Article Journal of Asian Geography, 2023, Volume 2 (Issue 2), 15-22.
https://doi.org/10.36777/jag2023.2.2.2

Monitoring Lake Level Changes in Bosten Lake from 2003-2021 based on Multi-source Satellite Altimetry Data

Chunyan Cheng[1], Zhang Fei[2,*]

[1] Xinjiang University, College of Geography and Remote Sensing Sciences, Key Laboratory of Oasis Ecology, 830046 Urumqi, China.
[2] College of Geography and Environmental Sciences, Zhejiang Normal University, Jinhua 321004, China

*Correspondence: zhangfei3s@zjnu.edu.cn

Received: 15 Nov 2022, Revised: 20 Mac 2021; Accepted: 10 Apr 2023; Published: 22 Sep 2023

Abstract: The investigation of freshwater lake water resource changes in arid regions is crucial for understanding the evolution of regional lake dynamics under climate change, given their value and limited availability. This study aims to overcome the limitations of traditional water level monitoring methods and address the practical need for monitoring water level changes in Lake Bosten, located in the arid and semi-arid regions of China. To this end, we employed ICESat, ICESat-2, and CryoSat-2 altimetry data, as well as Landsat 8-OLI optical remote sensing data, to obtain the water level information for Bosten Lake from 2003 to 2022. We analyzed the temporal variation of the lake level and discussed the response of the lake level to climate and human activities in the context of temperature, precipitation data, and human water use. The water level of Lake Bosten exhibited a decreasing and then increasing trend, with three rising and three falling intervals, respectively. The intra-year variation of the lake water level exhibited bimodal characteristics, and the fluctuation range of water level during abundant water periods was greater than that during dry periods. Finally, we correlated the extracted lake water level with the measured water level at the hydrological station and found a significant positive linear correlation between the observed water level of Bosten Lake based on satellite altimetry and the measured water level at the hydrological station, with an overall correlation coefficient of 0.896 and 0.934 ($P < 0.01$), indicating high accuracy of the water level results obtained in this study. The dynamics of Lake Bosten are influenced by a combination of climate change, hydrological elements, and human activities, with a relatively weak relationship between climate change and lake volume and a strong influence of human activities. Multi-source altimetry satellites provide a powerful tool for monitoring lake water levels over a long time scale, which is critical for studying lake water level changes and their response to climate and the environment.

Keyword: CryoSat- 2; ICESat; ICESat- 2; Satellite altimetry; Water level.

1.0 Introduction

Lake level changes can affect many aspects of lake ecosystems, hydrological cycles, and water resources management, and lake level extraction is an important issue in hydrological research. Long-term serial water levels can reflect regional climate change and the impact of human activities on the lake (Cooley et al., 2021). Bosten Lake is the largest inland freshwater lake in China. Due to the combined effects of global climate change and large-scale industrial and agricultural production activities, the dramatic increase in population in the Yanqi Basin, and the unreasonable exploitation of water resources, the water volume of Bosten Lake into the lake has decreased, and water resources have undergone some degree of spatial and temporal changes (Yao and Chen, 2021).

In the early days, the monitoring of water level changes in lakes was mainly carried out by using the field observation data of hydrological stations, while for some lakes located in remote areas not easily accessible to human beings, the water level information could not be obtained. The traditional method of lake level observation mainly relies on the hydrological stations around the lake, but due to the uneven distribution of observation points and the limited number of hydrological stations, the traditional method can hardly meet the demand for comprehensive observation of lake level. The satellite altimetry technology has the advantages of global coverage, high accuracy, and no geographical limitation, which can overcome the limitations of the traditional methods and provide comprehensive lake water level observation data (Dettmering et al., 2020; Wei et al., 2021). The concept of satellite altimetry was first introduced in 1969 by W.M. Kaula, a leading American geodesist (He, 2002). In the 1970s, countries started to launch altimetry satellites one after another. In 1973, NASA launched the first satellite-borne active microwave remote sensing vehicle, Skylab, and in 1982, Brooks began using lake elevation data observed by the Seasat altimetry satellite for mapping purposes (Brooks, 1982). In 1994, Birkett verified the accuracy of radar altimetry data for lake water applications (Birkett, 1994). In 1992, many scholars successively monitored water level changes in dozens of large lakes around the world using TOPEX/Poseiden satellite data (Birkett, 2000; Jekeli and Dumrongchai, 2003; Mercier et al., 2002; Hwang et al., 2005). Envisat satellite, the successor of ERS-1 and ERS-2, was launched in 2002, and some scholars used T/P and Envisat data to provide water level measurements in different watersheds (Alsdorf et al., 2001; Frappart et al., 2006). In 2003, the ICESat laser satellite with high spatial resolution was launched, enabling dynamic monitoring of water levels over small areas of water (Abshire et al., 2005; Luo et al., 2021). 2010 saw the launch of ESA's high-precision radar satellite CryoSat-2 with an advanced SIRAL altimeter (Laxon et al., 2013), and in 2012, Drolon et al. In 2016, the Sentinel-3A satellite, which can reach millimeter accuracy for lake level monitoring, was launched. In addition, the ICESat-2 satellite, which was launched in 2018, provides higher accuracy and altimetric data on more lakes (Cooley et al., 2021). Since 2020, there have been many studies using ICESat-2 satellite data to achieve high-accuracy measurements of lakes or reservoirs in different regions around the globe (Akbar et al., 2020; Smith et al., 2020; Xiao et al., 2021). Satellite altimetry technology uses the working principle of altimeter to achieve high-precision measurement of lake water level through the processing of reflected signals, and because of the wide coverage of satellites, it can achieve efficient and high-frequency lake water level monitoring, which is now widely used in the dynamic monitoring of lake water level.

