Quantitative Detection of Area of Lakes in the West of China

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Abstract

Expanding or shrinking of lakes can be used as an indicator of climatic and environmental changes. There are a lot of lakes in the west of China, including lakes in the Tibet Plateau and in the arid areas. Most of them have been in shrinkage, some of them were changed into swamps and some dried dramatically up, causing abrupt changes of the lake environment. These abrupt changes of lake environments could be recognized as the result of natural processes or climate warming because there are little human activities. In this paper, the areas of lakes in the west of China are calculated using satellite data. We focus on Lake Qinghai, Lake Bosten, Lake E-Ling and Zha Ling and Lake NaMoCuo. The climatic elements that affect the area changes such as precipitation, temperature and evaporation are analyzed.

I. INTRODUCTION

Lake Qinghai is in the Qinghai province in the west of China. It has been declared as the most beautiful lake in China. But there is evidence that the ecological environment in Lake Qinghai degenerated in these years. Lake Bosten is in Xinjiang Province, Lake E-Ling, Zhaling and Lake NaMoCuo are in the Tibetan Plateau. Studies (Feng Song, et al., 2000; Ma Yu, 1996; Liu Xiaoyuan, 2001; Wang Run, et al., 2003; Lanzhou Institure of Glaciology and Geocryology, CAS, 1987; Guo Ni, et al., 2003) showed that the water level of Lake Qinghai was decreasing and the water level of Lake Bosten was increasing in recent years.

These lakes are all in the interior land areas, and there is little human activity. So they are affected mainly by meteorological and climate conditions. Changes in their area and fluctuations of the water level can be used as indicators of climatic and environmental changes. In this paper, the areas of these four lakes are estimated using satellite data. The climatic elements that affect the area changing such as precipitation, temperature and evaporation are analyzed.

II. DATA

To obtain a long-term series of the lake area, NOAA's Advanced Very High Resolution Radiometer (AVHRR) data are used. The NOAA AVHRR has five channels, which includes Channel 1: 0.58–0.68μm, Channel 2: 0.725–1.00μm, Channel 3a: 1.58–1.64μm, Channel 3b: 3.55–3.93μm, Channel 4: 10.3–11.3μm, and Channel 5: 11.5–12.5μm, with a nadir resolution of 1 km. The clear day in April, July and October from 1988 to 2004 are selected to calculate the lake areas.

III. DETECTING THE WATER BODY OF THE LAKES

In order to estimate the area of lakes and the area changes, water bodies are first distinguished from other objects. We use channel 1, channel 2 and channel 4 to detect the water body(Sheng Y, et al., 1998; Barton I J, et al., 1989; Xiao Q, et al., 1987; Sheng Y, et al., 1994).

A. Reflectance of channel 2

For channel 2, water body indicates lower reflectance than vegetation and other land surface covers. So the water bodies are discriminated from land and mixed surfaces using reflectance of channel 2 as indicated below.

$$pixel = \begin{cases} water, & if\ CH_2 \le T_1 \\ Mixed, & if\ T_1 < CH_2 \le T_2 \\ Land, & if\ CH_2 > T_2 \end{cases} \quad (1)$$

The pixels are identified as water body if the reflectance of channel 2 is lower than the threshold T_1, as land if it is higher than threshold T_2, and as mixed pixels if it is between T_1 and T_2.

Based on the histograms(Pornphan Dulyakarn, et al., 1999; Sahoo P K, et al., 1988) of channel 2, the threshold values of the T_1, T_2 are determined. Figure 1 gives an example of Lake Qinghai on 18, Oct 1992. The histogram has two peaks, one indicates water region and the other indicates land. As there are clear separations between the land and water body, the threshold values of T_1 and T_2 is obtained as indicated in the figure. The thresholds are slightly different for different satellite images. The thresholds are determined in a similar fashion for all the images.

