This study integrated remote sensing, geographic information system, landscape ecology, and spatial analysis, and is based on meteorological data and four remote sensing images (2000-2015). The aim of this study was to analyse climate trends and spatiotemporal changes in agricultural landscape patterns, and calculate agricultural ecosystem service value (AESV) in Xinjiang, China. In addition, correlation analysis further enabled the quantification of agricultural landscape pattern changes in response to climate change. Results showed that temperature and precipitation registered a fluctuating ascending trend in most areas of Xinjiang. Landscape diversity and fragmentation increased during the same period. AESV showed a trend of gradual increase, the waste disposal and the water retention are the most important ecological functions. Besides, agricultural landscape pattern significantly correlated to climate and the effect of precipitation on agricultural landscape patterns has been greater than the effect of temperature during 2000-2015.

1. Introduction
Sustainable development is a key factor that characterizes modern agricultural practices [1, 2], and ecological agriculture is the foundation for the sustainable development of agriculture. Thus, ecological agriculture has gradually become a relevant research topic [3]. An agricultural landscape is formed by the interaction of a patch, which is one of the most widely distributed landscape types in the world. Indeed, because of the effects of the natural environment and human activity, agricultural landscape structures are constantly changing, and tremendous efforts have been made to understand the driving forces [4] underlying agricultural landscape patterns, and their ecological environmental effects [5] and so on. Recently, climate change characterized by global warming has become one of the most important environmental problems in the world [6]. Climate change has not only a significant impact on agricultural production [7, 8], but also leads to alterations in the composition, structure, and function of agricultural ecosystems, as well as changes in biodiversity [9]. Studies on the dynamic changes of agricultural landscapes as a result of the background effects of climate warming will make great contribution to farmers and science community [6]. Agricultural ecosystems play important roles in water conservation, gas regulation as well as in many other dynamics [10], and agricultural ecosystem service value (AESV) is one embodiment of agricultural ecological effectiveness. In previous work, Costanzo [11] has had the most far-reaching impact on the quantification of values for global ecosystem services.
The goals of this study are to: analyze climate trends and spatiotemporal changes in agricultural landscape patterns during 2000-2015; calculate AESV of Xinjiang; and further quantify agricultural landscape pattern changes in response to climate change.

2. Materials and methods

2.1. Study area
Xinjiang is located in the northwest of China (73°32′–96°21′E, 34°22′–49°33′N), and encompasses about one-sixth of total Chinese land area. Indeed, large variations in temperature, reduced precipitation, and a dry climate with the annual precipitation of only 167.1 mm and the annual average temperature of 10°C are observed [12]. In Xinjiang, agricultural production predominates, especially cotton production, and the area of cultivated land is the largest in China. As the core area of the Silk Road Economic Belt, the agricultural development of this region is hugely important to economy [13], but because this region comprises arid and semi-arid inland environments, conditions for the development of ecological agriculture are relatively poor [14].

2.2. Data sources and analysis
Four periods of Chinese remote sensing land use data for 2000, 2005, 2010, and 2015 were collected from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (http://www.resdc.cn). These data were visually interpreted from Landsat TM/ETM remote sensing images and comprise six types. In this study, agricultural landscape is defined as including farmland, forest, grassland, and water.

Meteorological data (2000-2015) were retrieved from National Meteorological Administration, including meteorological stations (54), which have data of daily precipitation, and daily average temperature. The Kriging interpolation, which takes sufficiently the size, shape and spatial position of the certain points into account, especially the correlation of spatial position between the unknown points [15], was calculated to obtain a spatial distribution map of extreme highest temperature (EHT), extreme lowest temperature (ELT), annual average temperature (AAT) and annual precipitation (AP) via ArcGIS.

Grain crop data were extracted from the ‘Xinjiang Statistical Yearbook’ and ‘National Agricultural Product Cost and Income Data Compilation’. The major crops in Xinjiang include rice (6%), wheat (50%), corn (40%), and barley (2%).

