

The Current Ecological Environment Issues and Thoughts of Glaciers and Lakes on the Qinghai-Xizang Plateau

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ABSTRACT

The Qinghai-Xizang Plateau is home to the world's highest-altitude and largest number of plateau lake groups. In recent decades, the lakes on the Qinghai-Xizang Plateau have undergone significant changes in terms of water volume and other aspects such as salt content and nutrient content. In addition, the ecology of these lake areas has also changed significantly, including changes in microorganisms and plants. The logic and mechanism behind these continuous changes are outlined in this article, especially the review of the lake system changes under the increase of lake water volume. In addition, the ecological risks of lakes on the Qinghai-Xizang Plateau and their countermeasures are proposed, and case analyses are conducted in combination with the two large lakes, Selin Co and Qinghai Lake.

KEYWORDS

Qinghai-Xizang Plateau, Glacial Lakes, Current Situation Question, Countermeasures and Thoughts.

1. INTRODUCTION

The Qinghai-xizang Plateau is known as the "water tower of Asia". It is home to 36,793 modern glaciers. The glacier area is 49,873.44 square kilometers and the ice reserve is 45,61 cubic meters. It nourishes more than ten rivers in Asia, including seven of the most important rivers: the Yangtze River, the Yellow River, the Ganges, the Indus River, the Yarlung Zangbo River and the Lancang river. (Yao Tandong, Yao Zhijun, 2010) (Chinese Nature Magazine) Since the 1980s, against the backdrop of global warming, the Qinghai-Xizang Plateau has witnessed a trend of accelerated transformation from surface solid water resources to liquid water resources, characterized by glacier retreat, reduced snow cover, increased runoff variation, wetland degradation, and permafrost degradation (Wang Xin et al., 2023, *Advances in Water Science*).

The Qinghai-Xizang Plateau is home to the world's highest-altitude and largest number of plateau lake groups, and it is also the world's largest high-altitude inland lake area. Lakes also play a very important role on the Qinghai-Xizang Plateau. The total area of the lakes is approximately 42,521 square kilometers, accounting for 1.9% and 57.2% of the global and Chinese lake areas respectively (Wang Xin et al., 2023, *Advances in Water Science*). The lakes on the Qinghai-Xizang Plateau provide water for nearly 2 billion people on the plateau and in the lower reaches of China and India, constituting an important part of the "Asian Water Tower". These lakes are also valuable habitats for flora and fauna, maintaining biodiversity and providing crucial ecosystem services, including the absorption and storage of carbon dioxide. In addition, due to the unique geographical and climatic development conditions, the types and functions of lakes on the Qinghai-Xizang Plateau are rich and diverse. Besides providing important water resources and habitats for organisms, some salt lakes contain a large amount of salt mineral resources (Liu Zhiqi et al. 2022, *Environmental Science*).

The lakes on the Qinghai-Xizang Plateau are extremely sensitive to global warming. The lakes in this region are mainly supplied with water by precipitation, snow cover and the melting of glaciers. Therefore, since the 20th century, with the fluctuating warming of the global climate, especially the rapid warming since the 1980s, as most glaciers are in a retreat trend. This change has profoundly altered the hydrological conditions and ecological processes of plateau lakes, leading to drastic alterations in lake area, water volume and water chemical properties, mainly reflected in the expansion of lake area and the increase in water volume. Meanwhile, with the development of regional social economy, the intensity and scope of human activities (such as tourism, animal husbandry and mineral exploitation) have been continuously expanding, posing new and increasingly severe pressures and challenges to the originally fragile plateau lake ecosystem.

Previous studies have mostly restored the changes in the number and area of lakes in the Qinghai-Xizang Plateau region through remote sensing methods. Some investigations have studied the water quality of lakes such as salinity and eutrophication status (Wang Xin et al., 2023; LIU zhiqi et al., 2022), and very few studies have involved the changes in lake organisms and ecosystems. Overall, some important conclusions have been drawn, such as the significant expansion of lakes, the sharp increase in water volume, the general trend of "freshwater" in lakes [1], and even it has been found that the lake ecosystem on the Qinghai-Xizang Plateau is undergoing reorganization (Chenliang Du, 2025, communications earth& environment) . However, comprehensive and integrated studies on the area, water volume, water quality and aquatic ecology of lakes on the Qinghai-Xizang Plateau are still relatively scarce. Even fewer are comprehensive evaluations of the changes in lakes in this region and the proposal of comprehensive management countermeasures. Therefore, as a review article, this paper hopes to have a more comprehensive understanding of the current ecological environment problems and future development trends of lakes on the Qinghai-Xizang Plateau.