At present, there have been many studies on lake level changes in the middle and lower reaches of the Yangtze River, the Qinghai-Tibet Plateau, and the Amazon Basin (Frappart et al., 2006; Li et al., 2007; Song et al., 2014; Jiang et al., 2017). Since the operational lifetime of a single satellite is limited and the time coverage is mostly between 5 and 10a, the combined multi-source satellite altimetry data can effectively extend the observation time (Song et al., 2015; Lin et al., 2020), and the orbits and elevation references of different satellites are different, and the satellites selected for different study areas are not fixed. There are few studies on the use of multi-source satellite altimetry data to monitor the water level of Bosten Lake. In summary, combined remote sensing and satellite altimetry provide new observational means for analyzing global water level changes. In this study, the largest inland throughput freshwater lake in China, Bosten Lake, located in the arid zone of China, is selected as the study area, and the water level changes of Bosten Lake from 2003 to 2021 are jointly monitored using altimetry data from various radar satellites. The causes of water level changes in the lake were analyzed to provide a reference for the steady development of the ecological environment and sustainable utilization of water resources in the Bosten Lake basin.

2.0 Study Area

Bosten Lake is located in the southeastern part of Yanqi Basin at the foot of the southern Tianshan Mountains, in the territory of Bohu County, Xinjiang Uygur Autonomous Region, and is an inter-mountain trap lake with a geographical range of 45°56'~42°14' N and 86°40'~87°56' E (Figure 1). Bosten Lake consists of three parts: a large lake area, a small lake group, and a lakeside wetland. Among them, the water recharge of Bosten Lake mainly comes from the snow and ice melt water, atmospheric precipitation, and surface runoff in the mountainous areas of the Kaidu River, Huangshuigou, and Qingshui River basins. At the same time, the lake water overflows from the western part of the lake through the city of Korla, forming the Peacock River. The watershed belongs to the warm temperate dry desert climate, influenced by the altitude difference, precipitation, temperature, and other differences. The annual average temperature of Bosten Lake lakeside area is 8.2 ~11.5 °C, the lowest in January, the highest in July, and the highest temperature extremes reached 40.0 °C or more. The annual precipitation is about 70 mm, mainly concentrated in May–September, and the annual evaporation is more than 1 880 mm (Wu, 2019; Yao et al., 2021). There is a large variation in the intra-annual variation of the water level of Lake Bosten, and the study found that the water level of Lake Bosten is changing drastically. With the influence of global changes and human activities, the ecological and environmental problems of Lake Bosten have been highlighted, such as lake shrinkage, water pollution, and soil salinization, which seriously affect the ecosystem and ecological security of Lake Bosten (Chen et al., 2013).

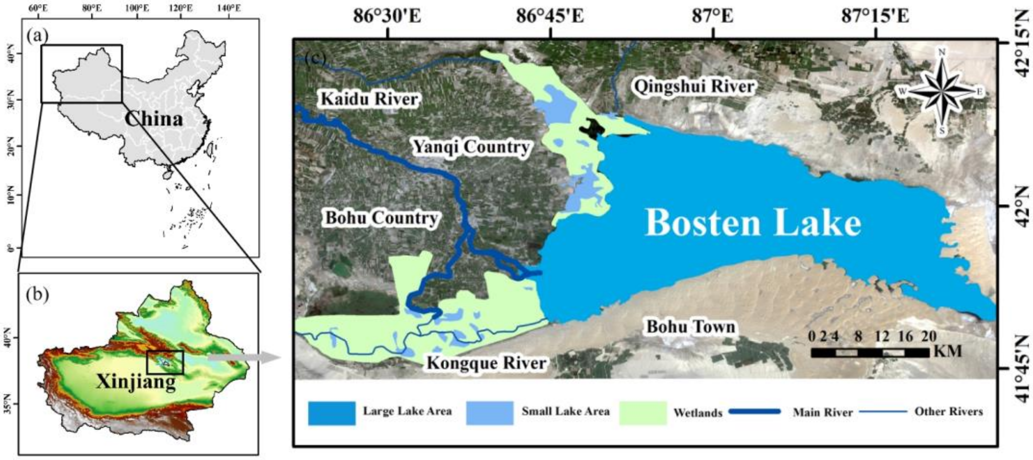

Figure 1: Maps and images of the study area: (a) The location of Xinjiang in China; (b) The location of the Bosten Lake at the center of the basin; (c) An overview of the location of Bosten.

3.0 Materials and Methodology

3.1 Materials

3.1.1 Multispectral remote sensing data.

To extract the lake boundary, Landsat 8 OLI remote sensing images without ice and cloud cover (⩽5%) on the lake water surface in August 2021 were selected and downloaded through the USGS Query. After geometric correction, geographic alignment, radiometric correction, and atmospheric correction, the images were used for lake water extent identification.