2.3. Landscape metric analysis
Landscape metrics can be used to effectively reflect information on landscape patterns from structural composition and spatial distribution characteristics. In order to reflect properties of a whole landscape, highlight important features and avoid redundant information, metrics including total landscape area (TA), patch density (PD), Shannon's diversity index (SHDI), contagion index (CONTAG) and aggregation index (AI) for this study were selected. Landscape metrics were calculated using Fragstats 4.2 software.

The equation for the calculation of change in agricultural landscape pattern was as follows:

\[ R = \frac{V_{t+n} - V_t}{V_t} \times 100\% \]  \hspace{1cm} (1)

Where \( R \) is the change rate of agricultural landscape metrics between the year \( t+n \) and year \( t \), \( V_{t+n} \) is the landscape pattern metric for the year \( t+n \), \( V_t \) is the landscape pattern metric for the year \( t \), \( n \) is the time interval.

2.4. Assessment of AESV
According to Xie et al [16], the equation used for assessing ecosystem service values is as follows:
\[ E_a = \frac{1}{7} \sum_{i=1}^{n} m_i \cdot p_i \cdot q_i \]  

(2)

Where \( E_a \) is the value of the unit equivalent factor, \( p_i \) is the national average price for crop \( i \), \( q_i \) is the unit yield for crop \( i \), \( m_i \) is the growing area for crop \( i \), and \( M \) is the total planting area for all crops. The ecosystem service values for different land use types were calculated using the following equation:

\[ AESV = \sum (A_k \times VC_k) \]  

(3)

Where \( AESV \) denotes the ecological service value, \( A_k \) represents the area of land use of \( k \) type, while \( VC_k \) is the ecological service coefficient of this land use type.

3. Results and discussion

3.1. Climate change

![Climate of Xinjiang (2000-2015).](image)

**Figure 1.** Climate of Xinjiang (2000-2015).

|               | EHT | ELT | AAT | AP  |
|---------------|-----|-----|-----|-----|
|               | T1* | T2  | T3  | T1  | T2  | T3  | T1  | T2  | T3  |
| Aksu          | -1.8| 0.8 | 1.4 | -2.8| 0.4 | 1.8 | -0.5| 0.8 | -0.5| 46  | 69.2| -16.4|
| Altay         | -0.9| 0.5 | 0.0 | -2.1| 0.2 | 1.5 | 0.3 | -0.9| 1.2 | -4.1| 75.4| -56.8|
| Korla         | -1.3| 0.9 | 1.6 | -1.3| -0.6| 2.0 | 0.3 | 0.3 | 0.3 | 5.9 | 11.7| 32.7 |
| Bole          | -0.1| -0.8| 2.7 | -4.0| 1.4 | 1.9 | -0.6| 0.2 | 0.1 | 46.3| 109 | -53.4|
| Changji       | -1.1| 0.1 | 1.1 | -2.3| -2.3| 4.0 | 0.6 | -0.5| 0.8 | -14.4| 75.7| 19.9 |
| Hami          | 0.3 | 1.0 | -1.3| -1.5| -0.7| 2.3 | 1.3 | -0.3| 0.7 | -3.8 | 5.6 | 64.3 |
| Hotan         | -1  | 0.7 | 0.2 | -0.1| 0.1 | -0.1| -0.4| 0.9 | -0.6| 43.9 | 63.9| 10.2 |
| Kashi         | -0.6| 1.2 | -1.0| -0.3| 0.0 | 0.0 | -0.9| 1.2 | -1  | 78.3 | 75.3| -16.5|
| Karamay       | -0.4| 0.1 | 1.4 | -3.3| 2.0 | 0.4 | -1.3| 0.1 | 0.1 | 72.9 | 92.9| -32.4|
| Artax         | -0.6| 2.1 | -3.2| -2.3| 0.4 | 1.0 | -0.3| 1.1 | -0.8| 81.7 | 29.2| 22.9 |
| Shihezi       | -0.9| 0.3 | 2.2 | -2.9| -1.5| 3.8 | -0.5| -0.2| 0.4 | -6.5 | 104.2| -41.8|
| Tacheng       | -0.4| -0.2| 1.4 | -2.8| 1.3 | 0.7 | -0.3| -0.2| 0.4 | 25.3 | 91.8| -38  |
| Turpan        | -1.2| 0.3 | 1.8 | -0.2| -0.9| 1.1 | -1.5| 0.3 | 0.2 | 21.5 | 74.3| 15   |
| Urumqi        | -1.2| -0.3| 1.6 | -2.6| -2  | 3.8 | 0.7 | -0.9| 1.2 | -75  | 74.8| -7.9 |
| Yining        | -0.8| -0.2| 2.7 | -4.0| 2.4 | 1.1 | 2.0  | 0.1 | 0.3 | -83  | 58.3| 37.7 |

