The impact of climate changes on water level of Qinghai Lake in China over the past 50 years

Bu-Li Cui and Xiao-Yan Li

ABSTRACT

Understanding the variation regularity of lake level and the potential driver factors can provide insights into lake conservation and management. In this study, inter- and inner-annual variations of lake level in Qinghai Lake during the period 1961–2012 were analyzed to determine whether climatic factor or runoff factor were responsible for the variations. The results showed that lake level decreased significantly during the period 1961–2004 at a rate of -7.6 cm/yr, while increasing significantly during the period 2004–2012 at a rate of 14 cm/yr, and all were significant at a p value of <0.01. Lake level was most sensitive to climate and river runoff. Precipitation and river runoff had directly positive effects on lake level, but inverse evaporation and wind speed played a significantly negative role on lake level. The relative contributions of influencing factors in the Southeast Asian monsoon (SEAM) and the westerly circulation periods on annual lake level variations were approximately 49.8% and 27.8%, respectively. The relative contributions of temperature, precipitation, evaporation, and wind speed on lake level variation were approximately 13.8%, 36.3%, 27.1%, and 18.4%, respectively. In general, the annual lake level was primarily influenced by precipitation and evaporation of the SEAM period.

Key words | climate change, lake level variation, principal component analysis (PCA), Qinghai Lake, river runoff

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INTRODUCTION

Understanding the variation regularity of lake level and the potential driver factors can provide insights into the fields of engineering design, ecological conservation, and environmental management around a lake region, so the variations of water level in lakes all over the world have attracted increasing global attention in recent years (Wantzen *et al.* 2008; Wen *et al.* 2011; Reid *et al.* 2013). In the past few decades, water level of lakes on the Asian continent (e.g., Aibi Lake, Issyk-Kul Lake, Lop Nor Lake, Qinghai Lake) have decreased continually (Qin 1999; Liu 2008; Yuan *et al.* 2015). However, the reasons for each lake level decrease were different: natural factors (climate and runoff), human activities, or comprehensive influences of natural factors and human activities. For example, alpine lakes on the Tibetan Plateau were minimally disturbed by

human activities and were sensitive indicators of climate variability (Song *et al.* 2014a). Qinghai Lake is the largest inland lake in China, lying in the cold and semiarid region of the northeastern Tibetan Plateau (Figure 1). The lake is a national nature reserve and an important water body that influences the ecological integrity of the entire region (Tang *et al.* 1992). In the past few decades, 50% of the rivers flowing into the lake have dried up due to climate change and human activity (LZBCAS 1994; Li *et al.* 2007); the lake level elevation has declined from 3,196.55 m in 1959 to 3,194.26 m in 2012. This reflects an average annual decline of 4.75 cm over the 53-year period (Li *et al.* 2012). These hydrological changes have contributed to a series of environmental problems in the basin, including desertification, erosion, loss of grazing grassland, and

deterioration of water quality and quantity (Qin & Huang 1998; Hao 2008; Zhang et al. 2011a). Therefore, researching the factors that have contributed to the changes in Qinghai Lake level is critical for exploring possible solutions to the environmental problems, and may contribute to planning strategies and recommendations for future water resource use in the basin.

Previous studies have compared Qinghai Lake annual level trends with annual river runoff trends and climatic data; these studies have tried to investigate the impacting factors of the Qinghai Lake level (Tang et al. 1992; Ma 1996; Liu 2004; Li et al. 2005; Li et al. 2007; Liu et al. 2008; Shi et al. 2010; Zhang et al. 2011a; Jin et al. 2013). Most studies have concluded that annual lake level variations before the 2000s were primarily driven by climate and runoff (Ma 1996; Li et al. 2007; Zhang et al. 2011a; Jin et al. 2013). However, Qinghai Lake lies in a critical transitional zone (Figure 1), where the Southeast Asian monsoon (SEAM), the westerly circulation (WC) and the Qinghai-Tibet Plateau monsoon

meet. These forces impact the lake differently in different time periods (LZBCAS 1994), making the distribution and moisture source of the precipitation highly complex and unusual (Wang et al. 2004, 2008; Xu et al. 2007; Henderson et al. 2010; An et al. 2012; Cui & Li 2015b). Due to the lake watershed being closed, precipitation is the sole source of river runoff, and the runoff lags behind the precipitation (Cui et al. 2011). Therefore, due to using and comparing annual data of lake level, runoff, and precipitation, the reason for Qinghai Lake level variation is not fully explained. Nor is the contribution of each factor on lake level variation yet fully understood.

