# THE RESPONSE OF LAKE VARIATIONS TO CLIMATE CHANGE IN TIBETAN PLATEAU IN LAST 40 YEARS

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## ABSTRACT

The Qinghai-Tibet Plateau is the largest lake area in China, with a total area of existing lakes of 36,900 km2, accounting for 49.5% of the total lake area of China The expansion and shrinkage of lakes in the Tibetan Plateau play critical roles in the water cycle and ecological and environment systems of the Plateau. In this paper, bases on the topographic map in 1970s, and the MASS and TM/ETM satellite remote sensing images from 1970s to 2008, the areas of the lakes were extracted, and a multivariate statistical analysis method was used to analyze 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 results suggest the variations of lakes in the Qinghai-Tibet Plateau are closely related to the warming and humidified climate change in the recent years such as rise of the air temperature, increase of the precipitation, etc.

**KEY WORDS:** lake variation; global change; Qinghai-Tibet Plateau

## INTRODUCTION

The Qinghai-Tibet Plateau is the largest lake area in China, with a total area of existing lakes of 36,900 $km^2$, accounting for 49.5% of the total lake area of China (Wang and Dou., 1998). The expansion and shrinkage of lakes in the Tibetan Plateau play critical roles in the water cycle and ecological and environment systems of the Plateau. The change of lake area and the variation of lake chemical properties will greatly alter the earth surface conditions and influence the general circulation of atmosphere (Yu and Harrison, 1995; Qin et al., 1997). In the other hand, by influencing the hydrological cycle of surface water and water phase variety, temperature and precipitation variations combine lake with glacier strongly, and contrarily they impose some feedback on climate system, and obviously impact the environment of human being (Singh and Bengtsson, 2005; Harrison et al., 2006; IPCC, 2007).

Most of the lake area in the Tibetan Plateau is sparsely populated, and has very poor natural conditions. Because of natural and physical constraints, lacking of systematic observation data, it is difficult to acquire the data of the lake changes. The spaceborne remote sensing technology provides effective tools for lake change research due to its advantages of vast covering area, massive information and high revisit. Some researches focused on some lakes or single lake have been carried out using remote sensing and geographic information system technologies (Yang et al., 2003; Lu et al., 2005; Bianduo et al., 2009;, Li et al., 2007; Ye et al., 2007; Wu and Zhu, 2008, Zhu et al., 2010). In this paper, based on the MASS and TM/ETM satellite remote sensing images in 1970, 1990 and 2000, the areas of the lakes in the Tibetan Plateau were firstly extracted. Then 11 typical lakes were selected to extract the area variations in last 40 years during 1970-2008, and a multivariate statistical analysis method was used to analyze the relationship between the area of the lakes and the global climate change, including the change of the temperature, the precipitation, and other factors from weather stations.

## TEST SITE

The test site is located in Tibetan Plateau with most intensive lakes and inland lake which have the highest elevation, the largest area and number. There are more than 700 lakes with the area over 1km$^2$ (Wang et al., 2005), they are mainly distributed between 4000m to 5000m high elevation. The distribution of the lakes is uneven, there are more indraft areas, indraft lakes and salty lakes than outflow area, outflow lakes and flesh lakes. Precipitation, underground water, meltwater from frozen soil and glaciers are the main water supply to lakes because of cold and dry climate, rarely precipitation and intense evaporation. Lakes in Tibetan Plateau are mainly generated by fault subsidence, most of them are inland lakes with short inflow rivers, except some outflow lakes in eastern and southern Tibet.

In this study, the areas of 328 lakes which are labeled in topographic map at a scale of 1:100000 were extracted based on the remote sensing images. Then 11 lakes were chose as typical lakes to analyze lake variation in last 40 years. The reasons of the choice are: first, these 11 lakes are distributed in the typical region of Tibet where contain weather stations, which offer necessary meteorological data; second, the largest lake and the lake with the greatest change are included. More over, these 11 lakes are contained in the region with most intensive lake distribution. Figure 1 shows the locations of the lakes and weather stations, while Table 1 shows the basic information of the lakes.