2. DATA AND METHODS

The data in this article mainly comes from the Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences. The remote sensing team of this institute has provided a large amount of rich information on the quantity and area changes of plateau lakes. At the same time, this article also refers to the rich achievements of the scientific expedition to the Qinghai-Xizang Plateau in recent years by this institute, especially the report on the investigation and research of lakes in China (Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences) "2023. In addition, this article also refers to some articles published in international journals in recent years, as well as some unpublished graduate student theses.

3. RESULTS

3.1. The number, area and changes of lakes

LI SHENGMING et al. Research on the dynamic changes and driving factors of the glacier-fed lakes in typical global areas 2018 found that in the past two decades, the changes of lakes replenished by glaciers on the Qinghai-Xizang Plateau have mainly shown an expansion change, and the degree of change of lakes varies at different stages. The dynamic rate of lake area was 5.6% from 2005 to 2015, and 11.3% from 1995 to 2005. The expansion rate of lake area from 2005 to 2015 was not as fast as that from 1995 to 2005, and the growth rate of the number of lakes from 2005 to 2015 was also not as fast as that from 1995 to 2005. The changes in the number of lakes are mainly characterized by new growth and expansion, and the overall number of lakes shows an increasing trend. In addition, in terms of the number of lakes, glacial replenishment lakes are mainly distributed in the Qiangtang Plateau, the southwestern rivers in southern Xizang, and the Yarlung Zangbo River Basin, while they are less common in the Qaidam Basin, the inland river basins of the Hexi Corridor, and the three

parallel rivers (Jinsha River, Lancang River, and Nu River) basins in southeastern Xizang. From the perspective of the changes in the area of lakes throughout the region, although the lakes are generally expanding, the changing trends of lakes in different areas are not consistent.

Wang Xin et al. (2023) demonstrated that from 1920 to 1995, lakes shrank significantly. The area of lakes smaller than 10 square kilometers expanded slightly, while those larger than 10 square kilometers generally retreated. From 1995 to 2010, there was a linear and rapid growth, and most lakes showed an expanding trend. Expansion trend is significant after 2000, in 99 new area is greater than 1 km² lake, expansion area of 240 km², accounting for 18.4% of the total area of the lake; It was relatively stable from 2010 to 2015 and further increased from 2015 to 2020. The area of lakes in the northern part of the plateau and the water volume of most lakes in the eastern inland flow area generally show an increasing trend, while the area and water volume of lakes in the southern part of the Qinghai-Xizang Plateau show a decreasing trend, which may be related to the reduction of precipitation, the increase of evaporation and the operation of water conservancy projects. The increase in the area of lakes mainly results from two aspects: on the one hand, the increase in precipitation or the accelerated melting of glaciers and snow leads to an increase in the inflow of lakes; on the other hand, the reduction in evaporation leads to a decrease in water loss. Since the mid-1990s, the expansion of lakes may also have been driven by the positive phase of the multi-age oscillation in the Atlantic Ocean. The inflection points of significant changes in lake area in 1997/1998 and 2015/2016 were attributed to strong El Nino events. In the northern, western and northwestern regions of the Qinghai-Xizang Plateau, glacial meltwater contributes significantly to the water volume of lakes. Under the combined effect of climate warming and other non-climate driving factors, the area and number of glacial lakes have increased rapidly. Glacial recharge lakes expand faster than non-glacial recharge lakes. The average rate of water level rise in glacial recharge lakes (0.24 m/a) is slightly higher than that in non-glacial recharge lakes (0.20 m/a). Precipitation may be one of the reasons for the changes in lakes throughout the Qinghai-Xizang Plateau region, while the increase of glacial meltwater with rising temperature may be an important reason for the expansion of lakes in the Qinghai-Xizang Plateau region.