This study analyzed monthly lake level, climate factors, and river runoff data (1960–2012) to investigate the reasons for lake level variation, using principal component analysis (PCA) as an analytical method. The objectives of this study were: (1) to investigate the monthly and annual variations of Qinghai Lake level; (2) to identify the reasons for lake level variation; and (3) to discuss future possible variation of lake
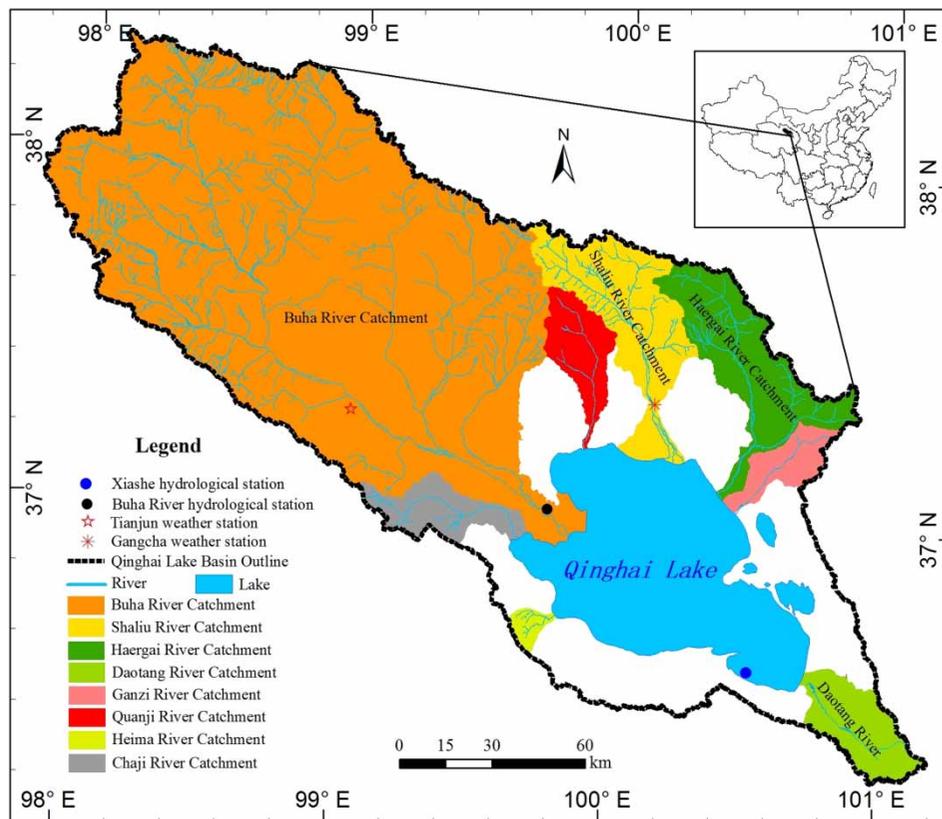

Figure 1 | Locations of the Qinghai Lake Basin and hydrological stations.

level. It is hoped that study results will provide insight into the hydrological processes of the Qinghai Lake Basin, and inform water resource management in the Qinghai Lake Basin and the northeastern Qinghai-Tibet Plateau.

STUDY AREA

Qinghai Lake (36 °32′–37 °15′N, 99 °36′–100 °47′E), a brackish lake with a water surface area of 4,400 km^2 and a water volume of 71.6×10^9 m^3 at an altitude of ~3,193 m above sea level (a.s.l.), is the largest lake in China (Figure 1). The lake is a closed basin with a watershed area of approximately 29,661 km^2 with no surface water outflow. It lies in the cold and semiarid region of China's NE Qinghai-Tibet Plateau. The average annual air temperature in the lake area is ~1.2 °C. The average annual precipitation is ~357 mm, with more than 65% occurring in summer. Evaporation is three to four times higher than precipitation (Li *et al.* 2007). The climate of Qinghai Lake is influenced by two air masses: SEAM and WC. The SEAM reaches this region in summer, while the WC dominates in winter, resulting in a clear seasonality of precipitation (An *et al.* 2012; Cui & Li 2015b).

The lake water has a salinity of 15.5 g/L and pH of 9. Its water chemistry is similar to many saline lakes in the Tibetan Plateau; the cations of lake water is in the order: $Na^+ > Mg^{2+} > K^+ > Ca^{2+}$, and anions is in the order: $Cl^- > SO_4^{2-} > HCO_3^-$. More than 50 rivers or streams flow into Qinghai Lake (LZBCAS 1994). The rivers are asymmetrically distributed, with most of them located north and northwest of the lake (Figure 1; Yan & Jia 2003). Most of the rivers are seasonal, with 85% of the annual discharge occurring between June and September. The main rivers are Buha River, Shaliu River, Haergai River, Quanji River, and Heima River (LZBCAS 1994; Li *et al.* 2007), with a total discharge of 1.43×10^9 m^3/yr. This river water accounts for 80.3% of the total surface water volume flowing into Qinghai Lake (Table 1).