B. Ratio of channel 2 to channel 1

The ratio of Channel 2 to Channel 1 can enhance the difference between water body and land, and decrease the effects of cloud and vegetation to a certain extent(Liu Xiaoyuan, 2001). So the

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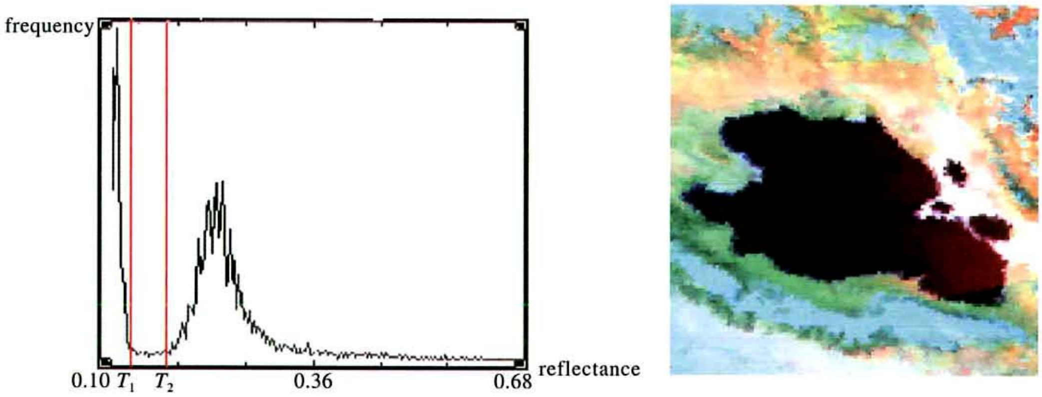


Figure 1. Histogram of scene around Lake Qinghai (left panel) and the satellite image around Lake Qinghai on 18 Oct 1992 (right panel)

pixels are identified as water if the ratio of the reflectance of channel 2 to channel 1 is lower than T_0, as equation (2) shows.

$$pixel = \begin{cases} water, & if\ CH_2 / CH_1 \le T_0 \\ Land, & if\ CH_2 / CH_1 > T_0 \end{cases} \tag{2}$$

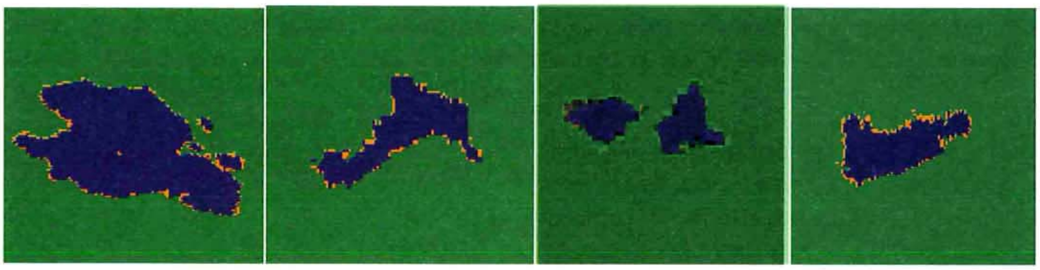
C. Brightness temperature of channel 4

In October, the water body in the southwest of the Lake Bosten is covered by vegetation, it cannot be identified using channel 2 and channel 1, but it can be identified using channel 4 as shown in equation (3).

$$pixel = \begin{cases} water, & if\ CH_4 \le T_3 \\ Land, & if\ CH_4 > T_3 \end{cases} \tag{3}$$

In the east of the Lake, the water body is still identified by the reflectance of channel 2 and the ratio of channel 2 to channel 1.

Lake Qinghai, Lake Bosten, Lake E-ling and Zhaling and Lake NaMoCuo are detected based on this method as shown in Figure 2(a)–(d). Blue Indicates water, Yellow is mixed pixels, Green is land.



(a) (b) (c) (d)

Figure 2. Examples of Water bodies of Lake Qinghai (a), Lake Bosten (b), Lake E-Ling and Zha Ling (c), and Lake NaMoCuo (d) detected from AVHRR

III. CALCULATION OF LAKE's AREA

For water pixel, it is easy to calculate its area based on its latitude and resolution. For the mixed pixel's area at the edge of Lake, we used the following methods(Sheng Y, et al., 2001).

