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Study on the relationship between the lake area variations of Qinghai-Tibetan Plateau and the corresponding climate change in their basins^{*}

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Abstract. Qinghai-Tibetan Plateau is the largest lake area in China, with a total area of existing lakes of 36,900km², accounting for 52% of the total lake area of China. Lakes on the Tibetan Plateau play critical roles in the water cycle and ecological and environment systems of the Plateau. The global trend of warming up is increasing obviously, which has led to major changes in the climate conditions in China, even in the world. Whereas, when they analyse the relationship they just use the weather station's recording data, without any spatial analysis of the climate data. Here, we will do some researches on the relationship between the 10 selected lakes' area variation and the corresponding climate change in their drainage basin and discuss how the lakes changes in recent 40 years using the climate data processed using the spatial kriging. Thus, the drainage area can be taken into account and a real relationship can be pointed out. In order to study the relationship, Landsat MSS data, Landsat TM, Landsat ETM images, the topographic map have been collected to extract the variation of lake area. The 131 weather stations climate data, including precipitation, temperature, sun shine duration, evaporation are chosen to study the relationship. After extraction of the area of the lakes, a multivariate statistical analysis method was used to test the relationship between the area of the lakes and the global climate change, including the change of the temperature, the precipitation, and other factors. The variation of lakes in Qinghai-Tibetan Plateau is related to the mean temperature, the precipitation and saturation vapour pressure. But the frozen soil may affect the lake area variation to some extent.

1. Introduction

The Qinghai-Tibetan Plateau (QTP) is the largest lake area in China, with a total area of existing lakes of 36,900km², accounting for 52% of the total lake area of China [1]. Lakes on the Tibetan Plateau play critical roles in the water cycle and ecological and environment systems of the Plateau. Presently, the global trend of warming up is increasing obviously, which has led to major changes in the climate conditions in China, even in the world. Global climate change has been paid more and more attention in recent years, with the phenomena such as glacial ablation accelerating, lake water level rising, the

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number of days of strong wind and sand storm decreasing and vegetation improving [2, 3]. The unique locations of the lakes in QTP make them sensitive to climate changes [4]. A better understanding of lake variations on the Tibetan is important for evaluating climate change on Tibetan Plateau under global warming. The remote sensing technique is an efficient tool to analyze the status and variations of lakes.

In the context of global climate warming, the water level of many large and medium dropped and a large number of small lakes gradually die out. However, under the influence of climate warming, the glaciers melt and retreat so that the lakes supplied by the glaciers expand and desalt [5].

Many researches have been done on lakes in QTP. JIANG *et al.* discussed the distribution, variation and the comparison with lakes in other part of China. He also discussed the character of climate change in QTP and the impact of climate change on the change of lakes [5]. Shao *et al.* studied the changes of 11 major lakes On the QTP in the past 25 years, based on the interpretations of the Landsat MSS images acquired during the middle 1970s and ETM+ images acquired in the late 1990s or at the beginning of the 21st century [6]. Based on Landsat MSS images in 1970's and ETM images in 2000, Wu *et al.* studied the dynamic changes of lake areas in QTP during the recent 30 years by using remote sensing and GIS technology [7]. He showed that the total area and the number of lakes have increased remarkably although the area of some lakes has been decreasing and the change trends are different in various areas. Bian *et al.* discussed the response of lake change to climate fluctuation in north QTP in last 30 years [1]. Shen *et al.* analyzed the change trend of the 145 lakes, especially 12 lakes in QTP, and the relationship between the change trend and the meteorological changes [8].

Some research has been done just focusing on some lakes but in a long period. WU *et al.* studied the response of lake-glacier area change to climate variations in Namco basin in different stages and showed the increasing rate $1.27\text{km}^2/\text{a}$ of Namco from 1970 to 2000 [9]. Sun *et al.* also studied the lake ice changes in Namco lake basin and its response to climate change [10]. Ye *et al.* studied the variations of glacier and lakes in the Mapam Yumco Basin to climate change using topographical maps and Landsat images and showed that the total lake area decreased from 782.24km^2 to 748.08km^2 [11]. LU *et al.* studied Yamzho Lake and Chencuo Lake variation using remote sensing technology and showed that these two lakes shrunk from 1970 to 200 but expanded in the period of 1990-2000 [12]. Liao *et al.* suggest that the variations in lake surface areas are closely related to the warming, humidified climate transition in recent years such as the rise of air temperature and the increase in precipitation. In particular, the rising temperature accelerates melting of glaciers and perennial snow cover and triggers permafrost degradation, and leads to the expansion of most lakes across the plateau. In addition, different distributions and types of permafrost may cause different lake variations in the southern Tibetan Plateau [13]. Zhu *et al.* analyzed the variations of lake area and water storage for Nam Co for the past 34 years and pointed out that the melting glacier caused by the rising temperature, the increasing basin precipitation and the decreasing lake surface evapotranspiration caused the increasing water storage for Nam Co with the melting glacier as the main source [14].