For this study, the runoff of Buha River was chosen to represent the hydrological characteristics of rivers flowing into Qinghai Lake. The Buha River is the largest river in the Qinghai Lake Basin (LZBCAS 1994; Li *et al.* 2007), with a catchment area of approximately 14,932 km^2, which is about 50% of the Qinghai Lake Basin. Its discharge

Table 1 │ Characteristics of the main rivers in the Qinghai Lake Basin

River name	Catchment area (km²)	Main stream length (km)	Mean annual runoff (10⁸m³/yr)	Percent of all basin discharge (%)
Buha River	14,932	286.0	8.09	45.5
Shaliu River	1,645	105.8	3.12	17.5
Haergai River	1,572	109.5	2.42	13.6
Quanji River	599	63.4	0.54	3.0
Heima River	123	17.2	0.11	0.6
Total	18,872	581.9	14.28	80.3

is 8.09×10^8 m^3/yr, which accounts for approximately 50% of the total volume of surface water flowing into Qinghai Lake (Cui & Li 2015a). Furthermore, from a study methods perspective, only two rivers (Buha River and Shaliu River) have hydrological observation stations at their estuaries, needed to quantitatively estimate runoff. Based on these factors, the Buha River was used as a representative river to represent the hydrological characteristics of all rivers flowing into Qinghai Lake.

DATA AND METHODS

Figure 1 shows the locations of meteorological and hydrological stations in the Qinghai Lake Basin. Monthly lake level records and river runoff records from 1961 to 2012 were collected from Xiashe hydrological station and Buha River hydrological station, respectively (Figure 1). There are only two weather stations (Tianjun and Gangcha weather stations) in the Qinghai Lake Basin (Figure 1). Precipitation and temperature, for example, observed at the Tianjun weather station were consistent with those observed at the Gangcha weather station (Cui *et al.* 2011; Cui & Li 2015b); the Gangcha weather station is approximately 13 km north of the lake and is the nearest weather station to the lake (Figure 1). Therefore, monthly climate-related factors (precipitation, temperature, evaporation, and wind speed) of Gangcha weather station were used to analyze the impact of climate changes on lake level variation. Annual data were derived from monthly data.

In this study, correlation analysis (CA) and PCA were used to study the impacts of climate and runoff on lake

level (Astel *et al.* 2007; Olsen *et al.* 2012). Calculations were done using SPSS 13.0 software. The PCA is a multivariate technique where observations about the data set are described using several inter-correlated quantitative dependent variables (Manly 2000; Davis 2002; Shaw 2003). A 'percent explained variance' approach is often used, where the first few principal components (PCs) explain a large fraction of the total variance (e.g., greater than 60–70%). A given variable is considered to be an important contributor if its absolute loading exceeds approximately 0.75 (Olsen *et al.* 2012). The analytical goal is to extract the most important information from the data set, to represent it as a set of new orthogonal variables called 'PCs', and to display similar patterns across observations and variables as points in maps (Shaw 2003).

RESULTS

Changes of lake level, climate, and river runoff

During the period 1961–2012, the lake level declined in 33 years and showed signs of recovery in 17 years (Figure 2). Figure 2 also points to two phases: one phase, from 1961 to 2004, when the water level trended downwards at a rate of −7.6 cm/yr; and a second phase, from 2004 to 2012, when the water level rose at a rate of 14 cm/yr. In 15 individual years, the level dropped more than 15 cm/yr; in 8 individual years, the level rose more than 15 cm/yr (Figure 2). The largest annual decrease was 41 cm in 1979; the largest annual increase was 64 cm in 1989 (Figure 2). The lake level declined significantly in the 1970s and early

1990s. Monthly variation of lake level (Figure 3; Supplementary, Figure S1, available with the online version of this paper) indicated that the lake level generally rose from May to September and decreased from October to April in each year. The maximum monthly increase was 7.1 cm/month in August, and the maximum monthly drop was −9.5 cm/month in November (Figure 3).