If the area of a mixed pixel is S, and α is the portion of water, then the land portion is (1–α). For Channel 1 and Channel 2, the reflectance of this mixed pixel can be expressed as equation (4) and (5).

$$CH_{1\,mix} = \alpha CH_{1\,water} + (1-\alpha) CH_{1\,land} \tag{4}$$

$$CH_{2\,mix} = \alpha CH_{2\,water} + (1-\alpha) CH_{2\,land} \tag{5}$$

Where $CH_{i\,land}$ is the reflectance of land part, $CH_{i\,water}$ is reflectance of water part. $CH_{i\,mix}$ is the reflectance of mixed pixel in channel i, i = 1 or 2. If we divide equation (5) by equation (4), we get

$$\frac{CH_{2\,mix}}{CH_{1\,mix}} = \frac{\alpha CH_{2\,water} + (1-\alpha) CH_{2\,land}}{\alpha CH_{1\,water} + (1-\alpha) CH_{1\,land}} \tag{6}$$

If we let $\frac{CH_{2\,mix}}{CH_{1\,mix}} = R_{mix}$

then α can be expressed in equation (7)

$$\alpha = \frac{CH_{2\,land} - R_{mix} CH_{1\,land}}{R_{mix} CH_{1\,water} - R_{mix} CH_{1\,land} - CH_{2\,water} + CH_{2\,land}} \tag{7}$$

and the area of the water in the pixel is given by

$$S = \frac{CH_{2\,land} - R_{mix} CH_{1\,land}}{R_{mix} CH_{1\,water} - R_{mix} CH_{1\,land} - CH_{2\,water} + CH_{2\,land}}$$

where S is the area of the whole pixel.

IV. LAKE AREA CHANGE AND ANALYSIS

With the aforementioned method, time series of twenty years of areas of Lake Qinghai, Lake Bosten , Lake E-ling and Zhaling and Lake NaMoCuo have been obtained.

A. Lake Qinghai

Figure 3(a) is the area of Lake Qinghai in July from 1988 to 2004. It can be found that area of Lake Qinghai in July is decreasing from 1991 to 2004.

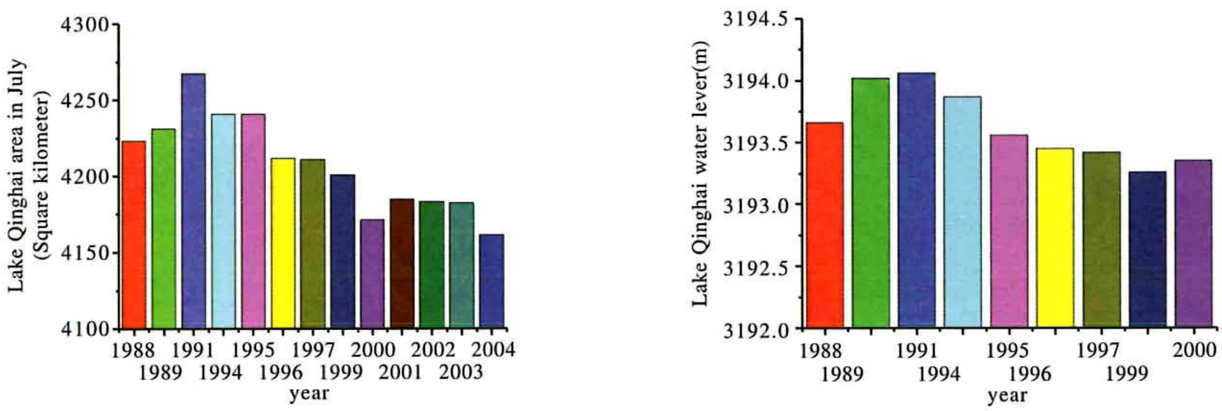
We compared the lake area with water level data in Lake Qinghai. The water level data is from the ship navigation detected by the Water Authority of China. The area of Lake Qinghai in July from 1988 to 2000 is shown in figure 3b.We can find that variation of water level is similar to area. Correlation coefficient between area and water Level is 0.80 for July.

