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Linkage of Climatic Factors and Human Activities with Water Level Fluctuations in Qinghai Lake in the Northeastern Tibetan Plateau, China

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Received: 23 May 2017; Accepted: 13 July 2017; Published: 24 July 2017

Abstract: Changes in the water level of Qinghai Lake, the largest inland lake in China, directly affect the ecological security of Qinghai province and even the northwest of China. This study aimed to investigate the lake level and identify causes of changes in the lake level of Qinghai Lake. The results showed that the lake level was 3196.55 m in 1959 and gradually declined to 3192.86 m in 2004, with an average decreasing rate of 8.2 cm·year^{-1} over 45 years. However, the lake level increased continuously by 1.04 m from 2005 to 2010. During the period 1961–2010, the annual average temperature showed an increasing trend in the Qinghai Lake basin, at a rate of 0.32 °C/decade, and the annual precipitation showed obvious fluctuations with an average precipitation of 381.70 mm/year. Annual evaporation showed a decreasing trend (−30.80 mm/decade). The change in lake level was positively correlated to precipitation, surface runoff water and groundwater inflow into the lake and negatively correlated to evaporation from the lake surface. The total water consumption by human activities merely accounted for a very small part of precipitation, surface runoff inflow and groundwater inflow (1.97%) and of lake evaporation (1.87%) in Qinghai Lake basin. The annual water consumption of artificial afforestation and grass plantation accounting for 5.07% of total precipitation, surface runoff inflow and groundwater inflow and 5.43% of the lake evaporation. Therefore, the water level depended more on climatic factors than on anthropogenic factors.

Keywords: lake level; climatic factors; human activities; Qinghai Lake; Tibetan Plateau

1. Introduction

The Tibetan Plateau, also known as the Qinghai-Tibetan Plateau, is the highest plateau in the world, with an average altitude of over 4000 m [1–3]; the permafrost over the Tibetan Plateau comprises approximately 70% of all of the permafrost regions in China [4]. The harsh natural conditions (low temperature and hypoxia) have won this area the reputation as the third pole of the world [5–7]. Qinghai Lake, the largest lake in China, is a special ecological function area in the northeastern Tibetan Plateau. Without Qinghai Lake, the sand in Tsaidam would devour most of China and the whole of northern China would become a desert [8]. Therefore, Qinghai Lake is important for sustaining the ecological safety of the northeastern Tibetan Plateau [9], because it is not only a natural barrier to prevent the spread of the desertification of the west to the east, but also as it has a significant influence on the climate in the Yellow River Basin [10]. Thus, the ecological status of Qinghai Lake basin is extremely momentous. Changes in the water level of Qinghai Lake directly affect the ecological system of Qinghai province and even the northwest region [11], as well as the security of water resources in the Yellow River [12] and, in turn, the daily lives of people in the region.

A considerable amount of research has focused on the influence of climate change on lakes elsewhere in China [13–16] and abroad [17–19]. Some of these studies have focused on climatic factors [20–22], while others were concerned with human activities [23]. Climatic factors such as precipitation, evaporation, and temperature variation would affect changes in the lake water level and its hydrological processes. Lee [4] has used re-tracked Enivsat radar altimeter measurements to generate water level change time series for Qinghai Lake and Lake Ngoring, in the northeastern Qinghai–Tibetan Plateau, and examined their relationships to precipitation and temperature changes. Additionally, human activities such as agriculture, dam construction, reservoir operation etc., may have an impact on changes in the water level. Hu [24] has concluded that climate change was the main reason for the changes, while human activities have had little influence on Qinghai Lake. Although there have been a number of studies on Qinghai Lake, the effect of artificial forestation and grass planting on the water level of Qinghai Lake has not been considered in those previous studies.

The water level has severely declined from 1959 to 2004 and has recovered from 2005 to 2010, which has stimulated more interest in studying the hydrological conditions of the lake [25]. The recent rise of the water level in Qinghai Lake is undoubtedly good news for stakeholders in Qinghai Province, China. However, until now, the reasons for lake level changes in Qinghai Lake have not been fully understood; therefore, it is urgent to achieve a full understanding of variations in the lake level, linked with climatic factors and anthropogenic activities. Specifically, the objectives of this study were (1) to reveal the variation in the lake level of Qinghai Lake during the period 1959–2010; (2) to investigate the variation in the climate, human activities, artificial afforestation and grass plantation during the period 1961–2010; and (3) to analyze the cause of the increased lake level in recent years. Additionally, the results can provide a reference for the control structure for the water of Qinghai Lake.