3.1.2 Multi-source satellite-based altimetry data.

This paper uses ICESat-GLAS altimetry data from June 2003 to October 2009 and ICESat-2/ATLAS inland surface elevation data products from February 2019 to October 2021. As shown in Figure 2(a), the ICESat-1 works by transmitting a laser signal to the sub-satellite through the GLAS and then measuring the round-trip time of the laser signal to calculate the distance from the satellite to the sub-satellite to obtain the elevation of the subsatellite. There are currently 15 data products (GLA01, GLA02,…, GLA15) used by the satellite for scientific research, and GLA14 altimetry data are used in this paper. The data set contains 95 parameters, such as time, latitude, longitude, T/P ellipsoid-based elevation, saturation correction parameters, and parameters to determine whether there is waveform saturation in the elevation data, etc. The ICESat-2 ATL13 data products include inland water bodies such as inland lakes, reservoirs, bays, and estuaries, along-track water surface elevation, along-track water surface slope, backscatter attenuation coefficient, effective wave height, etc. The ICESat-2/ATLAS was launched on September 15, 2018 to take over the ICESat/GLAS mission to continue monitoring polar ice caps, sea ice, and global forest canopy height changes, but it is also suitable for inland water monitoring. ICESat-2 uses six beams (three groups), each at a surface distance of about 3.3 km, and consists of strong and weak laser beams at a surface distance of 90 m and an energy ratio of about 4:1, to obtain higher precision elevation data at a pulse rate of 10 KHz, a footprint size of less than 17.5 m, and a sampling interval of 0.7 m along the trajectory, covering the entire globe (Schutz et al., 2005; Neumann et al., 2019). GLAS data and ATL data are available from the NSIDC at http://nsidc.org/data/icesat/.

In addition, this paper jointly uses CryoSat satellite radar altimetry data (Figure 2(b)) from February 2010 to December 2018. CryoSat-2 is equipped with SIRAL, which was launched by the European Space Agency (ESA) on April 10, 2010. The SIRAL altimeter was launched by ESA on April 10, 2010, with a period of 369 d and a subperiod of 30 d. It has three modes: LMR, SAR, and SARin. The data are provided by ESA and can be downloaded at: ftp://science-pds.cryosat.esa.int/.

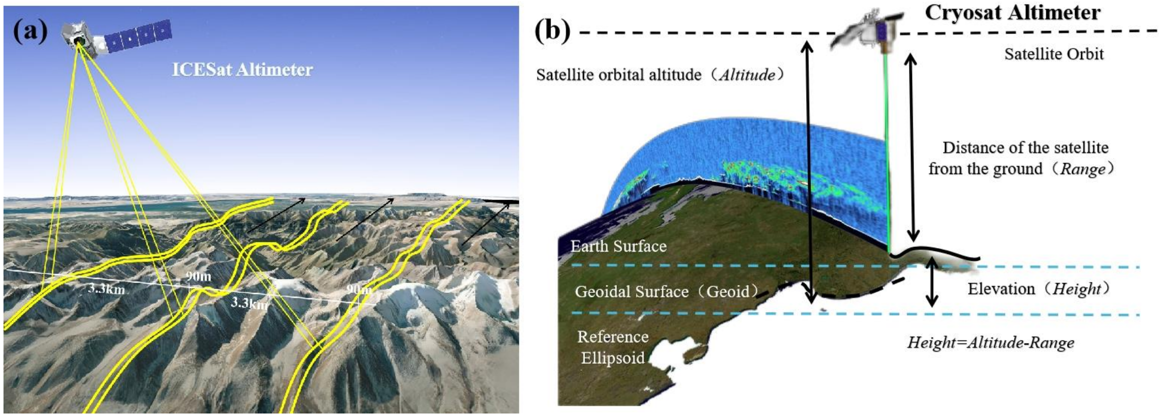

Figure 2: Working diagram of the satellite altimeter: (a) ICESat1/ICESat-2; (b) CryoSat-2 data

3.1.3 Meteorological data.

The meteorological observation data include temperature and precipitation data, which are collected from the NCDC of the U.S. The data include temperature, pressure, dew point, wind direction and speed, cloud volume, precipitation and other meteorological elements.

3.1.4 Measured water level and water consumption data

The measured water level data were obtained from the measured water level data provided by the Bosten Lake Basin Management Office of the Bayingoleng Administration of the Tarim River Basin in Xinjiang, covering the period from January 2004 to October 2019. The water consumption data were obtained from the average annual water supply and total water consumption data of Bayingoleng Mongol Autonomous Prefecture in the Xinjiang Statistical Yearbook, covering the period from 2005 to 2020.

3.2 Methodology / framework / theory

(1) Satellite altimetry data preprocessing Firstly, based on the Landsat 8 OLI optical remote sensing data, the remote sensing image stitching, reprojection, and cropping were carried out in the environment of ENVI 5.3 and ArcGIS 10.2 to convert the raster data into vector data, and the monthly lake boundaries from 2003–2019 were extracted by combining the NDWI index and manual visual interpretation so as to extract the corresponding sub-stellar point footprints.

