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Temporal and Spatial Evolution of Lakes in the Bashang Plateau for Nearly Recent 30 Years

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Abstract

Lakes are important ecological water sources in the Bashang Plateau. Its expansion or shrinkage directly affects the ecological security of the plateau and its surrounding areas. In this study, Landsat images from 1984 to 2015 were selected to monitor the area of lakes in the Bashang Plateau and to analyze the spatiotemporal evolution and driving forces of lakes in the Bashang Plateau. The results showed that there were 47 lakes in the Bashang Plateau in 2015, with a total area of 37.63 km^2, mainly distributed in the central and western regions of the region. From 1984 to 2015, the lakes in Bashang Plateau showed a shrinking trend. At the same time, there are obvious stage differences in lake changes. During 1984-1996, the number of lakes increased by 99 and the total area increased by 124.43 km^2. From 1996 to 2015, the number of lakes decreased by 142, and the total area decreased by 183.96 km^2. Before 1996, climate change was the dominant factor. However, the shrinkage of lakes after 1996 is the result of climate change and human activities. Among them, the large-scale planting of water consuming crops such as vegetables is the main human activity mode leading to lake shrinkage. This study will help to understand the expansion and contraction factors of the Bashang Plateau lakes in Hebei province and provide a reference for the future protection and management of the lakes.

Keywords

Bashang Plateau, Lake Area, Spatial and Temporal Patterns Evolution, Driving Force

1. Introduction

Lakes are an important part of the terrestrial hydrosphere [1] and the link be-

tween the earth's surface layers [2] [3]. The expansion and shrinkage of lakes not only reflect the richness of regional water resources but also restrict the sustainable development of the local ecological environment and social economy [1] [4]. Mastering the temporal and spatial evolution law of regional lakes is the premise and foundation for the rational utilization of regional water resources and the realization of sustainable development of the social economy and ecological environment.

Bashang Plateau is located in the transition zone between North China Plain and Inner Mongolia Plateau, semi-humid and semi-arid climate transition zone, and agricultural and pastoral activity ecotone [5] [6] [7]. The ecological environment is sensitive to climate change and human activities [7] [8]. Bashang plateau lakes are numerous and widely distributed [9] [10] [11]. As an important regional ecological water source, its expansion or shrinkage directly affects the ecological security in the region. In recent years, lakes in the Bashang plateau have been shrunk and drying up obviously [9] [10] [11]. A series of eco-environmental problems caused by the changes in lakes directly restrict the sustainable development of the local ecological environment and social economy [12].

Understanding the spatial and temporal evolution characteristics of lakes in the Bashang Plateau is the premise of effective prevention and control of lake shrinkage and ecological environment problems. Many scholars have carried out a series of studies on this issue [9] [10] [11]. The results show that: in recent years, lakes in the Bashang plateau have shrunk significantly, and some lakes have dried up. Climate warming and drying (an increase in temperature, an increase of evaporation, a decrease of precipitation, etc.) and an increase in human activity intensity (an increase in farmland area, large area of afforestation, etc.) are the main causes of lake shrinkage in the Bashang Plateau [10] [11] [13]. However, there are still many problems in the existing researches: 1) most of the researches are aimed at a single lake or lakes in a single county; 2) The research time is discontinuous and the time series is short, so it is lacking continuous monitoring of long time series; 3) Most of the researches focus on the lake before 2010, but lack of understanding of the latest distribution of lakes in Bashang plateau. Based on this, this study combined Landsat images from 1984 to 2015 to monitor the area of lakes in the Bashang Plateau, analyzed the temporal and spatial variation of the lake area and further explored the internal driving mechanism of lake and lake evolution combined with meteorological data and human activity data.