The annual temperature between 1961 and 2012 showed an obvious increasing trend at a rate of 0.3 °C/decade (Figure 4); the most significant warming trend occurred in the 2000s (Table 2). This trend was similar to trends seen in the 'Three-River Headwaters' regions (the Yangtze River, the Yellow River, the Lancang River) and on the Tibetan Plateau (Wang *et al.* 2008; Lan *et al.* 2010; Zhang *et al.* 2011b). Annual precipitation, evaporation, and humidity all fluctuated, but with no overall upwards or downwards trend from 1961 to 2012 (Figure 4). Precipitation was relatively high in the 1980s and 2000s and relatively low in the 1970s and 1990s (Table 2). Inversely, the evaporation was relatively low in the 1980s and 2000s and relatively high in the 1970s and 1990s (Figure 4). The annual average wind speed decreased from 4.27 m/s in 1969 to 2.77 m/s in 2012 (Figure 4), with a significant increasing trend in the 1960s. When considering monthly data related to climatic factors (Figure 3), temperature, precipitation, and humidity had similar trends: high in summer and low in winter. Evaporation was relatively high at the end of spring into the summer (April to August) and relatively low in the winter (December to February). Wind speed was relatively high in the spring (March to May) and relatively low at the end of summer into autumn (August to October).

From 1961 to 2012, Buha River runoff fluctuated obviously, ranging from $1.99 \times 10^8 \, \text{m}^3$ to $19.47 \times 10^8 \, \text{m}^3$
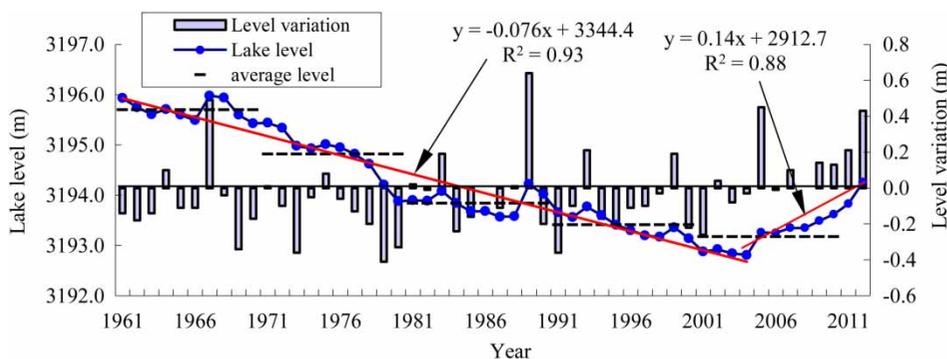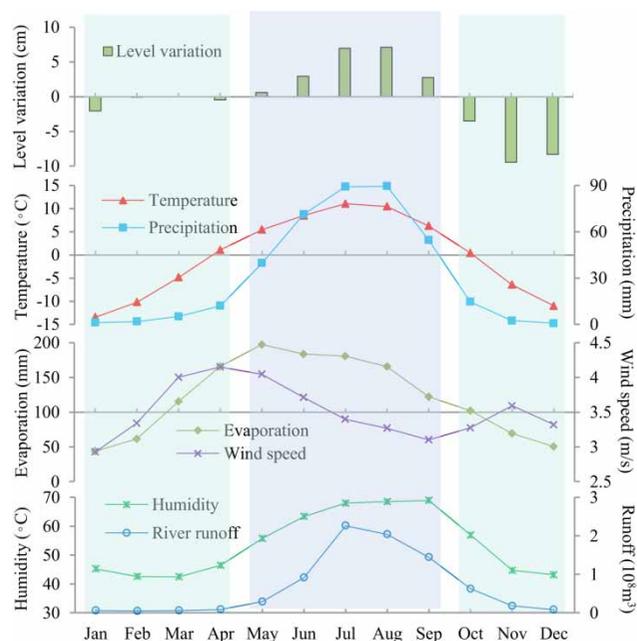
Figure 2 │ Annual lake level and level variation of Qinghai Lake from 1961 to 2012.

Figure 3 │ Monthly mean values of Qinghai Lake level and climatic factors during the period 1961–2012.

(Figure 4), but with no clear overall increase or decrease over time. River runoff was relatively high in the 1980s and 2000s and relatively low in the 1970s and 1990s (Table 2). Changes in runoff can be divided into three stages (Figure 4): (1) fluctuating and decreasing stage (1961–1980) with a decreasing rate of 0.34×10^8 m³/yr; (2) fluctuating stage (1981–1995); and (3) fluctuating and increasing stage (1996–2012) with an increasing rate of 0.44×10^8 m³/yr. Monthly runoff was relatively high in the summer (June to August) and relatively low in the winter (December to February) (Figure 3).