The pre-processing of ICESat-1 altimetry data mainly includes ellipsoidal conversion and saturation correction. Since ICESat-1 and CryoSat-2 elevation data are based on different reference ellipsoids, the reference ellipsoid (T/P ellipsoid) of ICESat-1 elevation data needs to be converted to WGS84 ellipsoid to eliminate the effect of ellipsoidal differences (Zhang et al., 2022). In addition, ICESat-1 may cause the elevation of the measured footprint point to be lower than the actual elevation value due to the waveform saturation phenomenon when performing elevation measurements, and thus it needs to be corrected for saturation. The principle of footprint point elevation calculation is shown in Equation (1).

$$H=h\text{-d\_deltaEllip+d\_satElevCorr-}N \tag{1}$$

Where: H is the positive height based on the EGM96 geoid; h is the elevation based on the T/P ellipsoid; $\mathrm{deltaEllip}$ is the difference between the T/P ellipsoid and the WGS84 ellipsoid; $\mathrm{d\_satElevCorr}$ is the saturation correction parameter, which can be obtained from the dataset; N is the local geoid gap, which can be calculated by the geoidheight function in the Matlab 2020.

The pre-processing of CryoSat-2 altimetry data mainly consists of various bias corrections. The scattering or refraction of CryoSat-2 satellite radar pulse signals during the propagation process affects their propagation speed and delays the round-trip time of the observed signals, and the distance estimates are biased by various natural factors, so they must be corrected (Jiang et al, 2017). The water level of the lake is calculated as follows.

$$H=H_{\mathrm{alt}}-R-\Delta R-N \tag{2}$$

Where: H is the positive height based on the EGM96 geoid; H_{alt} is the height from the satellite center of mass to the reference ellipsoid; R is the distance from the satellite to the lake surface; ΔR is each error correction; N is the local geoid gap, which can be calculated by the geoidheight function in MATLAB.

$$\Delta R=\mathrm{Dry}+\mathrm{Wet}+\mathrm{Ion}+\mathrm{Sol}+\mathrm{Pol} \tag{3}$$

Where: Dry is dry tropospheric correction; Wet is wet tropospheric correction; Ion is ionospheric correction; Sol is solid tide correction; Pol is polar tide correction.

The processing of ICESat-2 ATL13 data is mainly to determine the lake laser footprint points using the lake boundary vector data; the coarse difference in elevation along the track is removed, and the valid laser elevation points along the track are obtained and their average values are used as the lake level values along the track.

Among them, ICESat-1 data used T/P, EGM2008 reference system, and ICESat-2 and CryoSat-2 data used WGS84, EGM96 and EGM2008 reference systems. The three data used different elevation references, so they need to be fused before constructing the water level sequence. In this study, ICESat-1 data needs to be converted to the same reference system as ICESat-2 and CryoSat-2.

(2) Elevation anomaly removal: After the data pre-processing is completed, all the obtained water level values are processed to extract the water level sequence of the lake, and the specific removal steps are as follows:

Step 1: A 200 m buffer zone is made to the lake boundary toward the lake center, and satellite footprint points are screened according to the buffer zone to ensure that the data points fall completely into the lake and to reduce the interference of elevation points that may be in contact with the lake shore with the single-day water level data.

Step 2: The resulting water level data points were first visually interpreted to remove outliers that deviated greatly from most water level values by tens or even hundreds of meters.

Step 3: The anomalous values in the single-day water level data were removed using the 3σ criterion, and then the remaining valid water level values were averaged as the daily average water level. The 3σ criterion is shown in Equation (4): for the collected data samples, the root-mean-square deviation σ is obtained by taking the arithmetic mean $\overline{x}$ and the remaining error value v_i (Zhang et al., 2022).

$$\begin{cases} \overline{x} = \dfrac{1}{n}\sum_{i=1}^{n} x_i \\ v_i = x_i - \overline{x} \\ \sigma = \sqrt{\sum_{i=1}^{n} {v_i}^2 / (n-1)} \end{cases} \tag{4}$$

If $x_i - \overline{x} > 3\sigma$, the error is relatively large and x_i should be discarded, and the probability of occurrence of observations with error greater than 3σ is 0.003; if $\left|x_i - \overline{x}\right| \le 3\sigma$, x_i is normal and should be retained.

(3) Accuracy verification: The accuracy of elevation data is usually verified by comparing the satellite elevation water level with the measured water level. However, since the elevation reference systems of satellite altimetry data and actual water level data are inconsistent and the conversion is more complicated, this paper refers to the previous methods and indirectly evaluates the accuracy of satellite altimetry data by two indexes: correlation coefficient (*R*) and significance value (*P*).

4.0 Results

4.1 Analysis of water level change characteristics of Bosten Lake

4.1.1 Accuracy verification

In this study, the accuracy of the lake water level was verified using the Pearson correlation coefficient (R) and significance value (P). The water level of Lake Bosten was extracted using altimetry data from ICESat-1, ICESat-2, and CryoSat-2. Correlation analysis was performed with the measured water level at the hydrological station of Lake Bohol and the altimetry water level in the dataset to verify the accuracy and reliability of the satellite altimetry data. The results (Figure 2) show an extremely significant correlation ($R^2 \geqslant 0.8$, $P \leqslant 0.001$) between the CryoSat-2 satellite altimetry water level and the measured water level of the hydrological station. Similarly, the ICESat-1/ICESat-2 results also show an extremely significant correlation ($R^2 \geqslant 0.9$, $P \leqslant 0.001$) with the measured water level of the hydrological station, except for 2010, where the significance is relatively weak due to the relatively small number of measured water levels at the hydrological stations. These findings suggest that the three altimetry data sources can be used to monitor the long-term changes in lake level in the Bosten Lake basin.