2. Overview of Research Area

Bashang Plateau (N40˚57' - 42˚42' and E113˚49' - 117˚43') is located in the north of Hebei Province and on the southern edge of Inner Mongolia Plateau. Its administrative division includes all regions of Kangbao County, Zhangbei County and Guyuan County, Weichang Manchu and Mongolian Autonomous County, and part of Shangyi Counyr, Fengning Manchu Autonomous County, with a to-

tal area of 18,202 km^2 [6]. The plateau is high in the southeast and low in the northwest, and the altitude is between 1200 - 1500 m, which is an undulating plateau landform. Affected by topography, the Bashang Plateau has strong radiation, long sunshine duration and low temperature, with an annual average temperature of −0.3˚C - 3.5˚C. The Bashang Plateau is located in the transition zone of semi-humid and semi-arid climates. The precipitation in the region is less, the annual distribution of precipitation is uneven, the interannual variability is large, and the frequency of drought is high [7]. There are many lakes and a few inner rivers in the Bashang plateau. Except for a few areas belonging to Yongding River Basin and Luanhe River Basin, most of the areas are inland river basins [14]. Precipitation and runoff are the two main replenishment modes of lakes and lakes.

As the ecotone of agriculture and animal husbandry, the Bashang Plateau has developed into an agricultural economic structure with agriculture's main part and agriculture and animal husbandry mixed together. Agriculture plays an important role in the development of the regional economy [12] [14] [15]. In the arid area of the Bashang Plateau, the development of agriculture produces economic value consumes a lot of water resources at the same time. Especially in recent years, a large area of vegetable planting in the region has led to agriculture has become the largest water consumption mode of human activities in the Bashang Plateau [11] [14]. Taking the Bashang Plateau of Zhangjiakou City as an example, the total water supply of water conservancy projects in this area was 222.2902 million/m^2 in 2011, of which the agricultural water consumption was 186.9864 million/m^2, accounting for 84.12% of the total water supply in the whole region, and the water consumption of vegetables accounted for 89% of the agricultural water consumption [14]. Besides, in order to prevent and control vegetation degradation and soil wind erosion and desertification in Bashang Plateau, afforestation activities have been carried out in the large area since 1979, and transpiration of forest land also consumes a lot of water resources in the area [16] [17].

3. Data and Methods

3.1. Data Source and Preprocessing

The data used in this study include remote sensing data, meteorological data and statistical data. The remote sensing data are mainly Landsat satellite images, with a total of 121 scenes from the website (http://landsatlook.usgs.gov/). The downloaded remote sensing images are preprocessed by ERDAS software which includes radiometric calibration, geometric correction and projection coordinate transformation. The daily average temperature, daily precipitation data and daily average wind speed data of meteorological stations in the study area and its surrounding areas were downloaded from the national meteorological scientific data sharing service platform (http://data.cma.cn/) [18]. The potential evapotranspiration of each station is calculated using the Penman-Monteith formula recommended by FAO. The statistical data used in this study include grain yield, effective irrigation area, vegetable yield in Zhangbei County and Kangbao County

from 1984 to 2015, and forest land area data of Bashang Plateau in 1980, 1990, 1995, 2000, 2005, 2010 and 2015. Among them, the statistical data of livestock, grain yield, effective irrigation area and vegetable production were obtained from Hebei Rural Statistical Yearbook and Hebei Economic Statistical Yearbook. The area of forest land was obtained from the statistics of land use data products in China.

3.2. Method

At present, lake area monitoring methods include manual visual interpretation methods and automatic interpretation methods [3]. The manual visual interpretation method is simple and accurate [19] [20], but it is a time-consuming and heavy workload. The automatic interpretation method was highly automated and small workload, but it requires high quality of remote sensing images and is difficult to determine the threshold [20]. In order to ensure the monitoring accuracy, this study selected the manual visual interpretation method to monitor the Bashang Plateau lake (>0.1 km^2), and determined the following interpretation standard simultaneously (the minimum mapping unit is 3 × 3 pixels; The boundary interpretation error is controlled within 1 pixel).

In order to understand the change law of the lake area and its influencing factors, the linear least square method was used to calculate the interannual variation trend of meteorological elements and the interannual variability of the lake area θ_{slope}. The specific formula is as follows:

$$\theta_{\text{slope}} = \frac{n \times \sum_{i=1}^{n} i \times Y_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} Y_i}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2}$$

where n is the number of monitoring years; i is the i year of n years; Y_i represents the lake area or other element values in i year. At the same time, F was used to determine whether the changing trend was significant.