## Relationships between climatic factors and river runoff

According to Figure 4, at the annual scale, high evaporation peaks generally corresponded to low precipitation and low humidity, but also to relatively high temperature and high wind speed (e.g., 1969, 1979, 1995, and 2001). The opposite also holds true: low evaporation peaks generally corresponded to high precipitation and high humidity, but also to relatively low temperature and low wind speed (e.g., 1967, 1983, 1989, 2005, and 2012). CA results (Table 3) showed that the evaporation was highly negatively correlated to precipitation and humidity. Statistically, the

absolute values of correlation coefficients were all above 0.35, and all were significant at a p value of <0.05. These results suggested that high evaporation was closely related to dry climate, and low evaporation was closely related to wet climate. Humidity was positively correlated with precipitation (Table 3), namely, the precipitation had a positive effect on humidity. Due to the high wind speed despite low temperatures, monthly evaporation was relatively high in March and April (Figure 3).

At the annual scale, high runoff peaks generally corresponded to high precipitation and low evaporation (e.g., 1967, 1983, 1989, 1999, and 2005); conversely, significant drops in runoff generally corresponded to low precipitation and high evaporation (e.g., 1969, 1973, 1979, 1995, and 2001). Precipitation changes affected the generation of surface runoff directly, whereas temperature changes affected the evaporation of surface runoff (Cui & Li 2015a). These results indicated that drops in river runoff were closely related to a dry and relatively warm climate, whereas increases in river runoff were closely related to wet and relatively cold climates. Precipitation had a positive effect on runoff, while potential evaporation due to temperature and wind speed played a negative role (Li et al. 2007; Zhang et al. 2011a). Pearson correlation coefficients between river runoff and climatic factors showed that runoff was positively correlated with precipitation and humidity, but negatively correlated with evaporation and wind speed; all were significant at a p value of <0.01 (Table 3). However, the correlation coefficient between runoff and temperature was not statistically significant (Table 3). These results demonstrated the river runoff in the Qinghai Lake Basin was primarily influenced by precipitation.

Response of lake level variation to climate and runoff

According to Table 2 and Figure 4, lake level variation showed a similar trend as precipitation and runoff, but revealed an inverse relationship with evaporation when considering data by decade (relative low in the 1970s and 1990s, relative high in the 1980s and 2000s). Peaks in lake level increases corresponded to relatively high precipitation, humidity, and runoff, but also to relatively low evaporation and wind speed (e.g., 1967, 1983, 1989, 1999, 2005, and 2012; solid line in Figure 4). Drops in lake level corresponded to relatively low precipitation, humidity, and runoff, but also to relatively
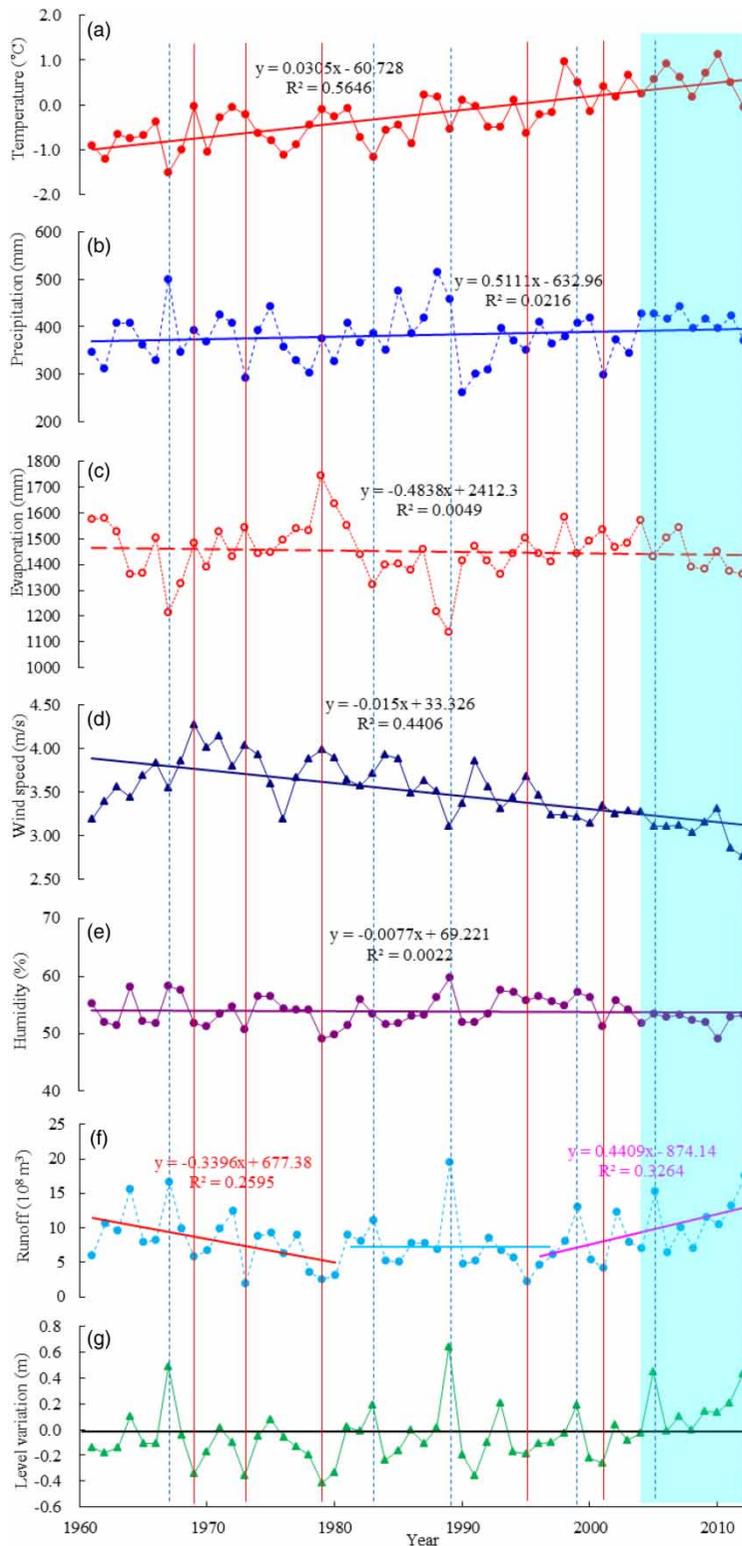
Figure 4 │ Annual climate factors, river runoff of Buha River, and Qinghai Lake level variation from 1961 to 2012. (a) Temperature; (b) precipitation; (c) evaporation; (d) wind speed; (e) humidity; (f) runoff; (g) lake level variation.