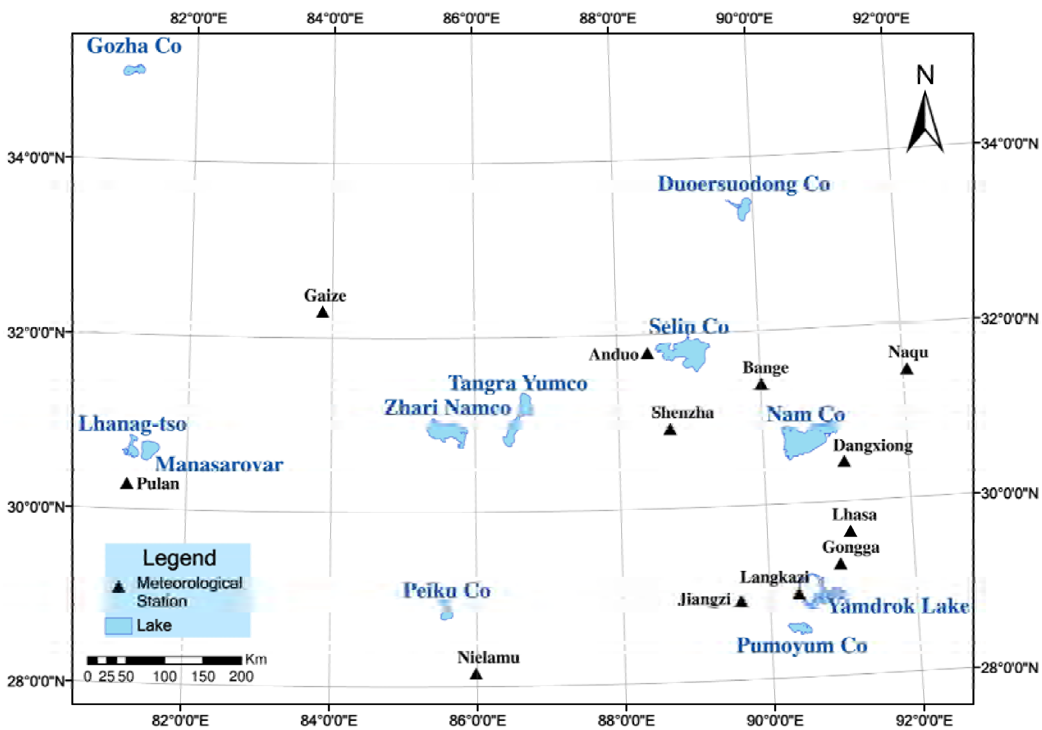


**Figure 1**. The locations of the lakes and weather stations.

**Table 1. Basic information of selected lakes in the test site**

| Lake | Location | Elevation （m） | Origin | Water supply | Weather stations |
|---|---|---|---|---|---|
| Peiku Co | N28°59′30.93″ E85°35′40.37″ | 4590 | fault basin | surface runoff | Nielamu |
| Zhari Namco | N30°55′24.93″ E85°37′34.57″ | 4613 | fault basin | surface runoff | Gaize, Anduo, Shenzha, Bange, Naqu, Dangxiong |
| Tangra Yumco | N31°2′18.85″ E86°34′58.62″ | 4528 | fault basin | surface runoff and precipitation | Gaize, Anduo, Shenzha, Bange, Naqu, Dangxiong |
| Lhanag-tso | N30°41′16.02″ E81°13′45.20″ | 4573 | fault basin | surface runoff | Pulan |
| Manasarovar | N30°41′5.76″ E81°27′39.86″ | 4588 | fault basin | surface runoff | Pulan |
| Gozha Co | N35°1′27.03″ E81°5′20.80″ | 5080 | fault basin | glacial meltwater | |
| Duoersuodong Co | N33°24′39.85″ E89°52′45.30″ | 4749 | | | Gaize, Anduo, Shenzha, Bange, Naqu, Dangxiong |
| Selin Co | N31°47′29.64″ E89°2′45.99″ | 4530 | fault basin | surface runoff | Gaize, Anduo, Shenzha, Bange, Naqu, Dangxiong |
| Nam Co | N30°42′31.61″ E90°28′10.80″ | 4718 | fault basin | surface runoff | Gaize, Anduo, Shenzha, Bange, Naqu, Dangxiong |
| Yamdrok | N28°59′26.87″ E90°44′8.38″ | 4441 | fault basin | precipitation | Lhasa、Gongga、Jiangzi、Langkazi |
| Pumayum | N28°34′3.95″ E90°24′31.87″ | 5030 | | surface runoff（ | Lhasa、Gongga、Jiangzi、Langkazi |