Figure 4(a) is the area of Lake Qinghai in October from 1989 to 1998 and Figure 4(b) is water level of Lake Qinghai for the same month. Lake Qinghai's area in October decreased from 1989 to 2004, similar to the water level. The correlation coefficient between area and water level is 0.93 in October.

B. Reasons for the decreasing trend of the Lake Qinghai

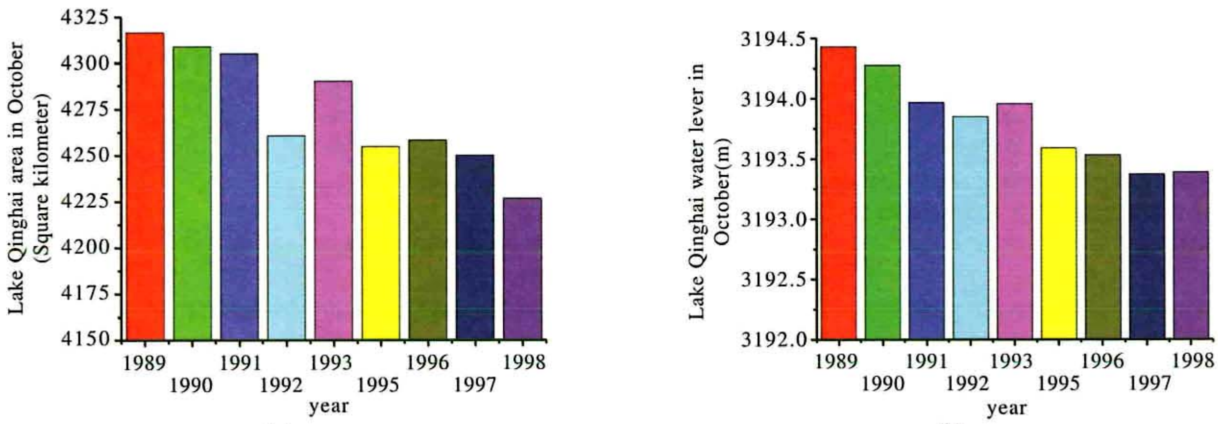
Why was the area of Lake Qinghai decreasing from 1989 to 2004? We analyzed climatic elements such as precipitation, temperature and evaporation. We used precipitation, temperature and evaporation data in 1988 to 2000 from four ground stations-GangCha, DuLan, ChaKa and QiaBuQia. These stations are located near Lake Qinghai and have long term series which can represent the climatic characteristic of Lake Qinghai. We used the method of Principal Components Analysis (PCA)(Shi Neng, 1995) on these variables. The variance contributions of first Principal Components of these four stations are 71.04% for precipitation, 85.58% for temperature and 77.1% for evaporation. So the first Principal Components can indicate the trend variations of these climatic elements.

Figure 5 shows the time series of the first principal component of precipitation, temperature and evaporation. Figure 5(a) is the variation of annual mean precipitation. Variations of precipitation in spring, summer, autumn and winter have similar trend as yearly mean and their time series are omitted (similar for temperature and evaporation). From these figures it can be found that the precipitation was decreasing in all four seasons, especially in spring and summer. The decreasing precipitation



(a) (b)

Figure 3. Area of Lake Qinghai from 1988–2004 and water level from 1988–2000 in July



(a) (b)