Table 2 │ Mean values of lake level variation, climate factors, and runoff of Buha River at different time periods

Period	1961–2012	1960s	1970s	1980s	1990s	2000s
Lake level variation (m)	−0.03	−0.06	−0.16	0.01	−0.09	0.09
Air temperature (°C)	−0.22	−0.82	−0.48	−0.39	−0.06	0.50
Precipitation (mm)	382.4	377.0	365.1	402.1	370.9	394.3
Evaporation (mm)	1,451.2	1,433.5	1,533.8	1,372.5	1,456.7	1,455.3
Wind speed (m/s)	3.51	3.68	3.81	3.59	3.42	3.14
Air humidity (%)	53.8	53.9	53.3	53.8	55.6	52.7
River runoff ($10^8 m^3$)	8.41	9.71	6.67	8.49	6.56	10.25

high evaporation and wind speed (e.g., 1969, 1973, 1979, 1995, and 2001; dotted line in Figure 4). Pearson correlation coefficients showed that lake level variation was highly positively correlated to precipitation, humidity, and river runoff, and negatively to evaporation and wind speed. All correlations were significant at a p value of <0.001 (Table 3). However, the correlation coefficient between lake level variation and temperature was 0.05, with a non-significant relationship. These results suggested that lake level increase was closely related to wet climate; lake level decline was closely related to dry climate. For monthly lake level variation, the maximum drops were in November and December and were closely related to the freezing of Qinghai Lake's surface from November to March (Che et al. 2009). The maximum increases in lake level were in July and August and were closely related to high river runoff and high precipitation in summer season (Cui et al. 2011).

Pearson correlation coefficients showed that during SEAM or WC periods, lake level was highly positively

correlated to precipitation, humidity, and river runoff, and negatively correlated to evaporation and wind speed (Table 4). However, the correlation coefficient between lake level variation and temperature was below 0.05 and the relationship was non-significant.