*a* T1, T2, and T3 represent the years 2000-2005, 2005-2010, and 2010-2015.
Results show that EHT, AAT, and AP all conform to a fluctuating ascending trend in most areas of Xinjiang, while the ELT declined. On the whole, climate change is relatively mild while there has been a significant change in precipitation as shown in figure 1. Table 1 shows changes of climate in each region of Xinjiang. From 2000 to 2015, changes of temperature and precipitation exceeded 1°C and 50 mm in many regions, among them, climate change in Karamay, Kashgar and Urumchi are most obvious. Distribution of EHT has gradually increased from northwest to southwest; meanwhile, the distributions of ELT and AAT are characterized by a gradual decrease from south to north. Of these, EHT in the Turpan was the highest, ELT and AAT in the Altay were lowest, and AAT in Hotan was the highest. In addition, because water vapor in this region comes mainly from the Atlantic and Arctic oceans, the precipitation distribution is characterized by enhancement from south to north and from east to west as shown in figure 2.

**Figure 2.** EHT (°C) (a), ELT (°C) (b), AAT (°C) (c), and AP (mm) (d) for Xinjiang (2000-2015).

### 3.2. Changes in agricultural landscape patterns

During 2000-2015, the pattern of agricultural landscape in Xinjiang in terms of area can be characterized as follows: grassland > farmland > water > forested land. Because of the impact of various natural, economic factors (GDP, industrial structure, etc.) and social factors (population, national policy, etc.), unused land in Xinjiang has been vigorously developed, resulting in a gradual increase in farmland area. In addition, the area of grassland has significantly declined, while areas of forested land and water first increased and then decreased over the time period of interest as shown in
figure 3. Overall, the total area considered as agricultural landscape has tended to grow as shown in table 2, with the major source being development and utilization of unused land. As a result of the continuous development of western regions, agricultural development in Xinjiang has gradually expanded.

![Figure 3. Land use in Xinjiang (2000-2015).](image)

|        | 2000      | 2005      | 2010      | 2015      | Change rate (%) |
|--------|-----------|-----------|-----------|-----------|-----------------|
| TA (1000 ha) | 62475.3   | 62707.8   | 62918.3   | 63025.7   | 0.4 0.3 0.2    |
| PD     | 0.014     | 0.015     | 0.016     | 0.016     | 13.2 1.9 1.3   |
| CONTAG (%) | 60.5      | 59.5      | 59.1      | 58.9      | -1.6 -0.7 -0.3 |
| SHDI   | 0.97      | 0.98      | 1.01      | 1.01      | 1.2 1.1 0.3    |
| AI (%) | 88.2      | 87.6      | 87.5      | 87.4      | -0.7 -0.1 -0.1 |

Results show that both PD and SHDI have gradually increased as shown in figure 4 and table 2. Landscape fragmentation and heterogeneity within agricultural landscape patches has increased, and this landscape type has become more abundant. A gradual reduction in CONTAG has resulted in connectivity of landscape mosaics as well as a balanced spatial distribution of various landscape patches. In addition, a gradual decrease in AI has translated into a reduction in aggregation degree of the same patch type. During 2000-2015, the change rates of the various landscape metrics have continuously lowered, and there has been a more substantial landscape pattern change in northern Xinjiang compared to the south. This result shows that the agricultural landscape pattern in Xinjiang has gradually stabilized, while development in the northern regions is faster than in the south.