## DATA SOURCES

The data used in the study includes MASS, TM/ETM images which cover total study area in 1970, 1990, 2000 and a topographic map published in 1975 at a scale of 1:100,000. The remote sensing images for 11 selected lakes were acquired during October to December provided by the NASA Landsat Program. The meteorological data from 1970 to 2008 of 12 weather stations close to the lakes, including temperature, precipitation, solar radiation, wind speed, vapor pressure, are provided by China Meteorological Data Sharing Service System.

## DATA PROCESSING

With the topographic map at a scale of 1:100,00 as the base map, the remote sensing used are corrected geometrically, with the error controlled within 1 pixel. The boundaries of lakes were extracted by visual interpretation and manual digitization. The area of each lake is calculated using ArcView. Meanwhile, the potential evapotranspiration of each lake is calculated based on Penman-Monteith model recommended by the Food and Agriculture Organization of the United Nations (FAO) in 1998 (Walter et al., 2000). Finally, correlation analysis between area of each lake and meteorological data is carried out.

## ANALYSIS OF AREA VARIATION OF THE LAKES

Based on MASS,TM/ETM images which cover all region in 1970, 1990, 2000, with the topographic map published in 1975 at a scale of 1:100,00 as the standard map in which 328 lakes are labeled, the areas of 328 lakes were extracted. The result showed that 145 lakes have changed with the rate 0.232 $km^2 \cdot a^{-1}$, the quantity of area variation varies with different stages, but the general trend is that lakes of area increased is more than that of area decreased (Table 2).

**Table 2. Lakes variations during 1970-2008**

| | 1970-1975 | 1975-1990 | 1990-2000 |
|---|---|---|---|
| The number of lakes with decreasing area | 71 | 65 | 56 |
| The number of lakes with increasing area | 74 | 80 | 89 |

Based on the results mentioned above, we choose 11 lakes to extract their areas (Table 3), then calculated the values of area variation of each lake during 1970-1990, 1990-2000 and 2000-2008 (Table 4). The conclusion is that lake area variation varied with different stages. During 1970-1990, the areas of Lake Peiku, Lhanag-tso, Manasarovar, Selin Co, Nam Co, Duoersuodong Co were increased, especially Selin Co, its increase is by 82.45$km^2$， and the variation rate is 5.02%， and the variation speed is 3.93$km^2 \cdot a^{-1}$. The areas of Zhari Namco, Tangra Yumco, Gozha Co, Yamdrok, Pumayum were decreased, especially Yamdrok, its decrease is by 35.09$km^2$, and the variation rate is 5.59%，and the variation speed is 1.67$km^2 \cdot a^{-1}$. During 1990-2000, the areas of Selin Co, Nam Co, Duoersuodong Co, Tangra Yumco, Gozha Co, Pumayum, Yamdrok increased, Selin Co is still the lake with the largest area increased, and its increase is by 156.71 $km^2$ , and the variation rate is 9.08%, and the variation speed is 14.25$km^2 \cdot a^{-1}$. The areas of Zhari Namco, Lhanag-tso, Peiku, Manasarovar were decreased, especially Zhari Namco, its decrease is by 29.38 $km^2$, and the variation rate 2.98%, and the variation speed is 2.67$km^2 \cdot a^{-1}$. During 2000-2008, Selin Co, Nam Co, Duoersuodong Co, Pumayum, Tangra Yumco are still expanded. Besides, Zhari Namco was joined the increased group. However, Selin Co is still the lake with the largest area increased, 314.21 $km^2$ added, and the variation rate is 16.70%, and the variation speed is 34.91$km^2 \cdot a^{-1}$. Otherwise, Peiku, Lhanag-tso, Manasarovar, Gozha Co, Yamdrok are shrunk. Yamdrok was the most decrease. In conclusion, during 1970 to 2008, Selin Co, Nam Co, Duoersuodong Co are the only three lakes which expanded all the time. Other lakes varied with different stages. But one conclusion we make is that these lakes in Southern Tibet such as Peiku, Lhanag-tso, Manasarovar，Yamdrok tend to shrunk, In South Central of Tibet, the trend is opposite, the lakes such as Zhari Namco, Selin Co, Nam Co, Duoersuodong Co, tend to expanded. Variations of Pumayum, Tangra Yumco, Gozha Co are not obvious.