Here, we will do some researches on the relationship between the variation of lakes in QTP and the corresponding climate change in their basins and discuss how the lakes changes in recent 40 years.

2. Study Area and Materials

2.1. Study area

The QTP is a vast, elevated plateau in Central Asia covering most of the Tibet Autonomous Region and Qinghai Province in China and Ladakh in Kashmir, India. It occupies an area of around 1,000 by 2,500 kilometers, and has an average elevation of over 4,500 meters. Sometimes called “the roof of the world”, it is the highest and biggest plateau, with an area of 2.5 million square kilometers. As the *world's third pole*, QTP responses to global climate change sensitively.

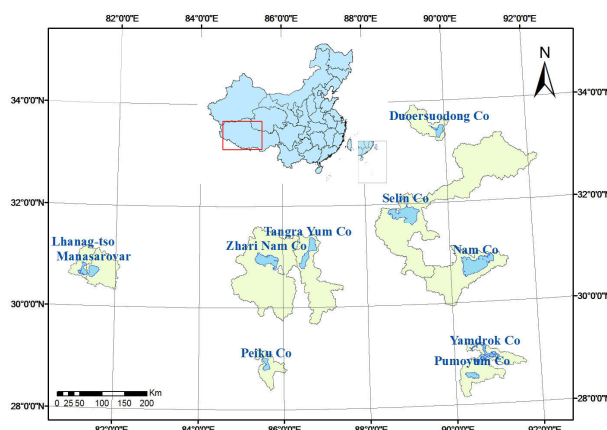


Figure 1. The selected 10 lakes, their corresponding basins and the location of weather station in QTP; the red square for the overview of the study area.

In QTP, there are 1091 lakes over 1.0km^2 with total area of 44993.3km^2 , 345 lakes over 10km^2 with total area of 42807km^2 [5]. The water supply of lakes on QTP can be natural precipitation, surface runoff, and glacier melt water and maybe frozen soil [13]. Due to the different water supply, the change trends of different lakes are different.

2.2. Data sources

In order to monitor and extract the variation of lake area in recent years, the available satellite remote sensing data for the lakes in the QTP have been collected, including Landsat MSS data, Landsat TM, Landsat ETM images, acquired from 1970 to 2000. Here we thank U.S. Geological Survey and the Center for Earth Observation and Digital Earth for providing these data. The topographic map used is the electronic version of map published in 1975 with the scale of 1:100,000. We also collected the meteorological materials for 117 meteorological stations including annual, monthly, daily temperature, precipitation and precipitation in the past 40 years (from 1970 to 2010) provided by the China Meteorological Data Sharing Service System hosted at China Meteorological Administration.

3. Methodology

All the Landsat images have been corrected geometrically. The projection system is *Albers Conical Equal Area* and the datum is WGS-84. The satellite image materials used here are managed under the Geographic Information System (GIS) tool--ArcGIS after pre-processed under the remote sensing platform. Then the lakes were extracted by artificial interpretation under ArcGIS and the areas of each lake in different year were calculated. The meteorological data were imported and processed under ArcGIS, including the kriging spatial interpolation to change the point data to raster data. The raster meteorological data then clipped using the lakes' basin polygon data (Figure 1). Then, the spatial meteorological data were carried on statistics under ArcGIS. The corresponding basins were extracted from SRTM data under ArcGIS [15, 16].

4. Analysis on the relationship between the variation of lakes and global climate change

4.1. Lake area variation

At present in the Tibetan Plateau, there are 833 lakes with an area $>1.0\text{ km}^2$, covering a total area of 28616.9 km^2 [17]. Thinking of the representativeness, 10 major lakes (Figure 1, Table 1) across the Plateau, from north to south, east to west, were selected to analyze the relationship.

Figure 2 shows that Nam Co and Selin Co have the largest area ($>1500\text{km}^2$), Zhari Nam Co, Tangra Yum Co and Yamdrok Co have the larger area ($>500\text{km}^2$) and Manssarovar, Duoersuodong Co, Peiku Co and Lhanag-tso have the smaller area ($<500\text{km}^2$). Figure 2 also shows the lake area variation trend for every lake with different variation. From 1970 to 1999, all the lakes changed with

small variety except Nam Co, Selin Co and Zharinam Co. From 1970 to 1999, Selin Co has the biggest increasing rate, and Nam Co has the bigger one. Zhari Nam Co and Yamdrok Co have the biggest decreasing rate. Tangra Yum Co, Manasarovar, Duoersuodong Co, Pumayum Co, Lhanag-tso and Peiku Co changed not obviously. After 1999, most of the lakes changed obviously. Selin Co increased dramatically from 1999, with the biggest increasing rate. Nam Co, Zhari Nam Co, Tangra Yum Co and Duoersuodong Co increased with a small rate. Yamdrok Co increased to 2003 and then decreased. Manasarovar, Pumayum Co, Lhanag-tso and Peiku Co changed not obviously.