ZHU Liping et al. [1] found that the total area of lakes on the Qinghai-Xizang Plateau in 2019 was approximately 46,980 square kilometers, among which 1,132 lakes had an area larger than 1 square kilometer. Among these lakes, 77% are closed inland lakes, distributed in the central, northern and western parts of the Qinghai-Xizang Plateau. The remaining 23% are outflow lakes, located in the eastern and southern parts of the plateau, flowing into major river systems. From 1986 to 2019, the total area of lakes on the Qinghai-Xizang Plateau increased from 37,109 square kilometers to 46,980 square kilometers, with an increase of 27%. Among the lakes with an increasing area, 65% are replenished by glacial meltwater and 35% are non-glacial replenished lakes. In addition, affected by the changes in the regional water cycle, the expansion rate of lakes on the Qinghai-Xizang Plateau was not constant during this period. Before 1995, the changes in lakes larger than 10 square kilometers were mainly controlled by reduced precipitation and restricted meltwater runoff under low-temperature conditions. Since 1995 until the present, with the increase in precipitation and meltwater supply, the expansion of lakes has shown a significant accelerating trend.

Although the research scales of various researchers vary, on the whole, the area and number of lakes on the Qinghai-Xizang Plateau have increased over the past few decades, especially those replenished by glacial meltwater. However, due to the vast area of the plateau, the characteristics of lake changes in each sub-region are not completely consistent.

3.2. The water volume of lakes and its variations

The research results of ZHU Liping et al. [1] and others show that the water storage capacity of lakes on the Qinghai-Xizang Plateau mainly fluctuates with the changes of replenishment factors such as precipitation, glacial meltwater and soil moisture content. Overall, the total water storage of these

lakes decreased by 45.2 ± 8.2 billion cubic meters from 1986 to 1995 and then increased by 214.9 ± 12.7 billion cubic meters from 1995 to 2019. Precipitation is one of the factors driving the increase in water storage in lakes. For instance, the expansion of lakes in the northern part of the plateau and the shrinkage of lakes in the southern part can be attributed to changes in the distribution of precipitation. The strengthening of the westerly wind leads to an increase in precipitation in the northern part of the plateau, while the weakening of the Indian summer monsoon results in a decrease in precipitation in the southern part of the plateau. Therefore, the water storage capacity of lakes in the northern and southern parts of the plateau also shows an increasing and decreasing trend respectively. Glacial meltwater is another important factor affecting the water volume of lakes. Among the lakes with increased water volume in the northern, western and northwestern parts of the plateau, glacial meltwater recharge lakes account for 40%, 51% and 100% respectively. Among the lakes with increased water storage on the entire Qinghai-Xizang Plateau, glacial meltwater recharge lakes and non-glacial meltwater recharge lakes account for 81% and 19% respectively. In addition, the degradation of permafrost and the melting of groundwater ice have also led to an increase in groundwater volume on the Qinghai-Xizang Plateau. Since 1995, the degradation of permafrost has led to an increase of approximately 0.005 cubic meters in the average soil moisture content in the northern part of the plateau every ten years, which has enhanced the recharge of groundwater to the water volume of lakes. Furthermore, Wang Xin et al. (2023) demonstrated that from 1976 to 2019, the water volume of the lake increased by 169.7 ± 15.1 Gt. A research team led by Song Chunqiao, a researcher at the Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, has shown that under the background of warm and humid climate, the lakes in the Qinghai-Xizang Plateau, especially in the Qiangtang inland flow area, have generally shown a rapid expansion trend. With the rapid rise in water levels, some lakes have overflowed from their original lake basins, thereby changing the hydrological connectivity between lake basins and triggering large-scale reorganization of water system basins.

3.3. The water quality of lakes and its variations

ZHU Liping et al. [1] et al. 's research indicates that high evaporation and the shrinking and reduction of lake water volume can lead to lake salinization. On the contrary, if the input of fresh water increases too much and the water volume of the lake rises, it will lead to the desalination of the lake. The lakes on the Qinghai-Xizang Plateau have long shown a trend of desalination. From 1986 to 2022, the average salinity of 352 lakes (each with an area of ≥ 10 square kilometers) across the entire plateau dropped from 48.76 psu to 23.76 psu (with a 95% confidence interval of 4.6-7.8 psu). ZHU Liping et al. 2025 During the same period, more than 140 saltwater lakes were transformed into brackish water conditions.