**Table 3 Areas of lakes extracted from remote sensing images since 1970 to 2008**

| Year | Peiku Co | Zhari Namco | Tangra Yumco | Lhanag-tso | Manasarovar | Gozha Co | Selin Co | Nam Co | Yamdrok | Duoersuodong Co | Pumayum |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1970 | 279.86 | 991.43 | 829.52 | 270.05 | 413.34 | 250.23 | 1642.87 | 1935.88 | 627.30 | 373.07 | 285.53 |
| 1975 | 292.96 | 997.86 | 829.07 | 268.50 | 413.97 | 245.04 | 1585.17 | 1929.30 | 626.64 | 358.91 | 304.36 |
| 1990 | 280.73 | 985.02 | 829.01 | 272.14 | 416.14 | 246.96 | 1725.31 | 1963.86 | 592.21 | 380.92 | 285.28 |
| 1998 | * | * | * | 261.70 | 409.92 | * | * | * | * | * | * |
| 1999 | * | 935.04 | * | * | * | 249.39 | * | * | 576.41 | * | 287.31 |
| 2000 | 274.68 | 955.64 | 830.14 | 259.15 | 411.37 | 250.95 | 1882.02 | 1981.51 | 595.04 | 395.29 | 288.98 |
| 2001 | 272.85 | 968.90 | 830.14 | 259.17 | 410.63 | 248.63 | 1922.02 | * | 595.85 | 405.78 | 292.42 |
| 2002 | 273.24 | 965.54 | * | 259.24 | * | 250.93 | 1995.91 | * | 597.97 | * | * |
| 2003 | 271.70 | 976.89 | 834.41 | 262.09 | 410.68 | 247.21 | 2055.12 | 1994.79 | * | * | * |
| 2004 | * | * | * | 260.35 | 409.50 | * | 2074.56 | 2013.92 | * | * | * |
| 2005 | 269.90 | 984.84 | 832.09 | 258.81 | 408.50 | * | 2141.71 | * | * | 450.54 | |
| 2006 | 270.03 | 972.72 | * | 258.49 | 410.17 | * | 2156.42 | * | 586.27 | 460.17 | 291.88 |
| 2007 | * | * | * | 257.52 | 409.33 | 250.91 | 2173.19 | * | 577.50 | 472.86 | 290.40 |
| 2008 | 269.39 | 1002.53 | 843.63 | 257.70 | 409.91 | 246.05 | 2196.23 | 2025.53 | 586.72 | * | 289.71 |

Note: that mark with *means no data

**Table 4. Area variations of typical lakes in Tibet since 1970 to 2008**

| Lake | 1970-1990 | | | 1990-2000 | | | 2000-2008 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Variations ($km^2$) | Variation rate (%) | Speed ($km^2 \cdot a^{-1}$) | Variations ($km^2$) | Variation rate (%) | Speed ($km^2 \cdot a^{-1}$) | Variations ($km^2$) | Variation rate (%) | Speed ($km^2 \cdot a^{-1}$) |
| Peiku Co | +0.87 | +0.31 | +0.04 | -6.05 | -2.12 | -0.55 | -5.29 | -1.93 | -0.59 |
| Zhari Namco | -6.41 | -0.65 | -0.31 | -29.38 | -2.98 | -2.67 | +46.89 | +4.91 | +5.21 |
| Tangra Yumco | -0.49 | -0.06 | -0.02 | +1.13 | +0.14 | +0.10 | +13.49 | +1.63 | +1.50 |
| Lhanag-tso | +2.09 | +0.77 | +0.10 | -12.99 | -4.77 | -1.18 | -1.44 | -0.56 | -0.16 |
| Manasarovar | +2.80 | +0.68 | +0.13 | -4.78 | -1.14 | -0.44 | -1.46 | -0.36 | -0.16 |
| Gozha Co | -3.27 | -1.31 | -0.16 | +3.99 | +1.62 | +0.36 | -4.90 | -1.95 | -0.54 |
| Selin Co | +82.45 | +5.02 | +3.93 | +156.71 | +9.08 | +14.25 | +314.21 | +16.70 | +34.91 |
| Nam Co | +27.98 | +1.45 | +1.33 | +17.66 | +0.90 | +1.61 | +44.02 | +2.22 | +4.89 |
| Yamdrok | -35.09 | -5.59 | -1.67 | +2.84 | +0.48 | +0.26 | -8.33 | -1.40 | -0.93 |
| Duoersuodong Co | +7.85 | +2.10 | +0.37 | +14.38 | +3.78 | +1.31 | +77.57 | +19.62 | +8.62 |
| Pumayum | -0.25 | -0.09 | -0.01 | +3.70 | +1.30 | +0.34 | +0.74 | +0.26 | +0.08 |