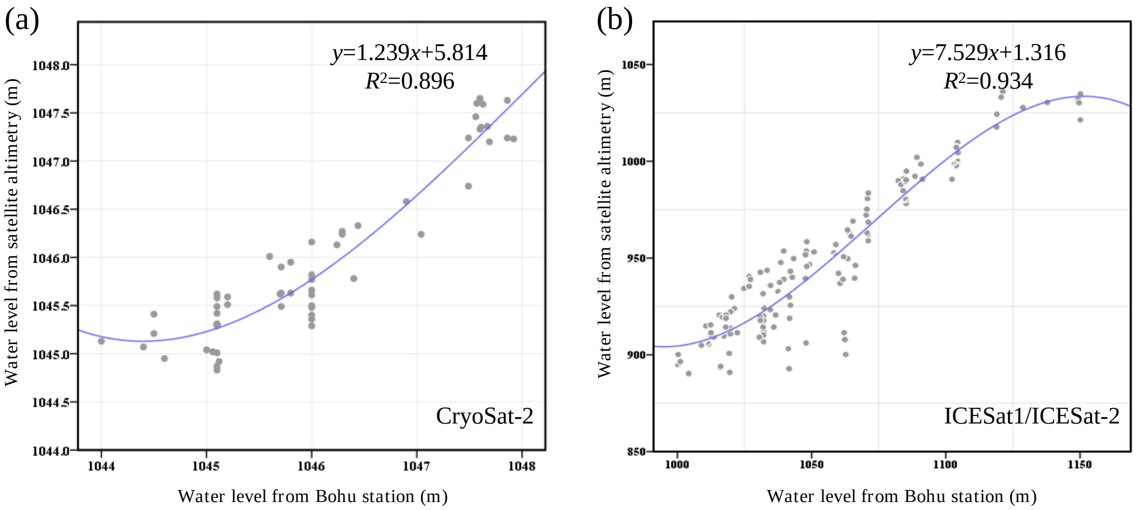

Figure 3: Accuracy validation results: (a) Accuracy validation results of CryoSat-2 data; (b) Accuracy validation results of ICESat1/ICESat-2

4.1.1 Time-series variation of lake water level

Combining the three types of satellite altimetry data to extract the water level series of Bosten Lake from 2003 to 2021, Figure 4 shows the water level time series from 2003 to 2019, from which it can be seen that both types of satellite altimetry data can obtain more accurate water level change trends and obvious seasonal and interannual fluctuations. From the seasonal water level variation, it can be seen that the highest water level is mostly in July and August in summer, and the lowest is mostly in January and February in winter. The water level generally starts to rise in April and gradually decreases in November, with the difference in water level between 0.5 and 1.2 m during the year. From the interannual variation, it can be seen that the peak values of water level occur in summer and the trough values occur in winter, which is consistent with the existing water situation report. The highest peak value of water level in Lake Bohu occurred in the summer of 2003, and the lowest trough value occurred in the winter of 2013. The water level trend was obtained by linear fitting of the annual water level values, and it can be seen that the node was around 2013, and the water level showed a decreasing trend from 2003–2013 and an increasing trend from 2014–2021. To further analyze the water level change trend, the linear trend terms of the water level change curves from 2003–2013 and 2014–2021 were extracted, and it is obvious that the linear trend of water level decrease during 2003–2013 is -0.416m/a. The water level increased during 2014; the linear trend of the water level increase is 0.324m/a for the period 2014–2021.