3.3. Changes in ecosystem service values
As a result of the development of eco-agriculture in Xinjiang, development efforts in the inland desert area have been re-invigorated, leading to constant increases in both farmland area and crop yield. In addition, substantial increase in prices has led to an increase in the value of an agricultural ecological unit equivalent factor in the period 2000 to 2015, 1034 Yuan/hm², 1060 Yuan/hm², 1713 Yuan/hm², and 2159 Yuan/hm², calculated using equation (2) for the years 2000, 2005, 2010, and 2015, respectively.
Figure 4. Changes of agricultural landscape metrics in each region during different temporal intervals.

Results indicate that the total AESV for this region has continuously improved, from 715.4 billion RMB Yuan to 1528.7 billion RMB Yuan, in the period 2000 to 2015. In terms of different land use types, the ecosystem service value for grassland is the highest, followed by water, forested land and farmland as shown in figure 5(a). Ecosystem service values for water, forested land, and farmland
have continuously increased, while this value for grassland declined in 2010. In sum, ecosystem service values produced on the basis of ecological function can be summarized as follows: waste disposal > water retention > soil formation and protection > biodiversity conservation > climate regulation > gas regulation > entertainment and culture > food production > raw materials as shown in figure 5(b), reflecting the large waste disposal capacity of forests and grassland, and the regulatory function of water bodies in Xinjiang.

Figure 5. AESV during 2000-2015.
The numbers 1-9 refer to gas regulation (1), climate regulation (2), water reservation (3), soil formation and protection (4), waste disposal (5), biodiversity conservation (6), food production (7), raw materials (8), and entertainment and culture (9).

3.4. Agricultural landscape patterns in response to climate change
Using the agricultural landscape metrics and meteorological data for the 15 prefectures in Xinjiang (listed in table 1) for the years 2000, 2005, 2010, and 2015, the relationships between meteorological factors and agricultural landscape patterns were quantitatively analyzed using Pearson’s correlation coefficients. Generally, EHT, ELT and AAT were significantly positively correlated to TA, CONTAG, and AI, and have a significant negative correlation to PD and SHDI. Of these, the highest correlation was observed between average temperature and TA, while the rise in average temperature extends into the allowable range of agricultural development, resulting in an increase agricultural landscape area. In contrast, AP was significantly negatively correlated with TA, CONTAG, and AI, but showed an obviously positive correlation to PD and SHDI. During 2000-2015, a changing pattern in AP is most significantly correlated with CONTAG, SHDI, and AI as shown in table 3.

Results show that landscape diversity, the extent of landscape fragmentation, and heterogeneity within patches decreased while aggregation increased as temperature rose. In contrast, an increase in precipitation led to increases in landscape diversity and fragmentation, as well as a reduction in heterogeneity within patches and aggregation. In the period between 2000 and 2015, both temperature and precipitation increased in Xinjiang while PD and SHDI rose, and CONTAG and AI decreased. These results suggest an enhanced effect of precipitation on the agricultural landscape patterns in the area.

Table 3. Pearson’s correlation coefficients between landscape metrics and climate characteristics.

|       | TA    | PD    | CONTAG | SHDI  | AI    |
|-------|-------|-------|--------|-------|-------|
| EHT   | ns**  | ns**  | 0.40   | -0.39 | 0.41  |
| ELT   | 0.49** | -0.42** | 0.39** | -0.40 | 0.36**|
| AAT   | 0.53** | -0.39** | 0.456** | -0.47 | 0.43**|
| AP    | -0.52** | -0.47** | -0.63** | 0.62  | -0.61**|

*No significant correlation; **p<0.01.
4. Conclusion
This study analyzed climate trends and spatiotemporal changes in agricultural landscape patterns in Xinjiang over the last 15 years, and evaluated the AESV. In addition, correlation analyses were used to quantify the association between agricultural landscape patterns and climate change. The study provides the scientific basis for the development of ecological agriculture, and promotes the sustainable development of agriculture into the future. However, because landscape pattern variations are the manifestation of the mutual interaction of natural environmental and human activities, the future work is to quantitatively analyze the driving force and influence mechanism.

Acknowledgments
The study was supported as a data compilation and processing project, National Special Program on Basic Works for Science and Technology of China (No. 2013FY110900).

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