4. Results and Analysis

4.1. Spatial and Temporal Distribution Characteristics

4.1.1. Spatial Distribution Pattern

In 2015, there were 47 lakes (>0.1 km^2) in the Bashang Plateau, with a total area of 37.63 km. In order to reflect the distribution status of lakes in the Bashang Plateau more intuitively, the lakes are divided into three levels according to their area: lakes with an area of more than 5 km^2, lakes with an area of 1 - 5 km^2 and lakes with an area of less than 1 km^2. The number of lakes less than 1 km^2 on the plateau was the largest, accounting for 80.85% of the total. The number of lakes with the area of 1 - 5 km^2 was the second, accounting for 17.02% of the total. The number of lakes with an area greater than 5 km^2 is the least, with only one (**Figure 1**). In terms of area, the areas of lakes with the area of more than 5 km^2, 1 - 5 km^2 and less than 1 km^2 are 7.94 km^2, 18.41 km^2, 11.28 km^2, respectively, accounting for 21.09%, 48.92% and 29.99% of the total area of Bashang Plateau lakes and lakes in 2015 (**Figure 1**).

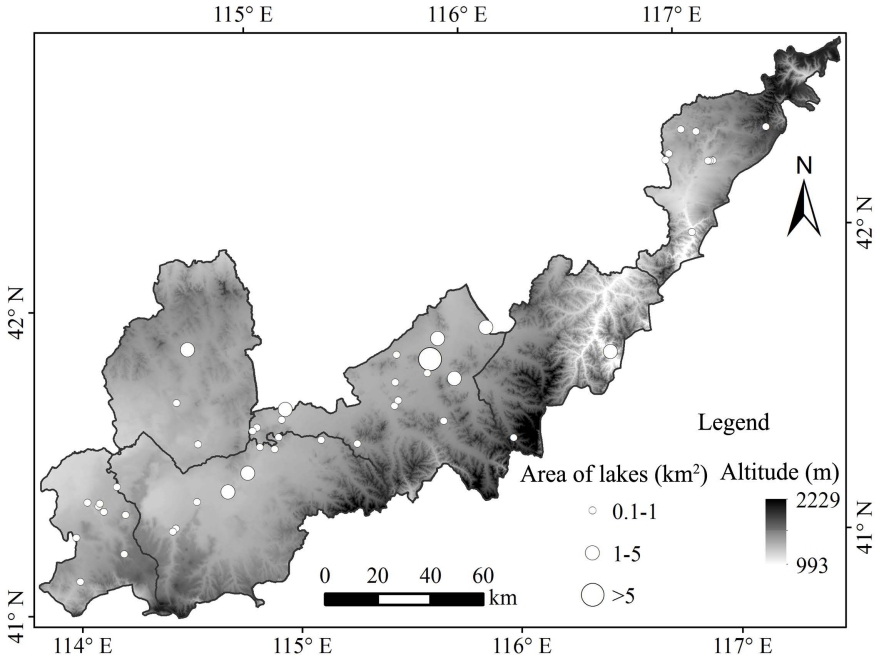


Figure 1. Spatial distribution of lakes (>0.1 km²) in the Bashang Plateau in 2015.

Spatially, Bashang plateau lakes are concentrated in the central and western regions. Among them, there are 21 lakes in Kangbao, Shangyi and Zhangbei counties in the west of the region, accounting for 44.68% of the total amount of lakes, and the total area of lakes is 10.87 km², accounting for 28.89% of the total area of lakes. There are 17 lakes in Guyuan and Fengning counties in the middle of the region, accounting for 36.17% of the total amount of lakes, and the total area of lakes is 25.03 km², accounting for 66.51% of the total area of lakes. The number of lakes in paddock Manchu and Mongolian Autonomous County in the east of Bashang Plateau is up to 9, accounting for 19.15% of the total amount of lakes. The total area of lakes is 1.73 km², accounting for 4.60% of the total area (**Figure 1**). The southern edge of the Bashang Plateau is higher, and the middle part is a wavy plateau with the alternating distribution of hills, beams and depressions. Under the influence of geological structure and topography, the surface runoff converges in the depression lakes. Therefore, the geomorphology of the Bashang Plateau is the main factor restricting the spatial distribution of lakes (**Figure 1**).