PCA results (Tables 5 and 6) showed that the cumulative variance for the first five PCs were relatively high and reached almost 85.4% (>85%), and the eigenvalue of PC5 was 1.1 (>1). In order to distinguish the contribution of potential influencing factors during two periods (SEAM and WC), the cumulative variance was selected above 95%, so PCs would be analyzed from PC1 to PC8 (Table 5). PC1 (variance of 38.0%) was strongly positively correlated with humidity and was negatively correlated with evaporation of the SEAM period, with each absolute loading exceeding 0.84 (Table 6). PC2 (variance of 18.0%) was strongly positively correlated with wind speed and was negatively correlated with temperature of the SEAM and WC periods, with each absolute loading exceeding 0.65. PC3 (variance of 11.8%) was strongly

Table 3 │ Pearson correlation coefficients between lake level variation and potential influencing factors in annual scale

	Lake level variation	Temperature	Precipitation	Evaporation	Wind speed	Humidity	River runoff
Lake level variation	1						
Temperature	0.045	1					
Precipitation	0.57***	0.11	1				
Evaporation	−0.64***	0.21	−0.43**	1			
Wind speed	−0.57***	−0.40**	−0.21	0.21	1		
Humidity	0.48***	−0.26	0.45***	−0.53***	−0.26	1	
River runoff	0.86***	−0.02	0.45***	−0.55***	−0.43**	0.40**	1

***Correlation is significant at the 0.001 level.
**Correlation is significant at the 0.01 level.

Table 4 │ Pearson correlation coefficients between annual lake level variation and potential influencing factors during two periods (SEAM and WC)

Period	Temperature	Precipitation	Evaporation	Wind speed	Humidity	River runoff
June to August (SEAM)	−0.04	0.61***	−0.67***	−0.40**	0.64***	0.74***
September to May (WC)	−0.05	0.66***	−0.61***	−0.49***	0.51***	0.68***

***Correlation is significant at the 0.001 level.
**Correlation is significant at the 0.01 level.

Table 5 │ Eigenvalues and cumulative percentage of PCs

PCs	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12
Eigenvalues	4.6	2.2	1.4	1.1	1.1	0.6	0.4	0.3	0.2	0.1	0.1	0.1
Variance/%	38.0	18.0	11.8	9.5	8.1	4.9	3.0	2.3	2.0	1.1	0.9	0.5
Cumulative/%	38.0	56.0	67.8	77.3	85.4	90.3	93.3	95.6	97.6	98.6	99.5	100.0

positively correlated with precipitation and river runoff of the WC period, with each absolute loading exceeding 0.66. PC4 (variance of 9.5%) was strongly positively correlated with wind speed of the SEAM period, with loading exceeding 0.56 (Table 6). PC5 (variance of 8.1%) was strongly positively correlated with evaporation of the WC period, with loading exceeding 0.53. PC6 (variance of 4.9%) was strongly positively correlated with temperature of the WC period, with loading exceeding 0.45. PC7 (variance of 3.0%) was strongly positively correlated with humidity of the WC period, with loading

exceeding 0.37. PC8 (variance of 2.3%) was strongly positively correlated with river runoff and precipitation of the SEAM period, with loading exceeding 0.3 (Table 6). In all, PC1, PC4, and PC8 represented the comprehensive contribution of influencing factors (climate and river runoff) of the SEAM period to annual lake level variation, with a sum variance of approximately 49.8%; PC3, PC5, PC6, and PC7 represented the comprehensive contribution of influencing factors of the WC period to annual lake level variation, with a sum variance of approximately 27.8%; and the comprehensive contribution

Table 6 │ Loadings of components

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
T-E	−0.08	−0.73	0.37	0.34	0.15	−0.33	−0.11	−0.13
P-E	0.73	−0.15	−0.28	0.20	0.42	−0.16	−0.14	0.30
E-E	−0.85	−0.03	0.36	−0.08	0.06	−0.25	0.11	0.10
W-E	−0.42	0.65	−0.01	0.56	0.04	−0.05	−0.20	−0.14
H-E	0.84	0.07	−0.37	0.28	0.06	−0.07	0.10	0.03
R-E	0.76	0.10	−0.05	−0.28	0.43	0.11	0.06	−0.31
T-W	0.03	−0.68	−0.06	0.49	−0.28	0.45	0.04	0.00
P-W	0.57	0.18	0.67	−0.22	−0.05	0.22	−0.10	0.19
E-W	−0.71	−0.23	−0.04	0.09	0.53	0.15	0.33	0.06
W-W	−0.57	0.65	0.03	0.24	0.27	0.23	−0.05	0.07
H-W	0.60	0.46	0.20	0.32	−0.30	−0.20	0.37	0.02
R-W	0.57	0.00	0.66	0.24	0.26	0.10	0.01	−0.05

T-E, temperature of the Southeast Asian monsoon period (SEAM); P-E, precipitation of the SEAM; E-E, evaporation of the SEAM; W-E, wind speed of the SEAM; H-E, humidity of the SEAM; R-E, river runoff of the SEAM; T-W, temperature of the westerly circulation period (WC); P-W, precipitation of the WC; E-W, evaporation of the WC; W-W, wind speed of the WC; H-W, humidity of the WC; R-W, river runoff of the WC.

of influencing factors of both the SEAM period and WC period was approximately 18.0% (PC2).

