Quantitative analysis of land use and land cover changes from the multi-temporal remote sensing data in the Bosten Lake Basin, Chinese Tian Shan

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Abstract: In this paper, the spatial changes of land use and land cover (LUCC) in Bosten Lake Basin from 1985 to 2015 were analyzed, based on the 3S technology and four periods of remote sensing images in 1985, 1998, 2008 and 2015. The driving force of the LUCC was analyzed quantitatively using principal component analysis (PCA) method. The results showed that there was a wide change of LUCC in the Bosten Lake Basin in the past 30 years. During this periods, natural grassland decreased with a rate of 62.6 km²/a, while cultivated land and residential land increased with a rate of 28.9 km²/a. The rapid expansion of cultivated land was the result of natural grassland and unused land reclamation. Meanwhile, other land use types changed slightly. The results of PCA analysis indicated that the LUCC change was result of the interaction of human activity (social and economic factors) and natural environmental changes (climate change). Therefore, it is necessary to consistently improve the natural environment of Bosten Lake Basin. This study can provide stable basis of the theory and practice for sustainable development of Bosten Lake Basin.

Key words: Bosten Lake Basin; Land use land cover; Human activities; Climatic change

1. Introduction

The dynamics of regional land use and land cover change (LUCC) play an important role in present strategies and policies for natural resource management and monitoring. In arid and semi-arid
environments, the LUCC often reflects the most sensitive indicator for the environmental changes because of human activities and natural forces[1]. At present, many international big projects, including the International Geosphere-Biosphere Program (IGBP), the International Human Dimension Program (IHDP), the World Climate Research Program (WCRP), and the International Program of Biodiversity Science (IPBS) have begun to research the relationship between land use and the hydrological cycle [2]. Recently, numbers of research results have showed that human being can understand natural ecosystem changes in the certain level by analyzing the modes of land use in the past, present, and future [3]. In addition, LUCC is an important factor that can modify hydrological traversing in the range of temporal and spatial scales in arid and semi-arid area.

2 Materials and methods

2.1 Study Area

Bosten Lake Basin (41°56′ N – 44° 40′ N; 86°14′ E – 90°56′ E) is located on the southern slope of the Tianshan Mountains and lies in the southeastern part of Yanqi Basin (Figure 1). The Yanqi Basin borders the Tianshan Mountains and the Kuruktag Mountains in the north and west, and it linked with Taklimakan desert in the south. Bosten Lake is one of the largest inland freshwater lakes in China with a surface area of 1000 km². The maximum water depth is 16.2 m, while an average depth is 8 m.

2.2 Data collection and data processing

This study used remote sensing images, climate data and Socio-economic statistical data to analyze the LUCC situation in the study area in the past 30 years and to assess the driving force quantitatively. The remote sensing data include Landsat TM / ETM and OLI image in 1985, 1998, 2008, 2015 respectively. In this paper, the data processing has completed using ENVI 5.0 and ArcGIS 10.2 software. We obtained the LUCC data from TM / ETM / OLI imagery, visual interpretation was based on image characteristics such as color, shape, size, shading, texture, structure, and relative spatial distribution of each class of land cover. We used a six-type classification system provided by the Resources and Environment Database of Chinese Academy of Sciences including cultivated land, forestland, grassland, water body, residential and industrial land, and unused land.

2.3 Study methods

(1) LUCC dynamic degree model

In this paper, regional difference in land use characteristics were determined using the land use dynamic degree model that could be mathematically expressed by the following relationship [4]:

![Figure 1. Location of the Bosten Lake Basin.](image-url)
\[ S = \sum_{i} \left( \frac{S_i - S_0}{S_0} \right) \times 100\% \]

where \( S \) is the LUCC rate, \( S_0 \) is the beginning of the monitoring period, \( n \) is the time period, and \( S_n \) is ending of the monitoring period. In a comprehensive manner, the dynamic degree represented the change of land use in the study region.

(2) Estimate the contribution of driving forces

This paper utilized PCA to assess the contribution rate of human activity and climatic force on LUCC changes in BLB.

