Remote sensing monitoring of monthly surface water changes in Bosten Lake (1990-2020)

Wang Hongxing¹, ², a, Hu Shanshan¹, b*, Zhang Tao², c*, Ji Miaomiao¹, ², d

¹Beijing Laboratory of Water Resources Security, College of Resource Environment and Tourism, Capital Normal University, Beijing, China
²Land Satellite Remote Sensing Application Center (LASAC), Beijing, China;
*email: 2190902174@cnu.edu.cn, demail: 2190902110@cnu.edu.cn

Abstract: Climate change and human activities have led to changes in the lake surface water, monitoring the long-term monthly changes of the lake surface water is of great significance to maintain the ecological balance of lakes. Based on the Landsat images and Google Earth Engine (GEE), we monitored the bi-monthly dynamics of the surface water of Bosten Lake in the past 30 years. The results show that: in the past 30 years, the maximum surface water of the lake is 1167.18 km²; the inter-annual dynamics of Bosten Lake surface water were divided into four stages: sharp decrease during 1990-1991, increase during 1992-2002, decrease again during 2003-2012, and finally recovery from 2013 to 2020; the annual changes of lake surface water have a certain pattern, decreasing from March to July, increasing from July to September, and then starting to decrease again. The inter-annual variability of the surface water of Bosten Lake was mainly affected by human activities and climate factors.

1. Introduction
Lakes are an important component of the global hydrological cycle and have the function of maintaining regional ecological stability [1]. In recent decades, with the impact of climate change and increasingly intensive human activities, the lake surface water has undergone a series of changes, either shrinking or expanding [2], which will affect the regional ecological environment, biodiversity, regional economic development and human life and well-being [3]. Therefore, it is necessary for us to monitor the dynamic changes of lakes, which can reveal the influence of climatic factors and human activities on lake waters, as well as the rational development, utilization and protection of lake waters.

Bosten Lake is the largest inland freshwater lake in China, and it is also the “mother lake” of Bayingoleng Mongolian Autonomous Prefecture in Xinjiang Uygur Autonomous Region [4]. In recent years, as climate change and agricultural reclamation in the river basin have gradually increased, vegetation has begun to degenerate, and the trend of desertification has become increasingly serious, resulting in the depletion of natural forests and grasslands, a sharp decline in animal numbers, and a series of changes in the lake area [5]. Therefore, the long-term dynamic monitoring of lake surface water is of great significance to the ecological environment protection of Bosten Lake and the development and utilization of water resources.

Since observations, relevant research has achieved significant research results in the areas of climate change in the Bosten Lake basin, changes in lake water levels, ecological water levels, water supply and...
demand balance, water resource scheduling and management, etc. [4-7] However, the research on the surface water of lakes is still based on the analysis of the annual changes in the long-term series of lakes based on several remote sensing data [5] or long-term continuous annual remote sensing data [7-9]. There is no long-term continuous series of monthly monitoring data. The emergence of GEE has greatly improved the computing power and provided the possibility for a large-scale lake to monitor the long-term continuous monthly dynamic changes of the lake surface water [10].

Based on this, we obtained all Landsat remote sensing images of Bosten Lake in the past 30 years based and extracted bimonthly precision water of the lake on GEE. Then analyze the change trend of the lake surface water, and discuss and analyze the driving force of the change trend of others’ research. This can provide certain guiding significance for predicting future changes in lake surface water under the influence of climate change and human activities, protecting the ecological environment of the lake, and rationally developing lake water resources.

2. Materials and methods

2.1. Study Area
Bosten Lake is located in the southeast of Yanqi Basin in Bianzhou area, Xinjiang, between 41° 56' ~ 42°14'N and 86° 40' ~ 87° 56'E. The continental climate is typical in this area, which the annual average rainfall is 72.3 mm, the annual average evaporation is 1887 mm, and the annual average temperature is 7.9 °C [4]. The water volume of the lake, which mainly comes from the snowmelt water, atmospheric precipitation and surface runoff in the mountainous areas of Kaiden River, Huangshiugou River and Qingshui River, will flows out and recharges the Konqi River. According to China’s second glacier catalogue, there are 700 glaciers in the basin [11].

![Figure 1 Location of the study area](image)

2.2. Materials
We obtained all Landsat 5, 7 and 8 optical remote sensing satellite images of the United States Geological Survey (USGS) in the study area from 1990 to 2020 as the data source to extract the surface water of the lake on GEE. The Landsat satellite is an earth resource observation satellite launched by NASA, with a return period of 16 days and a spatial resolution of 30 m. Due to its early launch and long in-orbit duration, it has been widely used by domestic and foreign scholars to monitor and analyze surface water resources in continuous long-term series [12,13].

2.3. Method

2.3.1. Remote sensing image processing method. We perform fusion processing on bimonthly remote sensing images, because some months of the study area are missing or poor in quality, and it is impossible to extract water bodies every month during the year. For a certain pixel, we define the median of all the image pixel values in two months as its value; if all the image values of the pixel in the two months are invalid, we will use the pixel value of the previous year and the same month for interpolation; if the previous year is also an invalid value, we will repeatedly interpolate to have a value. Finally, the synthesized image is named after the month in which it started.
2.3.2. Water extraction method. The water index method is currently the most frequently used method for optical image water extraction. In this study, we used AWEI_sh, mNDWI, NDVI and EVI to automatically extract water bodies. First, we automatically extract the water body based on AWEI_sh. In order to remove the image of the water body extracted by the vegetation, we combine mNDWI, NDVI and EVI to determine whether the pixel is a water body. We determine the pixel is a body of water, which (mNDWI > NDVI) or (mNDWI > EVI).