Table 1. The 10 selected lakes to delineate lake-extent changes using Landsat images

ID	Lake Name	Latitude (°)	Longitude (°)	Area (km ²)*	Elevation (m)**
1	Yamdrok Co	28.98	90.74	633.5	4447
2	Pumayum Co	28.60	90.40	283.8	5019
3	Peigu Co	28.90	85.60	277.6	4585
4	Lhanag-tso	30.69	81.23	274.4	4575
5	Manasarovar	30.68	81.46	415.5	4590
6	Selin Co	31.80	89.00	1628.8	4544
7	Nam Co	30.70	90.60	1909.9	4729
8	Zhari Nam Co	30.92	85.63	996.9	4613
9	Tangra Yum Co	31.00	86.57	835.8	4528
10	Duoersuodong Co	33.38	89.87	400.0	4921

* denotes that the area are before 1970's, ** denotes that the elevation are from Google Earth.

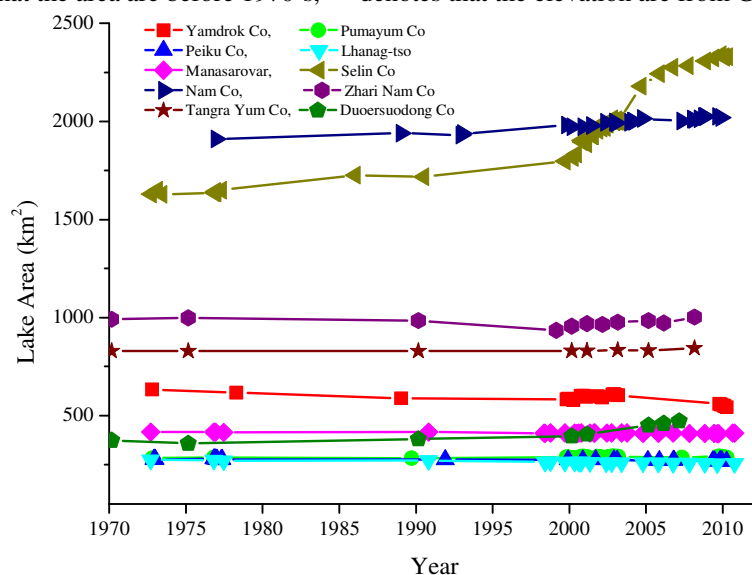


Figure 2. Area variations of the selected 10 lakes.

4.2. Climate changes

The changes in the annual mean temperature are generally consistent with the global warming trend, showing an obvious increasing trend (Figure 3). The annual mean precipitation express as a large fluctuation, but with not obviously increasing trends. The annual mean potential evapotranspiration (PE) also express a large scale fluctuation, with a small decreasing rate. The annual sunshine duration (SsD) expresses a large scale fluctuation, with a small decreasing rate.

5. Analysis of lake area change and climate change

Figure 2 shows that the lake areas in QTP had different change patterns in different areas and different periods. For Yamdrok Co and Pumayum Co, the temperature, precipitation, PE and the SsD had the same change trend. The basin's temperature, precipitation increased from 1970 to 2010. The PE

decreased from 1970 to 2003 and then increased from 2003 to 2010. The SsD changed not obviously. The lake area for Yamdrok Co decreased from 1970 to 2000, increased from 2000 to 2003, and decreased from 2003 to 2010. So the main driver for Yamdrok Co's variation is the increasing PE. The lake area for Pumayum Co increased from 1970 to 2003, and decreased from 2003 to 2010. So the main driver for Pumayum Co's variation is the increasing temperature, which accelerated the melting of glaciers and perennial snow cover and triggers permafrost degradation.