Owing to the closed basin of the Qinghai Lake, precipitation was the sole source of water inputting into the basin, meaning that river water was mainly fed by precipitation in the basin (Cui & Li 2005a). Further, precipitation directly affected humidity (Table 3), thus contributions of river runoff and humidity on lake level variation were merged into the precipitation's contribution. Therefore, the relative contributions of temperature, precipitation, evaporation, and wind speed to Qinghai Lake level variation were approximately 13.8%, 36.3%, 27.1%, and 18.4%, respectively (Tables 5 and 6). These all indicated that annual lake level variation was primarily influenced by precipitation and evaporation of the SEAM period.

DISCUSSION

The results show that the changes of lake level were divided into two stages: decreasing stage (1961–2004) and increasing stage (2004–2012) (Figure 2). Pearson correlation coefficients between lake level variation and influencing factors suggest that: the lake level during the decreasing stage (1961–2004) was controlled by the comprehensive effect of climate and river runoff; and the lake level during the increasing stage (2004–2012) was only sensitive to river runoff (Table 7). Increase of river runoff would be dependent upon the combined effects of changing rainfall patterns (increase in intensity of individual summer rainfall) and improving grass vegetation within the basin as a result of global warming (Jin et al. 2013). Furthermore, thawing permafrost (due to climate warming) would also increase river runoff in the alpine catchment (Ye et al. 2003; Walvoord & Striegl 2007; Connon et al. 2014), which contributes more surface water flowing into the lake, making

the lake level increase. However, annual precipitation did not clearly increase during this period of 2004–2012. Therefore, the contributions of melt water from glacier shrinkage and permafrost degradation, under climate warming on the TP, to river runoff cannot be ignored in any study of lake level variation on the TP.

Evaporated water vapor from Qinghai Lake strongly influenced local precipitation, creating a distinct regional water cycle. The annual contribution of lake evaporation to the basin's total precipitation was approximately 23%, or 26.7×10^8 m^3, concentrated mostly in the summer (Cui & Li 2015b). Annual evaporation from the Qinghai Lake was found to be approximately 39×10^8 m^3 (Liu 2004; Shi et al. 2010), meaning net output water of evaporation was approximately 12.3×10^8 m^3. The large number of lakes on the Tibetan Plateau, including more than 1,500 lakes covering a total lake area of 44,993 km^2 (Xu et al. 2011; Song et al. 2014a), clearly results in a significant contribution of evaporation from lake surfaces into atmospheric vapor. The contribution of evaporation on lake level variation could not be ignored.

A tree ring-width chronology of the northeastern Tibetan Plateau, spanning 4,500 years, suggested that large-scale climate warming might be associated with an even greater moisture supply in this region (Yang et al. 2014). If so, the lake's level would rise, due to increasing precipitation and runoff (Christensen et al. 2014; Song et al. 2014b). Consequently, the rising water level in Qinghai Lake since 2004 may reflect the comprehensive effect of increased precipitation and runoff and changing rainfall patterns, resulting from global warming. If warming trends continue, the lake level of Qinghai Lake may continue to rise in the future decades. Accordingly, a better ecological environment and richer biodiversity could be expected in the Qinghai Lake Basin after years with continuous rising water level (Li et al. 1999; Yang et al. 2003; Kong et al. 2011).

Table 7 │ Pearson correlation coefficients between annual lake level variation and annual potential influencing factors in two phases

Phase time	Temperature	Humidity	Precipitation	Evaporation	Wind speed	Runoff
1961–2004	−0.23	0.70***	0.58***	−0.69***	−0.44**	0.83***
2004–2012	−0.25	0.35	−0.27	−0.55	−0.53	0.97***

***Correlation is significant at the 0.001 level.
**Correlation is significant at the 0.01 level.

CONCLUSION

Overall, Qinghai Lake water level was sensitive to climate and river runoff. Precipitation, river runoff, and evaporation had direct effects on lake volume, while temperature, humidity, and wind speed had indirect effects on lake volume. Precipitation and runoff had directly positive effects on the lake level, evaporation and wind speed negatively impacted lake level. The relative contributions of influencing factors in the SEAM and WC periods to annual lake level variations were approximately 49.8% and 27.8%, respectively. The relative contributions of temperature, precipitation, evaporation, and wind speed on lake level variation were approximately 13.8%, 36.3%, 27.1%, and 18.4%, respectively. In general, annual level variation of Qinghai Lake was primarily influenced by precipitation and evaporation of the SEAM period.

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