2.3.3. Surface water verification and analysis methods. Based on the moving average method; the abnormal value detection was performed on the time change trend line of the lake surface water extracted by GEE. Then, obtained the surface water change trend after inspection, and verify the abnormal value through manual visual inspection. We select kappa coefficient and overall classification accuracy (OA) to verify the accuracy of the results, and based on the analysis of mutation points in the time series of Crame’s detection of lake surface water.

3. Results & Discussion

Based on the water body index method and GEE, we extracted the lake surface water results of Bosten Lake from 1990 to 2020, and produced its change trend map (Figure 2). Outliers often occur in November and January of the year. Except for a small amount of image quality problems, the main cause is snow accumulation, which is particularly serious in January. This is consistent with the results of Aikem et al. [14] that the snow cover rate in the Bosten Lake basin increased from more than 50% in November to a maximum of 87.5% in January. In order to verify the accuracy of the extraction, we choose the 6-period data in 2019 as samples, and the synthesized Landsat image as the high-precision image. Each period automatically generates 300 sample points for human-machine mutual viewing verification. The results showed that the overall kappa coefficient reached 0.98 in 2019, and the OA reached 99%. The accuracy was the lowest in January, which have false mentions as the snow image was serious.

Figure 2 The trend chart of the water body extraction results of Bosten Lake from 1990 to 2020 (The red dot is an outlier detected based on the moving average method, which choose plus or minus 1% standard deviation as the threshold)

The surface water of Bosten Lake showed abrupt changes from 1990 to 2020, and the change trend is shown in Figure 3. We found that the surface water had abrupt changes in January 1991, January 2003, and November 2012, as we used Crame detection to detect the final surface water change trend after verifying and eliminating outliers. The surface water first decreased by 9.54 km²/m to January 1991; then increased at a rate of change of 2.70 km²/m to the maximum value of 1167.18 km² in January 2003; then decreased by 3.29 km²/m to November 2012; finally, began to recover with a rate of change of 4.15 km²/m. This is consistent with the lake surface water change results of Wu et al. [6] and Maimat et al. [5] and the lake water level changes results of Li et al. [15] and Guo et al. [16] Many studies have pointed out that the main driving factor of the inter-annual variation of the surface water of Bosten Lake is a change trend from meteorological factors to human activities and finally returning to meteorological factors [4·7·15-17]: the rise and change of the lake from 1991 to 2002 was mainly due to the increase in the runoff into the lake due to climate warming and the decrease in water diversion in the Kaidu Irrigation District; later, under the influence of human activities, the inflow of the lake decreased, the outflow increased, and the precipitation decreased at the same time, resulting in a drop in surface water;
under the influence of increased precipitation and increased temperature, the surface water began to rise at 2013.

Figure 3 The trend of surface water changes from 1990 to 2020 after Bosten Lake inspection

The surface water of Bosten Lake does not change much during the year, but there is a certain change pattern, and its change trend is shown in Figure 4. When analyzing the changes in the year, except that January was too much affected by the snow cover and was not selected, we calculated the multi-year average for the remaining months. The results showed that the average monthly surface water for many years showed a decreasing trend from March to July, increased from July to September, and then began to decrease. The research of Hu et al. [4] showed that the multi-year average monthly water level of Bosten Lake showed double-peak fluctuations, which decreased in March-July and September-January of the following year, and increased in the rest of the time period. This is roughly the same as our changing trend. However, their research all pointed out that September is the maximum water level, which is not consistent with our research. This may be because September is a flood season, and the water level may fluctuate significantly within a month, and the water level recorded by remote sensing images at the time is lower than the monthly average water level. Many studies have shown that the annual variation of lake water level is mainly affected by precipitation, temperature, runoff and irrigation water [4]: In March and April, the temperature warmed, and the increase of glacial melt water caused the surface water to increase to a peak; afterwards, the irrigation water is higher than the runoff, resulting in a slight reduction of surface water; with the entering of flood season in September, the surface water increased to a peak due to the increase of precipitation; subsequently, the watershed entered winter irrigation, and the reduction of surface runoff resulted in a reduction of surface water.

Figure 4 Trend of monthly average surface water changes in Bosten Lake for many years

4. Conclusions

The surface water is changed by climate change and human activities, which in turn affects climate, ecosystem diversity and human society. Here, we used all land satellite images from 1990 to 2020 to monitor the changes in the surface water of Bosten Lake. We got the following conclusion:

(1) In the past 30 years, there have been obvious abrupt changes in the surface water of Bosten Lake. The changes can be divided into four stages: the surface water dropped sharply to the minimum from 1990 to 1991; then it rose back to the maximum in 2003; Reduced to 2012; finally, began to recover.

(2) The monthly average surface water of Bosten Lake has realized a certain regular change for many years: it decreases from March to July, then increases to September, and finally begins to shrink again.

(3) Literature analysis shows that the main driving factor of the surface water changes in the past 30 years is a change trend from meteorological factors to human activities and finally back to meteorological factors; the year is mainly affected by the laws of meteorology and human activities.
Dynamic Monitoring of Surface Water Change in Bosten Lake

Dynamic monitoring and its driving force analysis are of great significance to protect and develop its water resources reasonably and promote the harmonious development of agriculture and ecology in this region. Although we have analyzed the changes in lake surface water on a monthly time scale, there are still some shortcomings. Future research can be analyzed from the following aspects: (1) Combined with Modis data to monitor monthly water level changes. (2) Combined with monthly water level data at the same time to analyze the changes in water storage. (3) Based on the obtained monthly water storage changes carry out quota planning on agricultural irrigation water consumption.

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