4.1.2. Temporal Evolution Law

From 1984 to 2015, the lakes in the Bashang plateau showed a shrinking trend. Compared with 1984, the number of regional lakes decreased by 43 in 2015, and the total area of lakes decreased by 59.53 km², equivalent to 61.27% of the total area of regional lakes in 1984. In terms of the changing trend, 227 lakes and lakes were shrinking from 1984 to 2015, mainly distributed in the central and western regions of the Bashang Plateau. There are 49 lakes and lakes with an expanding trend, which are scattered in the plateau (**Figure 2**).

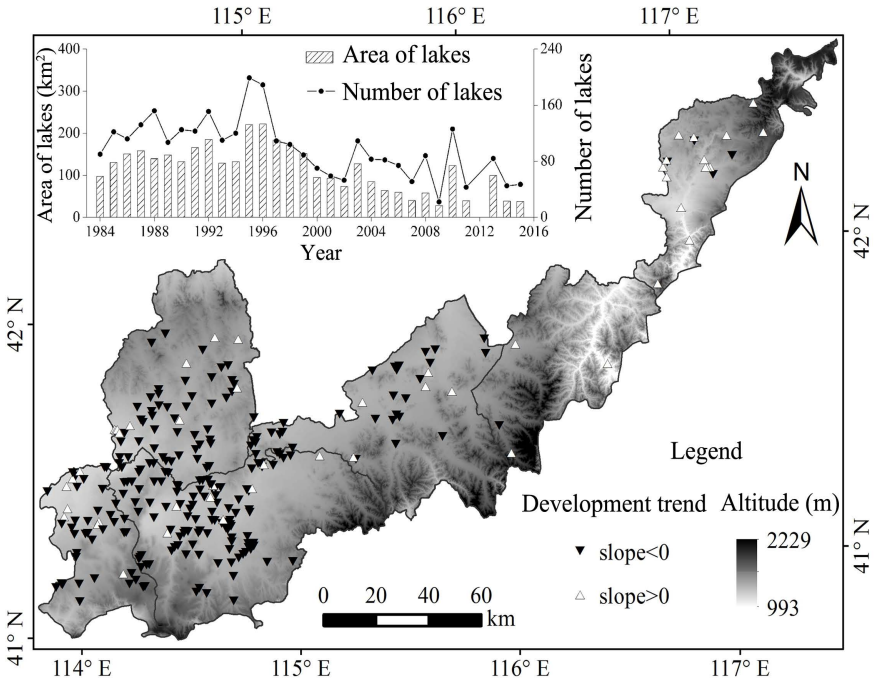


Figure 2. Change trend of lake area in the Bashang Plateau from 1984 to 2015.

In addition to the overall shrinking trend, the changing trend of lakes in the Bashang Plateau from 1984 to 2015 also showed obvious stage differences. Taking 1996 as the boundary, the lake showed an obvious expansion trend from 1984 to 1996. From 1996 to 2015, the lakes showed an obvious shrinking trend (**Figure 2**). From 1984 to 1996, the total area of lakes in the Bashang Plateau increased by 124.43 km^2, equivalent to 128.08% of the total area in 1984. Among them, the number of expanding lakes is 195, and the number of shrinking is 58 (**Figure 3**).

From 1996 to 2015, the number of lakes in the Bashang plateau decreased by 142, and the total area of lakes decreased by 183.96 km^2, accounting for 83.02% of the total area of lakes in 1996. Among them, there are 53 lakes with an expansion trend and 179 lakes with a shrinking trend (**Figure 4**).