From 2002 to 2022, the average annual rate of salinity decline was -0.83 psu/ year (95% confidence interval: -0.39 to -0.23 psu/ year), indicating that the desalination trend is strengthening compared to the -0.51 psu/ year rate observed from 1986 to 2001. This weakening trend is more pronounced in the central and northern regions of the plateau where lakes expand more rapidly, while in the southern regions where lakes are shrinking, the salinity trend remains stable or weakens. As the lake basins on the Qinghai-Xizang Plateau are mainly covered by natural grasslands, most of the lakes on the Qinghai-Xizang Plateau are of oligotrophic type. However, in some lakes affected by human activities, the concentration of nutrients has increased. For instance, a rapid increase in total phosphorus concentration has been observed in the lakes in the northeastern part of the plateau where urbanization and human activities are highly intense. The growth rate of total phosphorus concentration in Qinghai Lake and Toso Lake reached 0.1 mg P/L/ ten years, which is twice the average of 76 lakes on the plateau. Furthermore, as most of the lakes on the Qinghai-Xizang Plateau are oligotrophic saltwater lakes with limited nutrient input, the increase in nutrient salt concentration is related to the enrichment process of dissolved substances, and this process is also associated with the rise in salinity. It is worth noting that the decline in salinity and the increase in nutrients jointly promote the production and

growth of microorganisms and plankton in lakes. When salinity drops to a relatively low level, the inhibitory effect of high salinity on microorganisms and plankton weakens. Under the conditions of its own aquatic ecosystem succession, the content of nutrients may gradually increase.

Historically, the Qinghai-Xizang Plateau region has had relatively low human interference, and its lakes and rivers have been relatively natural, clear and less polluted. However, in recent years, the concentrations of water quality parameters such as total nitrogen (TN) and total phosphorus (TP) have also increased in some lakes and rivers with good water quality on the Qinghai-Xizang Plateau. Studies have shown that the concentration of nutrients in lakes in the Qinghai-Xizang Plateau region is on the rise. In 2016, the total emissions of chemical oxygen demand (COD), TN and TP in the plateau environment were on average 1.15 to 2.72 times that of 1990. The water environment in the lake area deteriorated and heavy metal pollution increased (Wang Xin et al., 2023). LIU zhiqi et al. (2022) evaluated the lakes using the TLI index as follows: Except for Xiaochaidan Lake and Chaka Salt Lake, whose scores were below 30 and belonged to the oligotrophic state; The scores of the remaining lakes are all between 30 and 50, indicating that they are in a mesotrophic state. The TLI index of each lake shows relatively small seasonal differences. The evaluation results of lakes using the WQI index are as follows: The scores of L1-class lakes are all between 40 and 60, which belongs to the medium level. The scores of L2 class lakes are all between 60 and 80, while those of L3 and L4 class lakes are both between 80 and 100, which are respectively poor and extremely poor. Among them, the WQI index of Cuona Lake, Selin Co, Zari Nanmu Co, Tuosu Lake, Xiaochaidan Lake and Chaka Salt Lake shows significant seasonal differences.

3.4. Changes in lake ecology

In the lakes of the Qinghai-Xizang Plateau, the richness, diversity and uniformity of microbial species all decrease with the increase of salinity. For instance, in the northeastern and central parts of the Qinghai-Xizang Plateau and the Qaidam Basin, microbial diversity is relatively low under conditions of increased salinity, and vice versa. Although some saltwater lakes (with a salinity range of 0.5 to 50 psu) may have microbial diversity similar to or even higher than that of freshwater lakes (<0.5 psu), the diversity level of ultra-saltwater lakes (>50 psu) will decrease. Therefore, the observed freshwater transformation of lakes on the Qinghai-Xizang Plateau and the conversion of ultra-saltwater lakes to saltwater lakes may have a positive impact on the microbial communities in these lakes. Although increased precipitation and glacial meltwater input have driven lake expansion and desalination, they are poor sources of nutrients. Therefore, the enhanced freshwater input from lakes in the northern part of the Qinghai-Xizang Plateau may have exacerbated the oligotrophic conditions. In contrast, the relatively weak area expansion and salinity decline of lakes in the southern part of the Qinghai-Xizang Plateau have less impact on the nutritional status.