3. Results and discussion

3.1 The characteristics of LUCC in BLB

The big change of land use and land cover is emerged in the middle part of the BLB. Table 1 and Figure 2 showed that cultivated land, grassland, unused land and water land were the main land use types in BLB in past thirty years, and they accounted for about 98.8% of the total area. Those land use types were responsible for the 92.2% of land use change during whole periods (1985~2015).

| Land use type | 1985 (km²) | 1998 (km²) | 2008 (km²) | 2015 (km²) | 1985-1998 (%) | 1998-2008 (%) | 2008-2015 (%) | 1985-2015 (%) |
|---------------|------------|------------|------------|------------|---------------|---------------|---------------|---------------|
| cultivated land | 2738       | 2872       | 3262       | 3606       | 4.9           | 13.6          | 10.6          | 31.7          |
| forest land   | 754        | 804        | 935        | 827        | 6.6           | 16.3          | -11.6         | 9.7           |
| grassland     | 26045      | 25864      | 23935      | 24167      | -7            | -7.5          | 0.97          | -7.2          |
| water area    | 6185       | 6129       | 6256       | 6259       | 0.9           | 2.1           | 0.05          | 1.2           |
| residential land | 163        | 395        | 468        | 547        | 34.8          | 18.5          | 16.9          | 86.68         |
| unused land   | 38954      | 38775      | 39983      | 39433      | -12.6         | 3.1           | -1.4          | 1.6           |

Land use types including cultivated land, forest land, residential land and unused land increased respectively by 31.7%, 9.7%, 1.2%, 86.68%, 1.6% during the entire period, while the areas of grassland decreased by 7.2% in the same period. Figure 2 shows that the LUCC of the study area mainly occurred in the southeast part of the Hejing county and middle part of BLB, as well as upper part of Yuli county. It can be known that there has been a wide change in land use and land cover in BLB in recent 30 years. The order of the change from large to small is as follows: residential and industrial land > cultivated land > forest land > grassland > unused land > water land. It showed that the expansion of cultivated land was contributed by the reclamation of grassland.

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3.2 Determination of the Driving forces for the LUCC in the BLB

It is apparent that both natural factors and human activities, and most likely their interactions were being the driving forces for tempo-spatial changes of the LUCC in Bosten Lake Basin from 1985 to 2015. Climatic conditions have play restraining role in utilization of land, which mainly shown in the distribution and composition of topography, grassland and forest, water resource, farming system and yield. Compared with the natural driving forces, human activities may have concentrated and immediate impacts on LUCC, whose effects usually take relatively long times to become noticeable.

In order to identify influential factors of LUCC change in BLB, we selected important factors to find out the main components of LUCC. For identifying the driving forces of LUCC in the BLB, this research take the cultivated land and residential land change quantity as the main changed land use types. According to PCA method, nine analysis factors are selected such as irrigation volume (X1), runoff volume (X2), temperature (X3), precipitation (X4), irrigated area (X5), GDP (X6), Per capita GDP (X7), population (X8) and primary industry (X9) etc.

The results of principal component analysis revealed that the accumulative contribution rate of the first and secondary principal components is 87.9% (Table. 2), which is larger than 85% threshold value of accumulative contribution rates. Thus, it is fit with the principal component analysis requirement. Therefore, most variation could be explained by two principal components. The accumulative contribution percentage of the first principal component is larger than the secondary principal component, and the first principal component has controlled the most of the changes in the whole changing process. The results showed that there is an obvious positive correlation between the first principal component and observation variables X1, X5, X6, X7, X8 and X9, and the correlation coefficients are more than 0.9. Similarly, there is significant a positive correlation between the secondary principal component and the observation variables X2, X3, X4, and correlation coefficients are over 0.83.

Table 2. Contribution rate of characteristic values and principal components.

| Component | Eigen values | % of Variance | Cumulative % |
|-----------|--------------|---------------|--------------|
| 1         | 6.308        | 63.084        | 63.084       |
| 2         | 2.482        | 24.820        | 87.904       |

Table 3. (Principal component) matrix.
From the Table 3, it can be indicated clearly that the first principal component which influences the change of cultivated land and residential land in BLB over the past thirty years shall be human activities. Those human activities include mainly the population growth and economic development. Therefore, it is determined that the first principal component is Socio-economic factors. The secondary principal component is composed by three factors and the sequence of their impact can be ordered as runoff volume > precipitation > temperature. The second principal component is related with hydro-climatic factor, which is defined as the natural factors.

4 Quantities analysis of driving force in BLB
4.1 Analyzing the influence of Socio-economic factors

PCA results indicated that, first principal component contains 63% of the variation rate, it is the main principal controlling factor and it can control the change of the other principal component. In the space, the first principal component express the social progress and the regional development process, as well as the impacts of human activities on the development of natural resources.