4.2. Cause Analysis of Lake Change in the Bashang Plateau

Understanding the interaction of different factors in the evolution of lakes is the premise and basis for accurately predicting the future change trend of lakes and scientifically preventing and controlling lake shrinkage [21] [22] [23]. Precipitation and evaporation are the main meteorological factors affecting regional water resources. Agricultural activities are the main human activities in the Bashang plateau [10] [11]. Therefore, precipitation and evaporation are selected to represent climate factors, and the number of livestock, effective irrigation area, grain yield, vegetable yield and woodland area were selected to represent the human factors meanwhile. Based on the above data, this paper analyzes the main factors that caused the evolution of lakes in the Bashang Plateau since 1984.

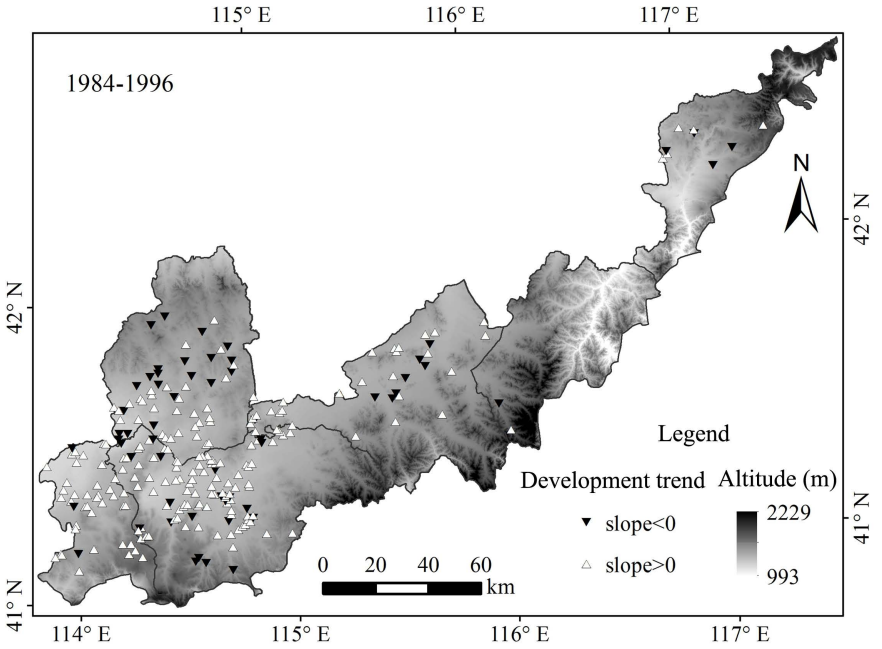


Figure 3. Variation trend of lake area in the Bashang Plateau from 1984 to 1996.