2. Materials and Methods

2.1. Study Area

Qinghai Lake is the largest closed-basin lake in China with no surface water outflow. It is located between 36°15′–38°20′ N and 97°50′–101°20′ E in the lowest valley in the northeastern Qinghai-Tibetan Plateau. The water surface area of Qinghai Lake is approximately 4317.69 km^2, with a length (west to east) of 104 km and a width (north to south) of 62 km. The lake water is saline and alkaline, with a pH value of 9.23, a relative density of 1.01 and a salinity of 14.13 g/L, respectively. The area of Qinghai Lake basin is 29,661 km^2, of which the mountain area accounts for 68.6%, while the rest is comprised of valley and plain areas. The topography of the basin decreases from the northwest to the southeast (Figure 1). The basin is an inter-montane basin surrounded by Datong Mountain, Riyue Mountain, Qinghai South Mountain and Amuniniku Mountain.

The Qinghai Lake basin has been of interest because it is one of the most sensitive regions to global climate changes; it is influenced by the East Asian monsoon, the Indian monsoon, northwest aridity and Tibetan Plateau coldness. Therefore, the climate of the region is characterised as having a dry cold, low rainfall, high wind and strong solar radiation. Simultaneously, the broad water body of Qinghai Lake adjusts the local climate, resulting in a typical semi-arid and cold plateau-climate. In general, the temperature declines from southeast to northwest in the basin; the average annual temperature is between −1.1 °C and 4.0 °C, with an extreme maximum temperature ranging from 24.4 °C to 33.7 °C and an extreme minimum temperature of between −26.9 °C and −35.8 °C. Precipitation is the main source of rivers, lakes and the groundwater of the Qinghai Lake basin. The average annual precipitation is between 300 mm and 450 mm, while evaporation is relatively high; the average annual evaporation is about 930 mm [26].

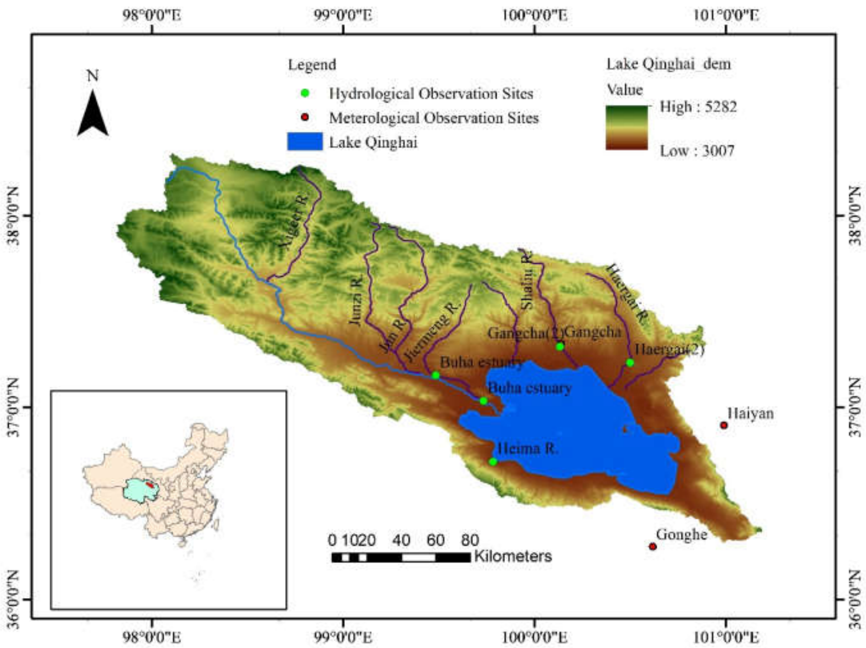

Figure 1. Location of the Qinghai Lake Basin.

Qinghai Lake receives discharges from more than 40 rivers, of which 16 tributaries have a catchment area greater than 300 km^2.The major rivers are the Buha River, Shaliu River, Haergai River, Ganzi River, Daotang River and Heima River (Table 1). Four of those rivers contribute 77.1% of the total runoff into the lake. The rivers are distributed asymmetrically, with large rivers in the northwest and small rivers in the southeast. The major water sources of the rivers are mainly precipitation and snow melt. The modern glacier are distributed at the source of the Buha River, covering an area of 13.9 km^2 and a reserve of 5.9 $\times$ 10^8 m^3, respectively. The huge glacier provides melt water of 0.1 $\times$ 10^8 m^3 per year on average.

Table 1. Characteristics of flow into Qinghai Lake from its main rivers.