4.1.1 Impact of population growth on LUCC.

Population growth can be an essential driving force for LUCC in the study area, and meanwhile, the dynamics of population can be a response to the change of environment (Zhao et al., 2013). The population of the BLB was $58.3 \times 10^4$ in 1985, $69 \times 10^4$ in 1990, $99 \times 10^4$ in 2000, $121.3 \times 10^4$ in 2010, and $146.8 \times 10^4$ in 2015 (Xinjiang Uygur Autonomous Region Years Book, 1985～2015). The population growth directly resulted in expansion of socio-economic related land uses. First, the growing population required more land to meet basic needs of living, including food and place of residence. Second, the population’s desire for economic development demanded more land for producing commodities. Particularly in this area, a significant proportion of cultivated land has been devoted to the profitable cotton production. Figure. 3 shows the correspondence between the growths of population and cultivated land in the BLB during 1985～2015. The correlation coefficient between the population and cultivated land is 0.942. The cultivated land had a slow growth from 1985～2000, and then had a jump during 2000～2015. With the continuous growth of population, large areas of wasteland and natural grassland had been reclaimed for cultivation. The area of cultivated land increased during 1985～2015, at the same time the population maintained a rising trend.

| Component | irrigation volume | runoff volume | temperature | precipitation | irrigated area | GDP | per capita GDP | population | primary industry |
|-----------|------------------|--------------|-------------|---------------|----------------|-----|---------------|------------|-----------------|
| 1         | 0.954            | 0.119        | -0.269      | 0.260         | 0.911          | 0.958| 0.972         | 0.981      | 0.969           |
| 2         | 0.060            | 0.905        | 0.830       | 0.833         | 0.077          | 0.321| 0.114         | 0.018      | 0.068           |
4.2 Analyzing the Influence of natural factors

In BLB, the LUCC is largely controlled by the volume and spatial distribution of water. In addition, climate factors including temperature and precipitation has a considerable effects on the LUCC. The mountain region of BLB is the characterized with abundant precipitation. The mountain areas are the formation zone of runoff. Then, the runoff flow into oasis and the desert region in the study area. Under global climate change, the runoff in the BLB has been experiencing a drastic change, and it is also a major driving factor for the LUCC.

4.2.1 The climate changes.

Figure 4 shows the temporal variation of climate in the BLB during 1985～2015. The temperature of the study area had an increasing trend, especially in recent two decades (1995～2015). The average annual temperatures during 1995～2015 (8.8 ℃) are higher than those during 1985～1994 (8.71 ℃). In past three decades, the precipitation also had a slightly increasing trend. The average annual precipitation for 1995～2015 (140.5 mm) is more than that for 1985～1994 (114.21 mm). On the one hand, the increases of precipitation in the study area were certainly beneficial to both the human system and natural vegetation in those areas, alleviated the competition between the two systems for water. On the other hand, the increased precipitation and the warming trend in the mountain region that had accelerated the melting of snow and glaciers had resulted in increased runoff, which bring positive effect for expansion of cultivated land. However, the extra water from the upstream areas in the form of runoff has given humans more control in the use and allocation of the water.
4.2.2 Hydrological change.

Figure 5 shows that the runoff of the Kaidue River had an increasing trend during the past three decades. In the most recent two decades, the average annual runoff of the Kaidue River in 1985, 1995, 2005, and 2015 are $29.8 \times 10^8$ m$^3$, $34.18 \times 10^8$ m$^3$, $42.59 \times 10^8$ m$^3$, and $42.8 \times 10^8$ m$^3$, respectively, with the amount of the second 10 years is greatly larger than that of the first 10 years. The average annual runoff of 1995~2015 is $39.9 \times 10^8$ m$^3$, a 3.2% increase compared with that of 1985~1994. It is apparent that the runoff of the northwest arid area strongly depends on glaciers. Glacier change has a significant impact on water resources change in the northwest arid area. The influence of temperature on Glacier is mainly expressed in the change of melted water, and in this way the temperature change result in the change of runoff amounts the arid region.

5. Conclusions

From the results, the following conclusions can be drawn: (1) From the four inch of remote sensing image interpretation, it was found that From 1985 to 2015 as the expanding land use types cultivated land, forest land, residential land and unused land increased 31.7%, 9.7%, 1.2%, 86.68%, 1.6% respectively, while the areas of grassland decreased 7.2% in the same period; (2) The result of PCA indicated that the observed LUCC have been caused by a combination of human activities and climate factor, and the first principal component contains 63% of the variation rate, it is the principal controlling factor and it can control the change of the other principal component; (3) the second component contains 24.8% of the variation rate, it is also one of the main component which significantly contribute to changes the LUCC.
Figure 5 Changes of Runoff and cultivated land in the BLB during 1985 ~ 2015.

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