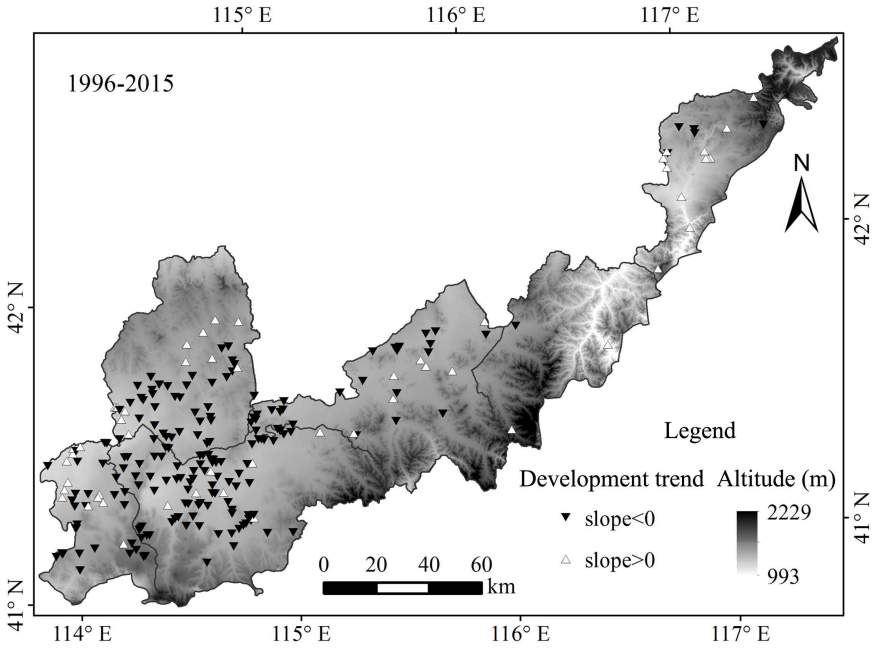
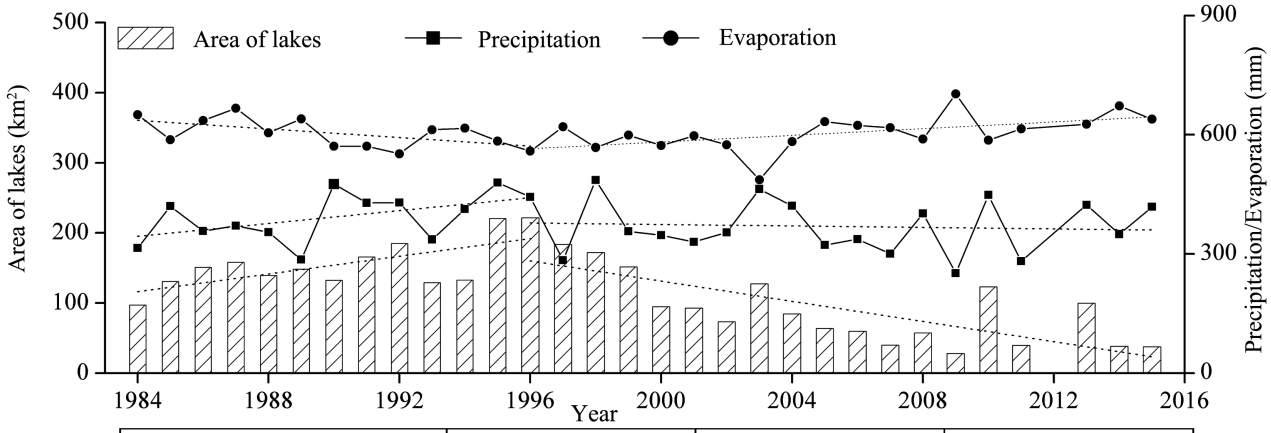


Figure 4. Change trend of lake area in the Bashang Plateau from 1996 to 2015.

The results showed that evaporation decreased significantly ($P < 0.05$) and precipitation increased in the Bashang Plateau from 1984 to 1996, and the humid climate was conducive to the enrichment of regional water resources (**Figure 5**). Different from the changing trend of meteorological elements, the effective irrigation area increased significantly from 1984 to 1996, but the vegetable yield and grain yield had no obvious change trend. The change in human activity intensity was conducive to the increase of water consumption of regional



Type		Evaporation		Precipitation		Area of lakes	
		θ_{slope}	p	θ_{slope}	p	θ_{slope}	p
Research period	1984-1996	-5.40	<0.05	8.11	0.07	6.32	<0.01
	1996-2015	4.22	<0.05	-0.92	0.74	-7.20	<0.01

Figure 5. Interannual variation of Bashang lake area and climate data from 1984 to 2015.

agricultural production and was not conducive to the expansion of lakes (**Figure 6**). However, the monitoring results showed that the lake area of the Bashang Plateau increased significantly from 1984 to 1996 ($P < 0.05$). Therefore, it can be inferred that the main reason for the expansion of regional lakes is climate wetting.