Figure 4. Area (a) and water level (b) of Lake Qinghai in October from 1989–1998

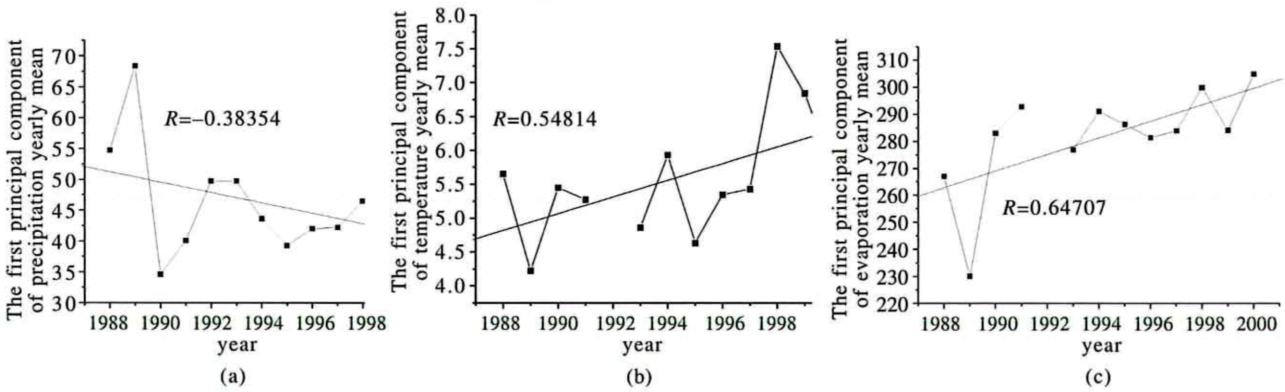


Figure 5

in spring and summer contributes most to the area change of Lake Qinghai. Figure 5(b) is the variation of yearly mean temperature and Figure 5(c) is for evaporation. It shows that the temperature around Lake Qinghai was increasing in these years and the evaporation was increasing. Temperature was increasing, evaporation was increasing and precipitation was decreasing since 1988.These elements can result in the decrease of Lake Qinghai area and water level.

In summary, the water bodies of Lake Qinghai in almost twenty years are identified with NOAA/AVHRR satellite data and its areas are calculated. The area of Lake Qinghai has been decreasing and water level descending from 1998 to 2004. Most of the decrease occurred in the north of Lake Qinghai. Increasing temperature, increasing evaporation and decreasing precipitation from 1988 are the main climate reasons for the decreasing of Lake Qinghai's area.

C. Lake Bosten

Figure 6(a)–(c) shows the area change of Lake Bosten in July, October and April from 1990 to 2004. The area of Lake Bosten was increasing in these years.

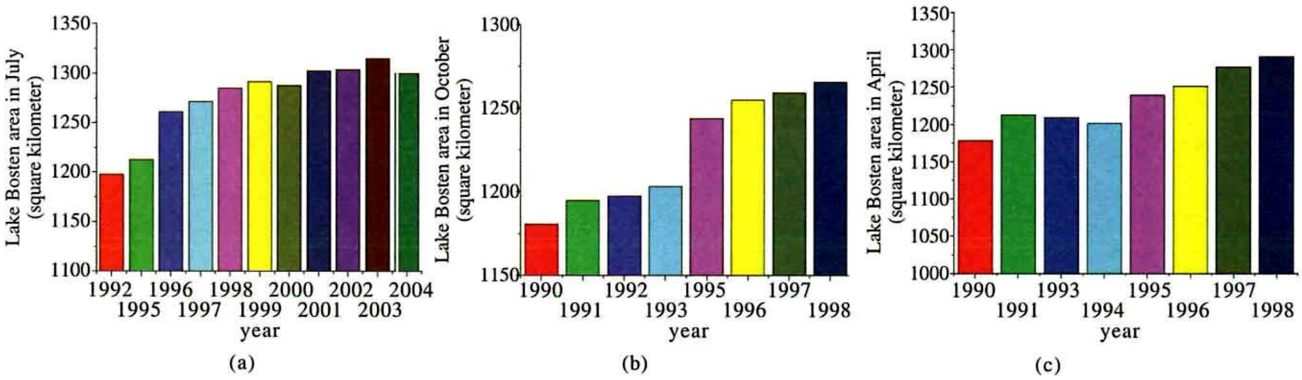


Figure 6. Area change of Lake Bosten in July (a),October (b)and April (c) from 1990 to 2004

D. Reasons for the increasing of the Lake Bosten

We analyzed the variation of precipitation, temperature and evaporation around Lake Bosten similar to Lake Qinghai .Figure 7 is the first principal component of temperature around Lake Bosten from 1988 to 2000. The temperature around Lake Bosten increased.