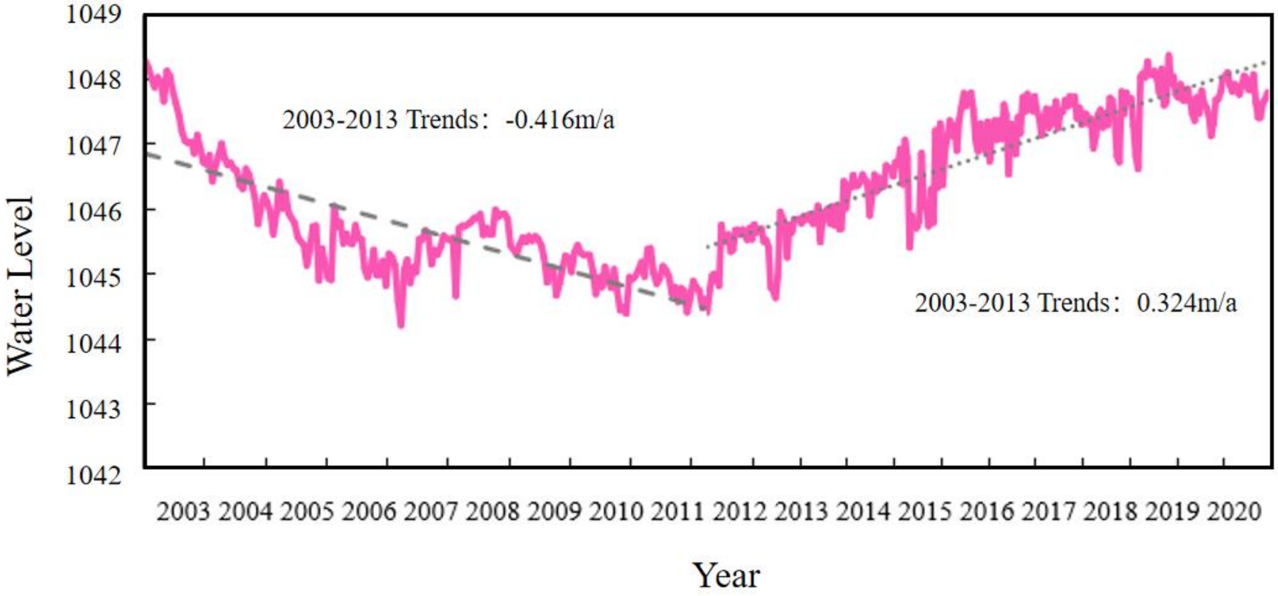

Figure 4: Time series of lake water level changes

4.2 Influence of climatic and anthropogenic factors on the water level of Bosten Lake

The temperature changes over the years are relatively small compared with the average monthly precipitation, but the dramatic changes in the water level of Lake Bosten are influenced by climate change (Yao et al., 2021). Since the 21st century, temperature fluctuations at high levels have increased evaporative demand and exacerbated regional drought, while the trend of increasing precipitation has weakened, causing a "wet-dry transition" in the regional climate and a relative decrease in lake levels. Therefore, the change in regional wet and dry climate may be the main reason for the change in hydrological elements in the lake. As can be seen from Figure 4, the temperature changes from 2003 to 2015 has a small increase, and the evaporation demand is strong, resulting in the regional climate tending to become dry and the precipitation decreasing significantly. After 2015, as the trend of increasing precipitation resumes, the regional climate tends to warm and humid again, and the lake water level increases.

On the other hand, the water cycle system in the Bosten Lake basin is very fragile, and global warming has increased water uncertainty. Therefore, human activities are largely altering the natural water cycle system in the Bosten Lake basin, and the future of Bosten Lake depends largely on the impact of human activities (Jiang et al., 2022). As can be seen from Fig. 5c, after 2011, the water consumption of residents increased steeply, and the water level of Lake Bosten continued to be low due to a combination of factors such as the decrease of water from the Kaidu River and the tighter water use in the Peacock River basin. Bosten Lake also did not implement ecological water transfer to the main stream of the Tarim River. As the water level of Bosten Lake continues to decline, the middle and lower reaches of the Peacock River are extremely short of water resources, the downstream river is basically in a state of disconnection, the groundwater level has dropped significantly, natural forests and pastures are seriously degraded, the desert riparian forest ecosystem on both sides of the middle and lower reaches of the Peacock River, mainly poplar, is seriously damaged, and the ecological environment of the Peacock River basin is facing serious challenges.

.

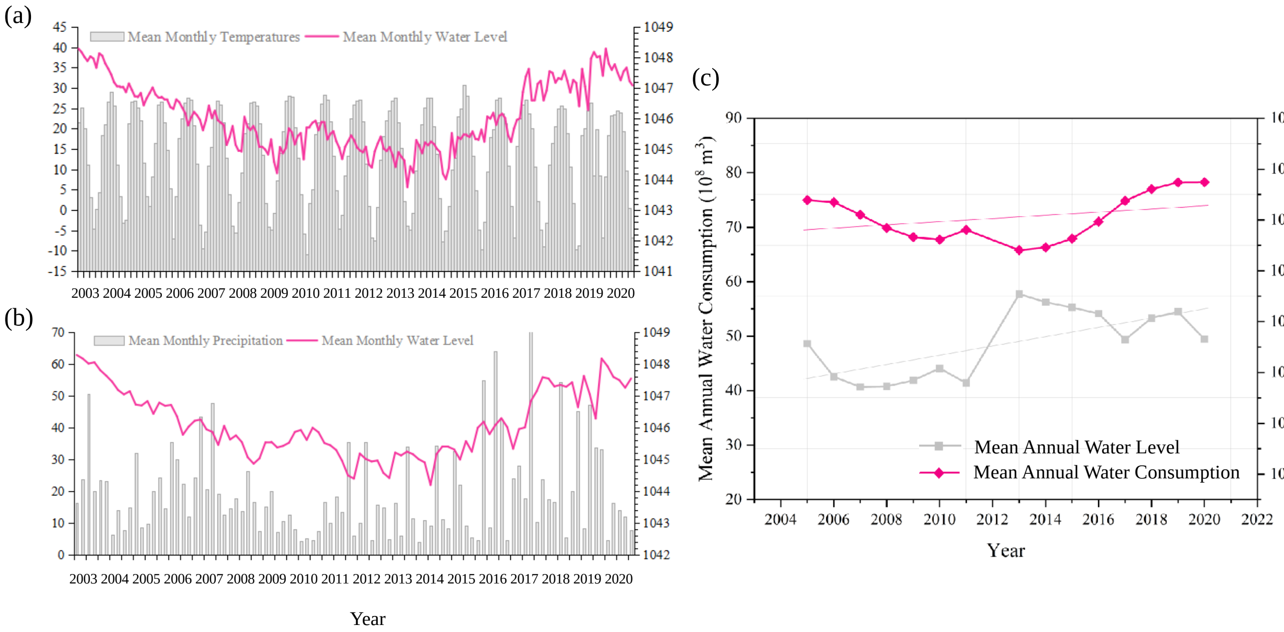

Figure 5: Changes in average monthly temperature, average monthly precipitation and total annual residential water use

5.0 Discussion

Changes in the water level of Lake Constance will affect the lake ecosystem as well as the socio-economic development of the lake shore. High water levels will bring flooding events to the surrounding river basin, while low water levels, especially when the combination of summer heat, prolonged drought, strong winds, and other disaster-causing factors are combined, will lead to ecological disasters in the basin. In 2014, for example, the continuous high temperature and low rainfall caused the water level of Lake Bosten to drop, leading to ecological disasters in the surrounding area. In addition, water level fluctuations can induce significant reductions in the number of key species in the biotopes around the lake (Dai et al., 2020). Therefore, reasonable water level regulation measures are crucial.