From 1996 to 2015, evaporation increased significantly ($P < 0.05$), precipitation decreased slightly, and climate drought was not conducive to the enrichment of regional water resources (**Figure 5**). In the same period, the effective irrigation area and vegetable yield increased significantly ($P < 0.05$), the forest land area decreased (**Figure 6**). The increase in effective irrigation area and vegetable yield leads to an increase in agricultural water consumption, and the decrease of forest land area results in the decrease of forest land transpiration water consumption. Meanwhile, the lake area and the number of the Bashang Plateau decreased significantly from 1996 to 2015 (**Figure 5**). The impact of climate change and agricultural activity intensity change on lakes is consistent with the actual change trend of lakes. Therefore, it can be inferred that the lake shrinkage in Bashang Plateau during 1996-2015 is the result of the joint action of climate change and human activities. The effective irrigation area increased significantly from 1984-1996 to 1996-2015 is 1.54×10^3 m^2/a and 1.03×10^3 hm^2/a respectively. From 1984 to 1996, vegetable production increased slightly, with an annual growth rate of 6900 t/a. From 1996 to 2015, vegetable production increased rapidly with an annual growth rate of 110,100 t/a. Crops planted in the Bashang Plateau mainly include buckwheat, potato, flax and vegetables [12]. Before 1996, although the effective irrigation area was increasing, buckwheat and flax were still the main crops, and the irrigation water consumption of these crops was relatively small. Since 1996, the planting structure has changed, and the vegetable

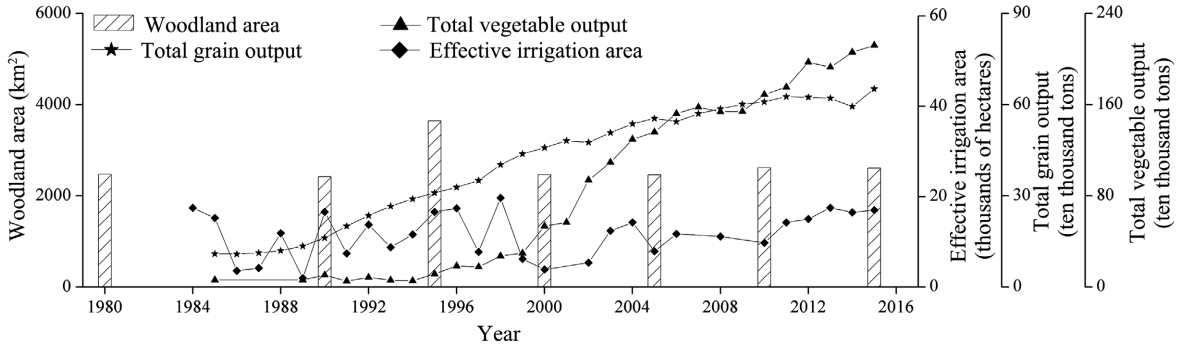


Figure 6. Interannual changes of forest land area and agricultural activity data of Zhangbei county and Kangbao county in the Bashang Plateau from 1984 to 2015.

planting area has increased rapidly, which has become the main channel of local wealth. Compared with other crops, the water consumption of vegetables is higher [14]. Therefore, it can be inferred that large-scale vegetable planting is the main agricultural activity leading to lake shrinkage.

5. Conclusions

The Bashang Plateau had 47 lakes in 2015, with a total area of 37.63 km^2. The small and medium-sized lakes with an area of fewer than 5 km^2 were mainly distributed in the central and western regions of the study area.

From 1984 to 2015, the lakes in the Bashang Plateau showed a shrinking trend, but the evolution trend of lakes in different periods was obviously different. Among them, the area and number of lakes in the Bashang Plateau increased significantly from 1984 to 1996, with the newly increased area of 124.43 km^2 and the number of lakes increased by 99. From 1996 to 2015, the area and number of lakes in the Bashang Plateau decreased significantly. The area of lakes in the Bashang Plateau decreased by 183.96 km^2, and the number of lakes decreased by 142.

The results of the driving force analysis showed that the evolution of lakes in the Bashang Plateau is the result of the interaction of climate change and human activities. Among them, climate change from 1984 to 1996 was the dominant factor in regional lake expansion. However, the lake shrinkage in the Bashang Plateau from 1996 to 2015 is the result of the joint action of climate change and human activities. The large-scale planting of water consuming crops such as vegetables may be the main human activity mode leading to lake shrinkage.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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