## ANALYSIS OF VARIATION OF LAKE AREA AND CLIMATE CHANGE

### Relationship Between Lake Area and Meteorological Factors

Correlation analysis between area variation and meteorological data which included temperature, precipitation, relative humidity, solar radiation, potential evapotranspiration were carried out to study the response of lake area variation to climate change (Table 5). Area variations of Lake Peiku, Lhanag-tso, Manasarovar, Yamdrok have negative correlation with temperature, but the correlation is positive between temperature and the area variations of Tangra Yumco, Selin Co, Nam Co Duoersuodong Co, Pumayum，and for Zhari Namco, the correlation is low. Tangra Yumco, Lhanag-tso are the only lakes that have high negative correlation between the area variations and precipitation. Area variation of Zhari Namco has negative correlation (0.5) with humidity while it's positive (0.4) to Selin Co and Nam Co. For solar radiation, the area variations of Peiku, Zhari Namco and Yamdrok have high positive correlation, while it's high negative to Selin Co, Nam Co, and Duoersuodong Co. Only the variations of Nam Co、Selin Co have obvious positive correlation with the potential evapotranspiration, others are not significant.

**Table 5. Correlation coefficients between areas of typical lakes and meteorological data**

| Lake | Temperature | Precipitation | Humidity | Solar radiation | Potential evapotranspiration |
|---|---|---|---|---|---|
| Peiku Co | -0.62 | 0.10 | -0.30 | 0.61 | 0.23 |
| Zhari Namco | 0.141 | -0.31 | -0.64 | 0.66 | 0.36 |
| Tangra Yumco | 0.55 | -0.61 | 0.06 | -0.16 | -0.34 |
| Lhanag-tso | -0.63 | -0.47 | -0.17 | -0.12 | -0.17 |
| Manasarovar | -0.59 | -0.25 | -0.15 | -0.09 | -0.04 |
| Selin Co | 0.42 | -0.07 | 0.47 | -0.77 | -0.41 |
| Nam Co | 0.38 | -0.05 | 0.54 | -0.88 | -0.55 |
| Yamdrok | -0.38 | 0.11 | -0.26 | 0.59 | 0.20 |
| Duoersuodong Co | 0.57 | 0.19 | 0.24 | -0.68 | 0.04 |
| Pumayum | 0.31 | 0.19 | -0.32 | 0.18 | 0.54 |

### Relationship Between Trend of Climate Change and Lake Variation

According to analysis of relative meteorological data, the annual mean temperature of Tibet rose, which is consistent with global warming. The influence of risen temperature on each lake is different. For Lhanag-tso and Manasarovar, temperature data from Pulan station rose, correlation between area variation and temperature is negative, meanwhile, precipitation of this area decreased, still it's negative that correlation between precipitation and area variation (Figure 2). The area variation in this area has a low correlation with the potential evapotranspiration and solar radiation. The potential evapotranspiration decreased, while solar radiation increased. So it's represented to us that the reasons for area decreased includes risen temperature, increased solar radiation and decreased precipitation.

