The Response of Lake to Glacier in Akesu River-Kaidu River Small Watershed during 30 Years

Hanwen Cui$^{1,2}$ and Qigang Jiang$^3$

$^1$ Department of Computer Science and Technology, Zhuhai College of Jilin University, Zhuhai 519041, China
$^2$ Zhuhai Laboratory of Key Laboratory of Education Ministry’s Symbol Computation and Knowledge Engineer, Zhuhai 519041, China
$^3$ College of geo-exploration science and technology, Jilin University, Changchun 130026, China

cuicui_0504@163.com

Abstract. Glacier is a sensitive indicator of the climate change, and also closely related to human beings. RS and GIS supply effective means to research the change of glacier. Those are important methods for compensating the shortage of previous ones. Small watershed is the basic unit of water circulation. Thus, the more reliable conclusion, which is the response of lake to glacier, will be obtained by the small watershed. In this paper, dividing the watershed into the smaller one, the Akesu River-Kaidu River small watershed was chosen as study area. Based on RS and GIS, under the climate change from cold-dry to warm-wet since 1977, 2000 and 2007, the variety of glacier was shown as decreasing firstly and then increasing a little. Meanwhile, the variety of lake was presented as increasing firstly and then decreasing greatly. However, the change tendency of glacier and lake was decreased. The decreased areas were 823.3 km$^2$ and 239.5 km$^2$ separately. According to the spatial bivariate auto-correlation analysis map, the negative correlation between glacier and lake was more distinct. In Tianshan Mountain, owing to the change mainly influenced by elevation, glacier was decreased and lake was increased. In Bosten Lake, glacier was increased and lake was decreased due to the change mainly affected by climate.

1. Introduction

In the Western China, the topography and cold environment supply the condition to glacier and lake [1-2]. According to the previous research, under the global climate warming [3-5], the glacier is decreased sharply.

Glacier is the important part of mountain environment and water cycle [6-9]. It has the great effect on the water resource [10]. Watershed is the special natural region type, the water is considered as the core. It is also the basic unit of the water cycle. Taken watershed as the study unit can compensate the shortage of administrative division.

In the Western China, the first level watershed is too large to analyze the response of lake to the glacier. As a result, those were divided into small watershed, so that the more reliable research will be obtained.
In this paper, small watershed was chosen as study unit. Based on the RS and GIS, the dynamic variety of glacier and lake was researched. The response of lake to the glacier indicated by the spatial bivariate auto-correlation analysis.

2. Study area
In the watershed of the glacier distribution in the Western China, the Tarim River watershed is the largest one. Many high mountains located in this region. The Mt. Qiaogeli with the elevation of 8611m, which is the highest peak of the Karakorum Mountain, is also distributed. So the glacier in this region owns large amount and huge scale.

Among the source of Tarim River, the Akesu River is the largest. The small watershed, which is composed by Akesu River and Kaidu River was chosen as study area (Figure 1). The region was located in the northwest and north of the Tarim Basin, with temperate continental arid climate. The south section of Tianshan Mountain is distributed in west and north of the study area, the high peak is also in the region. Bosten Lake, which is the largest fresh water lake in China, is located in the east of the study area. Its main recharge source is Kaidu River.

![Figure 1. Study area](image)

3. Method
According to the data about geology, geomorphology and hydrology, taking the Concise Glacier Inventory of China as reference, Western China was divided into 16 watersheds, and 50 small watersheds. Also, the ETM+ imageries and interactive interpretation technique were used.

This study uses MSS, ETM and CBERS-2 remote sensing imageries, with a time span of 30 years, since 1977, 2000 and 2007.

Firstly, images were preprocessed on the ERDAS software. In light of spectral characteristics and relative materials, combined with the previous studies, interpretation signs were set up. By using interactive interpretation technique, three periods’ glacier and lake data were obtained in MapGIS platform.

Secondly, the glacier and lake’s area change and spatiotemporal dynamic variety were approached by spatial analysis function of GIS so that the variety principle and distribution can be realized.

At last, a method of modified auto-correlation analysis was introduced in this paper, which was bivariate auto-correlation analysis method, used to investigate the spatial response of lake to the changes of the glacier. In terms of the LISA (Local Indicators of Spatial Association) method, which was put forward by Anselin [11], the local auto-correlation was chose to investigate the distribution of response relationships.

Local auto-correlation index formula is as follow:

\[
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\]
\[ I_p = \frac{(x_i - \overline{x}_i)}{\delta_i} \sum_j W_{ij} (x_j - \overline{x}_j) \]  

(1)

\( x_i \) and \( x_j \) refer to observation value in location \( i \) and \( j \) separately. \( W_{ij} \) means to weight, and \( \delta_i \) is the standard deviation of \( x_i \). \( I_p \)'s value is between -1 and 1. The value greater than zero indicates positive correlation, less than zero indicates negative correlation, equal to zero indicates random distribution in space. The bigger the absolute value is, the higher the correlation would be.