This study investigates the impact of climate factor changes on lake levels and provides an attribution analysis of water level changes in Lake Bosten over the past 18 years. However, due to the limitations of data availability and article length, this paper has not been able to complete the comprehensive discussion of more anthropogenic factors for the time being, so the specific impact of climate change and anthropogenic activities on the lake level has not been accurately quantified at present. The follow-up study of this paper will build on the existing work, strengthen the field observation and circum-lake survey of Lake Bosten, and construct a lake water balance model combined with hydrological process simulation to further reveal the influence mechanisms of climate change and human activities on the lake change of Lake Bosten in order to achieve a win-win situation of ecological protection, industrial development, and upgrading of the lake area (Adnan et al., 2019). Meanwhile, the subsequent study will compare and analyze multiple future climate prediction models and multiple data products in order to filter out the optimal future climate change scenarios and thus predict water level changes.

6.0 Conclusions

This study analyzes the changes in water level characteristics of Bosten Lake between 2003 and 2021 using altimetry data from ICESat-1, ICESat-2, and Cryosat, as well as lake hydrological observation data and climate and human activity elements. We discuss the possible influencing factors of the hydrological changes in the context of the Bosten Lake basin's climate and human activity change characteristics. Our findings reveal that the water level of Lake Bosten underwent two distinct phases of change over the past 18 years. A significant decline (shrinkage) occurred during 2003–2012, followed by a significant increase (expansion) after 2013. The Bosten Lake basin's climate has undergone distinct phases of change, characterized by a combination of regional dry and wet climate transitions and human disturbance that have caused dramatic changes in lake levels. Between 2003 and 2013, the temperature showed a dramatic increase, and there was a strong evaporative demand. The regional climate tended to become drier. After 2013, the climate tended to become warmer and wetter, and the trend of increasing precipitation resumed.

Acknowledgement: This research was funded by the National Natural Science Foundation of China (U2003205), and the Tianshan Talent Project (Phase III) of the Xinjiang Uygur Autonomous Region.

Conflicts of Interest: The authors declare no conflict of interest.

References

Abd-Elaty, I., Kuriqi, A., & Shahawy, A. E. (2022). Environmental rethinking of wastewater drains to manage environmental pollution and alleviate water scarcity. Natural Hazards, 110(3), 2353-2380.

Abshire, J. B., Sun, X., Riris, H., Sirota, J. M., McGarry, J. F., Palm, S., ... & Liiva, P. (2005). Geoscience laser altimeter system (GLAS) on the ICESat mission: on- orbit measurement performance. Geophysical research letters, 32(21).

Adnan, M., Kang, S., Zhang, G., Saifullah, M., Anjum, M. N., & Ali, A. F. (2019). Simulation and analysis of the water balance of the Nam Co Lake using SWAT model. Water, 11(7), 1383.

Alsdorf, D., Birkett, C., Dunne, T., Melack, J., & Hess, L. (2001). Water level changes in a large Amazon lake measured with spaceborne radar interferometry and altimetry. Geophysical Research Letters, 28(14), 2671-2674.

Birkett, C. M. (1994). Radar altimetry: A new concept in monitoring lake level changes. Eos, Transactions American Geophysical Union, 75(24), 273-275.

Birkett, C. M. (2000). Synergistic remote sensing of Lake Chad: Variability of basin inundation. Remote sensing of environment, 72(2), 218-236.

Brooks, R. L. (1982). Lake elevation from satellite radar altimetry from a validation area in Canada. Reporte, Geosci. Res.

Chen, Y., Du, Q., Chen, Y. (2013). Study on Sustainable Utilization of water resources in Bosten Lake Basin. Science Press, Bei Jing.(in Chinese)

Cooley, S. W., Ryan, J. C., & Smith, L. C. (2021). Human alteration of global surface water storage variability. Nature, 591(7848), 78-81.

Dai, X., Yang, X., Wang, M., Gao, Y., Liu, S., & Zhang, J. (2019). The dynamic change of bosten lake area in response to climate in the past 30 years. Water, 12(1), 4.

Dettmering, D., Ellenbeck, L., Scherer, D., Schwatke, C., & Niemann, C. (2020). Potential and limitations of satellite altimetry constellations for monitoring surface water storage changes—A case study in the Mississippi Basin. Remote Sensing, 12(20), 3320.

Ducet, N., Le Traon, P. Y., & Reverdin, G. (2000). Global high- resolution mapping of ocean circulation from TOPEX/Poseidon and ERS- 1 and- 2. Journal of Geophysical Research: Oceans, 105(C8), 19477-19498.