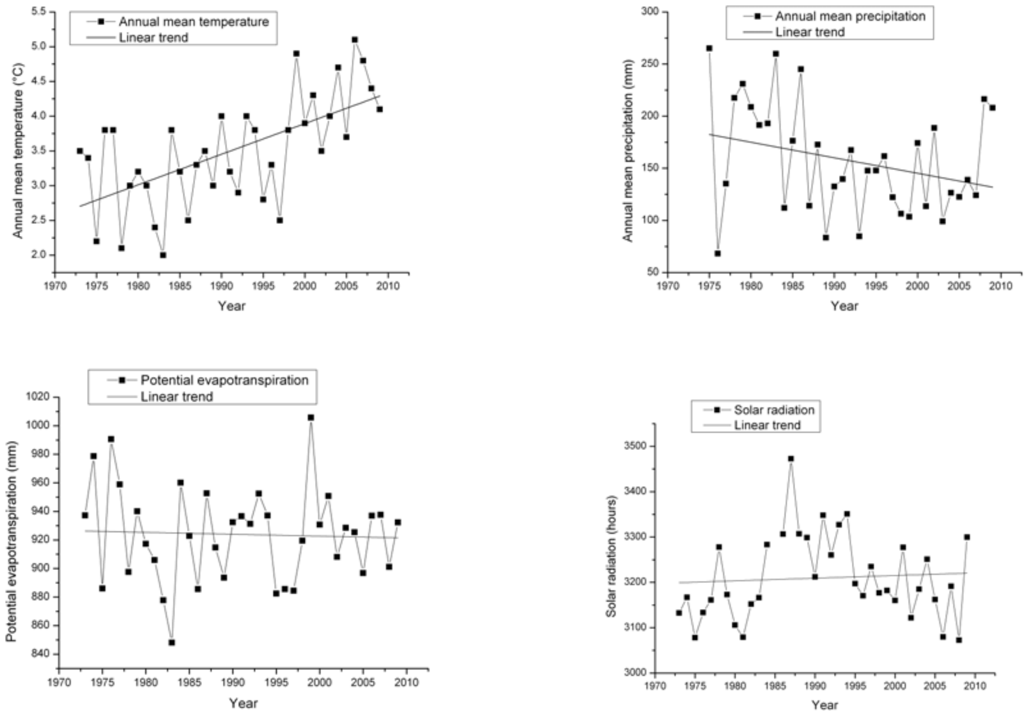


**Figure 2.** The change curve of annual mean temperature, precipitation, potential evapotranspiration and solar radiation in Pulan station.

For Lake Peiku, temperature data from Neilamu station rose, precipitation decreased, correlation between area variation and temperature is negative. Correlation between solar radiation and area variation (Figure 3) is also negative. But correlation between area variation and precipitation is low. For Yamdrok, annual mean temperature surveyed from Lhasa, Gongga, Langkazi and Jiangzi stations rose, precipitation increased, potential evapotranspiration and solar radiation decreased (Figure 4). So it shows that the reason for area decrease is risen temperature.

For Zhari Namco, Selin Co, Nam Co, Duoersuodong Co, temperature and precipitation surveyed from stations of Bange, Anduo, Naqu, Shenzha, Dangxiong and Gaize increased (Figure 5). The correlation between area variation and temperature is positive, and the correlation between lake area and potential evapotranspiration, solar radiation are obviously negative. These lakes located in South Central of Tibet where most of glaciers are small. Risen temperature induced glacier melting, besides, an increase of lake areas are also caused by the decrease of potential evapotranspiration and solar radiation.