Furthermore, the increase in the surface water temperature of the lake leads to the concentration of Chl-a remaining unchanged or increasing. Therefore, the biomass of phytoplankton in lakes on the Qinghai-Xizang Plateau varies not only with the concentration of nutrients but also with salinity and water temperature. In fact, in these lakes, there is a significant negative correlation between salinity and the species richness of phytoplankton, the concentration of Chl-a, and the biomass of phytoplankton, as just mentioned. Furthermore, further support from 20 lakes in the northeastern part of the Qinghai-Xizang Plateau indicates that although desalination is associated with an increase in phytoplankton biomass, there has been no significant change in species composition. And evidence from 16 lakes in the central part of the Qinghai-Xizang Plateau indicates that a salinity threshold of 8-9.5 psu has a strong impact on phytoplankton - below this threshold, diversity is higher and the structure is more complex, while above this threshold, diversity is lower and the structure is simpler. This indicates that salinity regulates the phytoplankton aggregation process in the lakes of the Qinghai-Xizang Plateau (ZHU Liping et al.,2025).

4. OVERALL DISCUSSION

4.1. Synergistic changes in lake water volume, water quality and ecology, and their mechanism analysis

The coordinated changes in water volume, water quality and ecology of lakes in the Qinghai-Xizang Plateau region are essentially due to the climate and other issues in the macro environment, which cause changes in one link and thereby affect several other factors. First of all, due to global warming, glaciers have melted and the water volume of lakes has increased significantly. Since the meltwater from glaciers is mostly fresh water, such an increase in water volume will also lead to changes in water quality, the most obvious of which is the change in salinity. Due to the inflow of fresh water, the salinity has decreased and the lake water has desalinated. The desalination of lake water will affect the changes in the lake's ecological environment. Many microorganisms or other plants, due to the alterations in lake water quality, including nutrient content and salinity, also experience changes in their growth and development. In conclusion, the coordinated changes in water volume, water quality and ecology of lakes in the Qinghai-Xizang Plateau region are a series of processes of influences initiated by a climatic factor.

4.2. Ecological Risks of Lakes

With the increase in the number and volume of lakes, the incidence of natural disasters such as floods has significantly risen, gradually inundating land and affecting downstream water supply, posing potential risks to the human living environment. In addition, the expansion, overflow and outburst of lakes on the Qinghai-Xizang Plateau will also have a negative impact on transportation infrastructure and mineral mining activities. For instance, in September 2011, the overflow of Zhuonai Lake in the northern part of the plateau led to a significant increase of 163 square kilometers (347%) in the area of the downstream salt lake, posing a serious threat to the stability of the Qinghai-Xizang Railway, the Qinghai-Xizang Highway and the Qinghai-Xizang Oil Pipeline, which are only 6 kilometers away. Similarly, the expansion of inland lakes in the central and northern parts of the Qinghai-Xizang Plateau may also submerge fertile pastures and surrounding infrastructure such as roads or residential areas. For instance, between 2000 and 2005, the total area of three lakes in the Nagqu region in the central part of the Qinghai-Xizang Plateau expanded by 118 square kilometers, submerging over 9,600 hectares of high-quality grassland. This led to 76 herders being forced to relocate and another 164 herders facing threats due to the rising lake levels. Such potential threats cannot be ignored [1].

4.3. Countermeasures

In response to the current problems, it is first suggested that a comprehensive three-dimensional monitoring system for water, soil, air and life in the lake basins of the cold and high-altitude areas of the Qinghai-Xizang Plateau should be established. The lakes on the Qinghai-Xizang Plateau are highly sensitive to climate change. They can not only reflect the influence processes of climate and various elements through different types of replenishment changes, but also produce a series of chain effects in the physical and chemical properties and ecological conditions of the lakes. Therefore, it is of great significance to build a comprehensive and systematic monitoring system. Secondly, a disaster prediction, early warning and emergency prevention and control system for the expansion of lakes on the Qinghai-Xizang Plateau can be established. Because the occurrence of natural disasters such as floods due to the increase in water volume in many lakes is very sudden, many residents or other buildings find it difficult to take proper countermeasures. Therefore, if there is a disaster prediction, early warning and prevention and control system, it can greatly reduce the impact brought by these natural disasters. Finally, it is suggested that various means such as on-site observation and water color remote sensing be combined to strengthen the research on the ecological evolution process and laws of lakes on the Qinghai-Xizang Plateau under the influence of hydrological and climatic changes,

and reveal the mechanism by which the lake ecosystem on the Qinghai-Xizang Plateau responds to global changes.

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