Frappart, F., Calmant, S., Cauhopé, M., Seyler, F., & Cazenave, A. (2006). Preliminary results of ENVISAT RA-2-derived water levels validation over the Amazon basin. Remote sensing of Environment, 100(2), 252-264.

He Yijun. Research and Application of Altimeter Remote Sensing in Ocean [M]. Science Press, 2002.(in Chinese)

Hwang, C., Peng, M. F., Ning, J., Luo, J., & Sui, C. H. (2005). Lake level variations in China from TOPEX/Poseidon altimetry: Data quality assessment and links to precipitation and ENSO. Geophysical Journal International, 161(1), 1-11.

Jekeli, C., & Dumrongchai, P. (2003). On monitoring a vertical datum with satellite altimetry and water-level gauge data on large lakes. Journal of Geodesy, 77, 447-453.

Jiang, L., Nielsen, K., Andersen, O. B., & Bauer-Gottwein, P. (2017). Monitoring recent lake level variations on the Tibetan Plateau using CryoSat-2 SARIn mode data. Journal of Hydrology, 544, 109-124.

Jiang, X., Fan, C., Liu, K., Chen, T., Cao, Z., & Song, C. (2022). Centenary covariations of water salinity and storage of the largest lake of Northwest China reconstructed by machine learning. Journal of Hydrology, 612, 128095.

Laxon, S. W., Giles, K. A., Ridout, A. L., Wingham, D. J., Willatt, R., Cullen, R., ... & Davidson, M. (2013). CryoSat- 2 estimates of Arctic sea ice thickness and volume. Geophysical Research Letters, 40(4), 732-737.

Li, J., Chu, Y., Jiang, W., Xu, X. (2007). Using satellite altimeter data to monitor lake level changes in the middle and lower reaches of the Yangtze River (Doctoral dissertation).(in Chinese)

Lin, Y., Li, X., Zhang, T., Chao, N., Yu, J., Cai, J., & Sneeuw, N. (2020). Water volume variations estimation and analysis using multisource satellite data: a case study of lake victoria. Remote Sensing, 12(18), 3052.

Luo, S., Song, C., Zhan, P., Liu, K., Chen, T., Li, W., & Ke, L. (2021). Refined estimation of lake water level and storage changes on the Tibetan Plateau from ICESat/ICESat-2. Catena, 200, 105177.

Mercier, F., Cazenave, A., & Maheu, C. (2002). Interannual lake level fluctuations (1993–1999) in Africa from Topex/Poseidon: connections with ocean–atmosphere interactions over the Indian Ocean. Global and Planetary Change, 32(2-3), 141-163.

Neumann, T. A., Martino, A. J., Markus, T., Bae, S., Bock, M. R., Brenner, A. C., ... & Thomas, T. C. (2019). The Ice, Cloud, and Land Elevation Satellite-2 Mission: A global geolocated photon product derived from the advanced topographic laser altimeter system. Remote Sensing of Environment, 233, 111325.

Schutz, B. E., Zwally, H. J., Shuman, C. A., Hancock, D., & DiMarzio, J. P. (2005). Overview of the ICESat mission. Geophysical Research Letters, 32(21).

Smith, A. J., Pavelsky, T. M., Legleiter, C. J., Durand, M. T., & Gleason, C. J. (2020). ICESat-2 Observations of Water Surface Elevation and Channel Geometry in the Yukon River Basin. Remote Sensing, 12(3), 463.

Song, C., Huang, B., & Ke, L. (2014). Inter- annual changes of alpine inland lake water storage on the Tibetan Plateau: Detection and analysis by integrating satellite altimetry and optical imagery. Hydrological Processes, 28(4), 2411-2418.

Song, C., Ye, Q., Cheng, X. (2015). Shifts in water-level variation of Namco in the central Tibetan Plateau from ICESat and CryoSat-2 altimetry and station observations. Science bulletin, 60(14), 1287-1297.

Wei, H.， Xu, R.， Yang, Q.， Zhou, Q.． (2021). Variation and effect analysis of the water level of the Taihu Lake based on multisource satellite altimetry data. Remote Sensing for Natural Resources，33(3) : 130-137.(in Chinese)

Wu, H.. (2019). Studies on changes in water level and storage of Bosten Lake based on satellite-borne radar altimetry data. Journal of Water Resources & Water Engineering (003), 030.(in Chinese)

Xiao, F., Li, X., Li, Y., & Yao, T. (2021). Monitoring water level changes of lakes in eastern Africa using ICESat-2 data. Remote Sensing, 13(8), 1452. doi: 10.3390/rs13081452

Yao, J., Chen. J., Dilinuer, T., Hu, W. (2021). Trend of Climate and Hydrology Change in Bosten Lake Basin and Its Influence on the Lake Level. PEARL RIVER, 42(4), 19.(in Chinese)

Zhang, C., Lv, A., Jia, S., & Qi, S. (2022a). Longterm multisource satellite data fusion reveals dynamic expansion of lake water area and storage in a hyperarid basin of China. Journal of Hydrology, 610, 127888.

Zhang, Y., Wang, N., Yang, X., Tai, X. (2022b). Dynamic monitoring of Balkhash Lake from 1970 to 2020 based on multi-source remote sensing data. Arid Land Geography, 45(2), 499-511. (in Chinese)