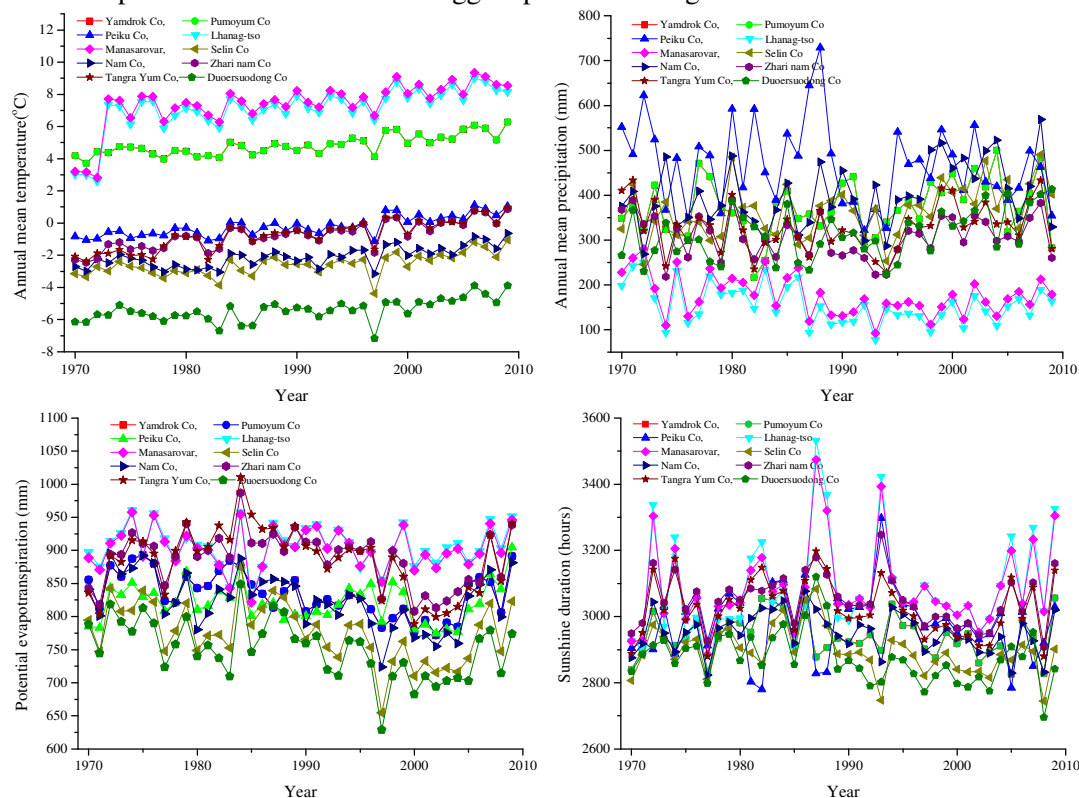


Figure 3. Variations in annual mean temperature, precipitation, potential evapotranspiration, and sunshine duration for the selected 10 lakes' basin.

The increasing temperature and PE led to the shrink for Peiku Co. The stable precipitation and SsD had little effect on the increasing area for Peiku Co. For Lhanag-tso and Manasarovar, the temperature, precipitation, PE and the SsD had the same change trend. The increasing temperature and decreasing precipitation led to the shrink for Lhanag-tso and Manasarovar. The stable precipitation and SsD had little effect on the increasing area for Lhanag-tso and Manasarovar. The increasing temperature and precipitation, and decreasing PE, SsD led to the increasing for Selin Co and Nam Co. The increasing temperature accelerated the melting of glaciers and perennial snow cover and triggers permafrost degradation to the expansion.

For Zhari Nam Co, the decreasing precipitation and increasing PE led the shrink for Zhari Nam Co from 1970 to 2000, whereas the increasing temperature and SsD had little effect. From 2000, Zhari Nam Co expanded with the increasing temperature, precipitation, PE and SsD. During this period, the increasing temperature accelerated the melting of glaciers and perennial snow cover and triggers permafrost degradation to the expansion.

From 1970 to 2000, Zhari Nam Co expanded with the increasing temperature. The precipitation decreased from 1970 to 1995, and increased from 1995 to 2010. The PE and SsD increased from 1970 to 1985, decreased from 1985 to 2000, and then increased again from 2000 to 2010. The increasing temperature led to the expansion of Zhari Nam Co. For Duoersuodong Co, the increasing temperature, precipitation and decreasing PE, SsD led the shrink.

The 10 selected lakes are located in different type of permafrost, continuous permafrost, island permafrost and sheet permafrost. Due to the different type, the permafrost may have an effect on the lakes' area variation to some extent.

6. Conclusion

Changing Environment of QTP is the response to global climate change, but also has to be sought it through its adjustment to reflect the new dynamic equilibrium [5]. In this work, 10 selected lakes were chosen to study the relationship between the lake area variations and the corresponding climate change in their basins. The study shows that lake areas in QTP had different change patterns in different areas and different periods. The temperature, precipitation, PE and SsD have different effect on the lake area variation. Meanwhile, the type of permafrost may have an effect on the lakes' area variation to some extent.

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