4. Result

4.1. Area statistic

During the 30 years, from 1977 to 2007, the area of glacier decreased firstly in 2000, and then increased slightly. At the same time, lake increased firstly and then decreased. The decreased lake area in later period (from 2000 to 2007) was 3.2 times larger than the increased lake area in former period (from 1977 to 2000). Thus, during the research period, it had a tendency that the area of glacier and lake became decreased (Table 1).

| Object Type | 1977 | 2000 | 2007 | Area Change | 1977-2000 | 2000-2007 |
|-------------|------|------|------|-------------|-----------|-----------|
| Glacier     | 5972.9 | 5064.2 | 5149.6 | -908.7 | 85.4 |
| Lake        | 1282.6 | 1391.8 | 1043.1 | 109.2 | -34.7 |

4.2. Spatiotemporal dynamic change

During the two research periods, according to the spatial distribution maps of glacier and lake’s dynamic changes, glacier mainly located at high altitude, in the east and north of the study area, where the Tianshan Mountain is. Lake was mostly distributed at low altitude.

In the former period, decreased glacier area (947.6km\(^2\)) was as 24.3 times as large as increased one (39.0km\(^2\)). Significantly decreased glacier mainly located in the north of study area. And decreased glacier also distributed sporadically in other glacier location area (Figure 2 (1)).

In the later period, decreased glacier area (278.8km\(^2\)) was less than increased one (364.2km\(^2\)). Decreased glacier located sporadically along the glacier distribution area. Increased area mostly located in the east of study area (Figure 2 (2)).

Lake located in the study area, except the southeastern region. In the eastern area, where the glacier was large distributed, the lake was located in the low latitude.

In the former period, the decreased lake area (126.3km\(^2\)) represented 53.6% of the increased one (235.5km\(^2\)). Decreased lake mainly distributed in the southwest and north of the study area, and around the Bosten Lake. Increased area located in the north and south of the area, around the Bosten Lake, and the flat site of western region where is the foot of the Tianshan Mountain (Figure 2 (3)).

In the later period, decreased lake area (360.3km\(^2\)) was 31.3 times larger than increased one (11.5km\(^2\)). Decreased area distributed in the north and south of the area, and the flat site of western region where is the foot of the Tianshan Mountain. Around the Bosten Lake, the decreased area was larger than increased one obviously. Increased area mainly located in the north of the study area (Figure 2 (4)).
5. Response analysis

Precipitation, temperature and those combinations are the dominant factors influencing the dynamic variety of glacier and lake. The most important factor for glacier is the temperature. The second factor is the precipitation. Glacier’s melting is decided by temperature, and accumulation is decided by precipitation. Making the comprehensive consideration, temperature, precipitation and elevation were considered to analyze the response of lake to glacier.

For the past 30 years, the annual mean temperature and precipitation had a curve upward tendency. They also showed the same rule in the 1977, 2000 and 2007 (Figure 3). The climate changed from cold-dry into warm-humid. It can explain the dynamic rule of the glacier well. Glacier mainly influenced by temperature in order that glacier gave priority to melt under the background of the rising temperature. However, with the increasing of the precipitation, glacier accumulated a little in the later period.

Figure 3. Annual mean temperature and precipitation change from 1977 to 2007
By means of the local index of the spatial auto-correlation analysis, the negative correlation between glacier and lake was more distinct. It was manifested as glacier decreased, lake increased (type one) and glacier increased, lake decreased (type two).

The response of increased lake to the decreased glacier located in the west and north of the study area, where the Tianshan Mountain located in (Figure 4). Those lakes were recharged mainly by melting glacier. Although the temperature was rising, but change of the lake was mainly influenced by elevation.

The response of decreased lake to increased glacier mostly distributed around Bosten Lake (Figure 4). In this region, the terrain is flat so that the correlation was mainly determined by climate factors. The Bosten Lake affected by its main recharge source, which is Kaidu River.

When the glacier melts to a certain degree, the ice sheet will thin out and the snowline will increase. Then, it will become a new balance. It is reduced that the amount of the small glacier at low altitude, which is most sensitive to the temperature change. In addition to slightly increased glacier, the recharge effect of melting glacier for Kaidu River is weak than before. As the Kaidu River’s reduction, the Bosten Lake will be decreased. Previous research showed that the flow of the Kaidu River was reduced in 2002. That verifies the reason analysis of the response relationship in this paper.

6. Conclusions

(1) During the 30 years, the variety of glacier was shown as decreasing firstly and then increasing a little. Meanwhile, the variety of lake was presented as increasing firstly and then decreasing greatly. However, the change tendency of glacier and lake was decreased. The decreased areas were 823.3 km$^2$ and 239.5km$^2$ separately.

(2) Glacier was mainly distributed in the north and west of the study area, where the Tianshan Mountain located. Lake was distributed in the low altitude of the small watershed beside of the southeast area.

Glacier was decreased significantly in the former period, and then increased remarkably in the later period. Those were located along the glacier distribution area and in the west of the small watershed separately. Lake was increased significantly in the former period and then decreased remarkably in the later period. Those were located in the flat site of western region, where is the foot of the Tianshan Mountain, and around the Bosten Lake.

(3) Annual mean temperature and precipitation had a curve upward tendency. Glacier was influenced by temperature more than precipitation.

(4) According to the spatial bivariate auto-correlation analysis map, the negative correlation between glacier and lake was more distinct. In Tianshan Mountain, owing to the change mainly influenced by elevation, glacier was decreased and lake was increased. In Bosten Lake, glacier was increased and lake was decreased due to the change mainly affected by climate.
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