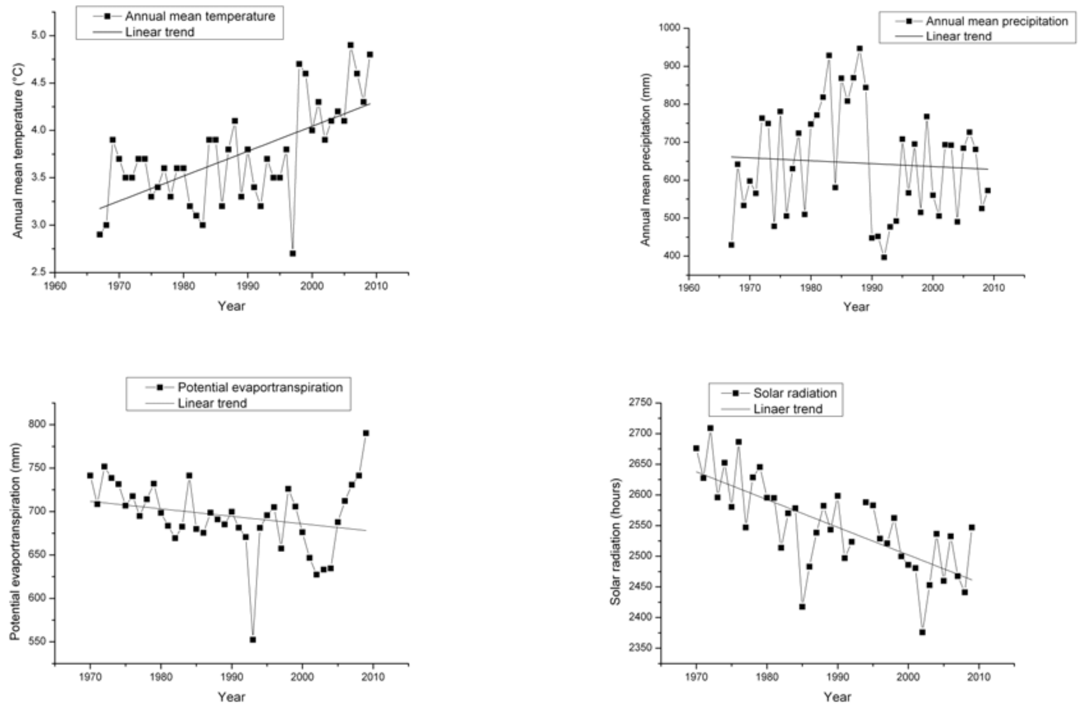


**Figure 3.** The change curve of annual mean temperature, precipitation, potential evapotranspiration and solar radiation in Nielamu station.

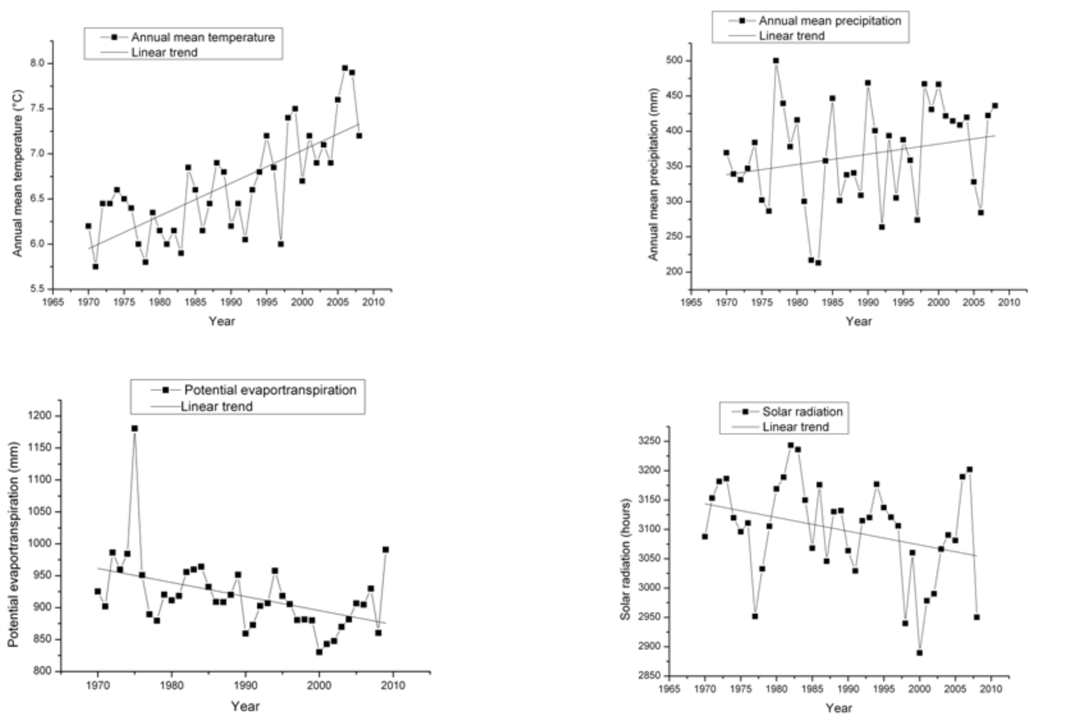


**Figure 4.** The change curve of annual mean temperature, precipitation, potential evapotranspiration and solar radiation in Lhasa, Jiangzi stations.