Lake Bosten is in the Xinjiang Province. The water of Lake Bosten comes from the River Kaidu shown in Figure 8. In the upper part of River Kaidu, there are two mountains, named Mountain Yilianbierga and Mountain Saerbing where about 473.97 square kilometers of glaciers are situated. Because of increasing temperature, glacial melted water entered River Kaidu. Melted water is 15.2% of runoff out of these mountains (Wang Run, et al., 2003; Lanzhou Institute of Glaciology and Geocryology, CAS., 1987). The runoff of River Kaidu was increasing since 1987 as shown in Figure 9. So there is abundant water resource in Lake Bosten. It results in area increasing of Lake Bosten.

The evaporation around Lake Bosten decreased and the precipitation increased. (Figure 10(a)–(b)). Other researches showed that water utilization by mankind and the water exiting has been stable since 1988. So, we concluded that the area of Lake Bosten has been increasing from 1990 to 2004 due to increases in glacial melted water resulting from the increasing temperature, increases in precipitation and decreases of evaporation. The water utilization by mankind and the water

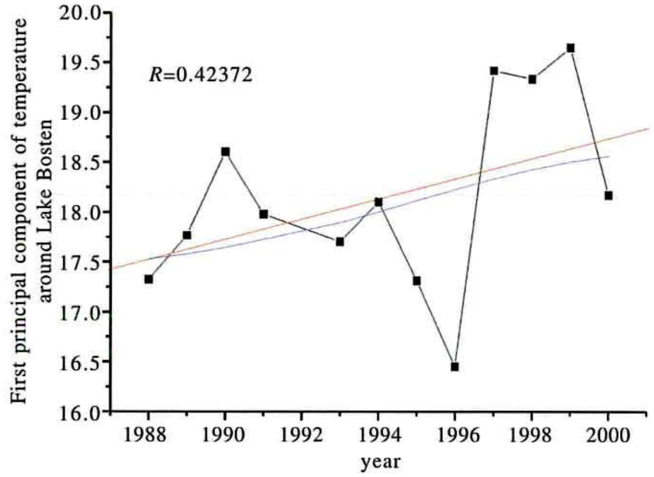


Figure 7. The variation of temperature around Lake Bosten

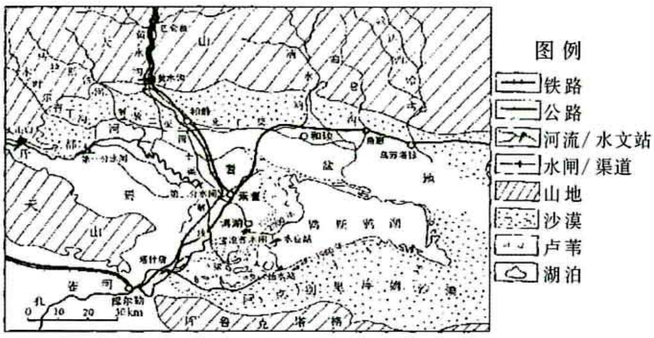


Figure 8. Location of Lake Bosten

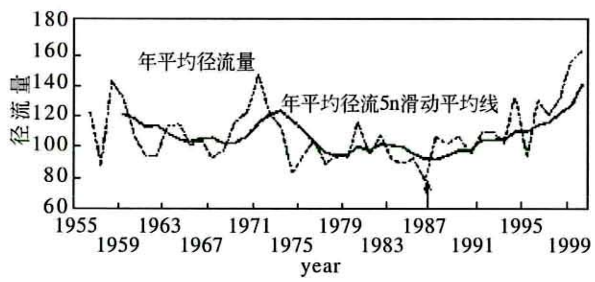


Figure 9. Runoff of River Kaidu
(Cited from Dr. WangRun's research)

exiting has been stable, or even has decreased since 1988.