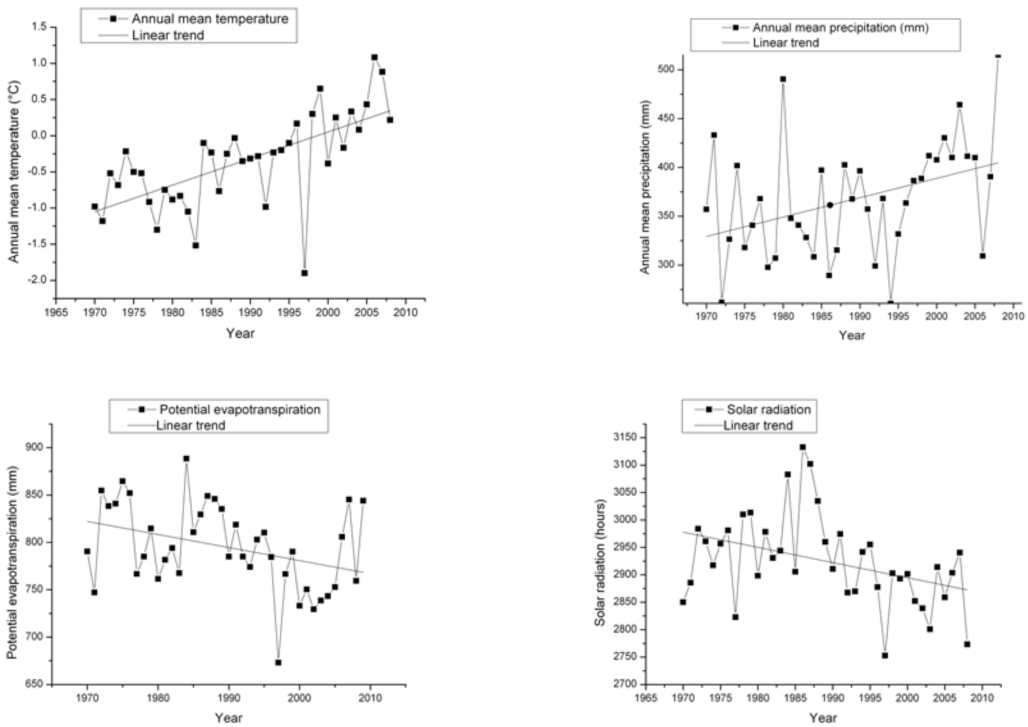


**Figure 5.** The change curve of annual mean temperature, precipitation, potential evapotranspiration and solar radiation in Bange, Anduo, Naqu, Shenzha, Dangxiong and Gaize stations.

## CONCLUSIONS

Climate change in Tibetan Plateau is characterized by risen temperature, increased precipitation. Otherwise, potential evapotranspiration and solar radiation decreased. The levels of influences of meteorological factors on area variation are different, but risen temperature impacted particularly remarkable. In Lhanag-tso-Manasarovar basin, the area decrease of lake has significant correlations with temperature rising and precipitation decreasing trend. While the levels of correlations between area decrease and potential evapotranspiration, solar radiation is not high. In Peiku-Yamdrok basin, the efficient cause of lake area decrease is temperature rising, the correlation between precipitation and area variation is not significant. According to the previous researches, the glaciers in basin of Yamdrok are retreating with the proportion 1.36% (Ye et al., 2007), so the reason for lake area expanding is not glacier retreating but temperature ascension. Previous results show that Nam Co-Selin Co basin is distributed the small glaciers, which thawed at faster speed caused by temperature ascension (Zhu et al., 2010). In this basin, precipitation increased while potential evapotranspiration and solar radiation decreased. Hence, the change of Nam Co-Selin Co basin is found to be sensitive to climate change.

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