E. Lake E-Ling/ZhaLing and Lake NaMoCuo

Figure 11(a) and (b) show the change of areas of Lake E-Ling/ZhaLing and Lake NaMoCuo in July. The area of Lake E-Ling/ZhaLing and Lake NaMoCuo in July was decreasing since 1988 in general. No analysis was made since no long-term climatic data are available for these lake areas.

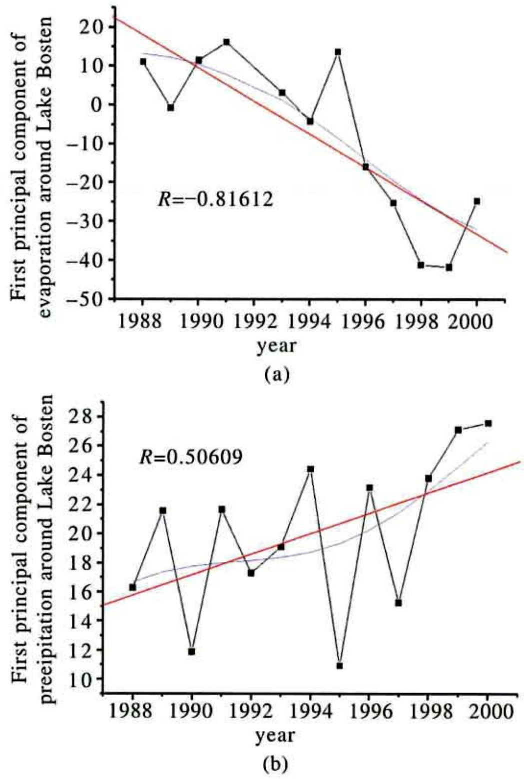


Figure 10. Variation of (a) evaporation and (b) precipitation around Lake Bosten

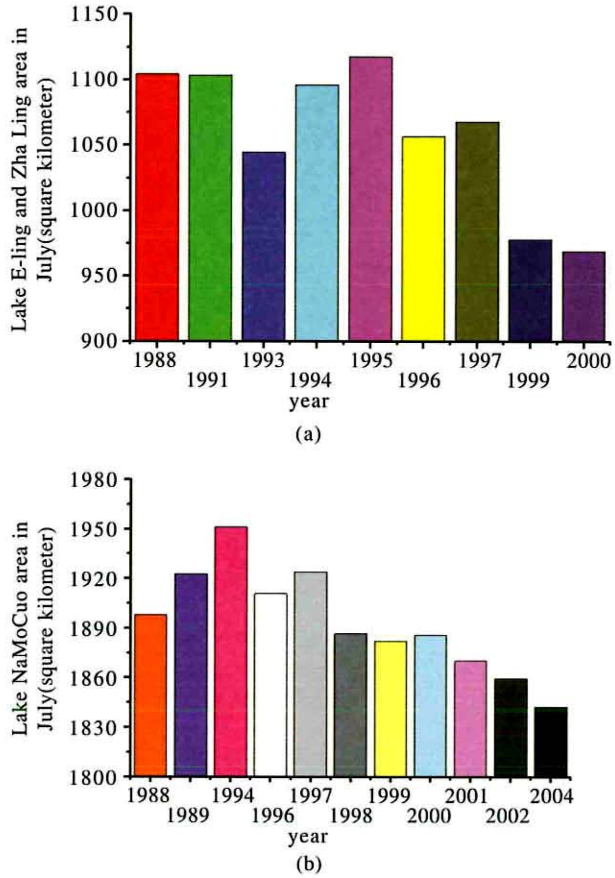


Figure 11. Change of area of (a) Lake E-Ling/ZhaLing and (b) Lake NaMoCuo

V. CONCLUSION

Changes of lake's area in the west of China are indicators of climate changes.

From analyses of four major lakes in west China, we found that the lake area and water levels in Lake Qinghai, Lake E-Ling/Zha Ling and Lake NaMoCuo in Tibetan Plateau are decreasing. Their shrinkages are attributed to temperature, precipitation and evaporation changes. However, the area and water level in Lake Bosten in Xinjiang is increasing. Its expansion is due to melting of snow and ice which are attributed to increases in temperature.

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