River Name	Catchment Area (km^2)	Length of River (km)	Mean Annual Discharge (10^8 m^3)	Percentage of Total Runoffs into the Lake
Buha R.	14,337	286	7.83	46.9%
Shaliu R.	1442	105.8	2.51	15.0%
Haergai R.	1425	109.5	2.42	14.5%
Heima R.	107	17.2	0.11	0.7%
Total of the above	17,311	518.5	12.87	77.1%
Jiermeng R.	1092	112	Ungauged	-
Ganzi R.	369	47.4	Ungauged	-
Daotang R.	743	60	Ungauged	-

Groundwater in the Qinghai Lake basin mainly comes from precipitation and surface runoff. Because of previous tectonic actions and long-term physical and chemical weathering, the rocks in the Qinghai Lake basin are relatively developed and easily accept the infiltration and recharge of precipitation. In the permafrost zone above 3800 m, there is generally a freezing layer of water underground. Due to the cold climate, abundant precipitation and surface freezing in winter, groundwater recharge is greatly reduced. When the temperature rises in summer, the upper layer of the frozen layer becomes ablated by 1–3 m and groundwater recharge is greatly increased.

The main choice for artificial grass in the area has been cold and drought-resistant, salt-tolerant plants such as *Caragana jubata* (Pall.) Poir., *Artemisia desertorum* Spreng., *Leymus secalinus* (Georgi)

Tzvel., *Achnatherum sibiricum* (Linn.) Keng, and *Stipa glareosa* P. Smirn. Artificial afforestation has been dominated by shrubs such as *Hippophae rhamnoides* Linn., *Potentilla fruticosa* Linn., and *Potentilla glabra*.

2.2. Data Preparation and Analysis

Precipitation, temperature and evaporation data from 1959 to 2010 were obtained from the national meteorological stations in Qinghai Lake basin (Table 2). The average annual precipitation levels of the Gangcha, Haiyan and Gonghe meteorological stations were 381.7, 385.1, and 319.5 mm, respectively. The level of precipitation decreased from the northern mountainous area to the south. Precipitation over the lake was calculated from precipitation data in the Gangcha, Haiyan and Gonghe meteorological stations surrounding Qinghai Lake.

Table 2. National meteorological stations in the Qinghai Lake basin.

Station Name	Establishment Time of Station	Initial Working Time	Latitude	Longitude	Altitude of Station (m)	Automatic Station Model	Automatic Station Manufacturer
Gangcha	1957/7/1	1957/7/1	37°19′50″	100°08′16″	3301.5	Milos500	VAISALA
Haiyan	1955/1/1	1976/1/1	36°54′20″	100°59′22″	3010.0	CAWS600	Huayun
Gonghe	1953/1/1	1966/11/1	36°16′27″	100°37′06″	2835.0	Milos500	VAISALA

Water level records and runoff data during the period 1959–2010 originated in hydrological stations in the lake (Table 3). The runoff in ungauged catchments was estimated based on the runoff in gauged catchments with the same underlying surface. The total runoff into the lake was then calculated as the sum of the runoff in gauged catchments and the estimated runoff for the runoff in ungauged catchments. The formula of the runoff in ungauged catchments could be written as follows:

$$R_{\mathrm{ungauged}} = S \times R_{gauged} \quad (1)$$

$$S = S_{ungauged} / S_{gauged} \quad (2)$$

where $R_{ungauged}$ was the daily runoff in ungauged catchments, R_{gauged} was the daily runoff in gauged catchments, S was the area correction coefficient, $S_{ungauged}$ was the area of the ungauged catchments, and S_{gauged} was the area of the gauged catchments.

Table 3. Hydrological stations in Qinghai Lake basin.

River	Station Name	Latitude	Longitude	Catchment Area (km^2)	Measured Years
Buha R.	Buha estuary	37°02′00″	99°44′00″	14337	1957.05–Now
Jiermeng R.	Jiermeng	37°10′00″	99°29′00″	926	1958.05–1960.12
Shaliu R.	Gangcha (2)	37°19′00″	100°08′00″	1442	1958.04–Now
Haergai R.	Haergai (2)	37°14′00″	100°30′00″	1425	1958.05–1963.12
Heima R.	Heima R.	36°43′00″	99°47′00″	107	1958.11–1961.12 1964.8–1994.12

Evaporation from the lake was estimated by the following formula:

$$E = E_{20} \times K_1 \quad (3)$$

where E was the evaporation from the lake, E_{20} was the evaporation rate measured by a 20 cm pan in the Gangcha meteorological station, and K_1 was 0.614, the conversion coefficient between E_{20} and E [27].

The transpiration water consumption of the artificial vegetation, which reduced the runoff into the Qinghai Lake from afforestation and grass, could be calculated by the water consumption quota of the afforestation vegetation and the corresponding vegetation area. The formula could be written as follows:

$$W = \frac{1}{1000} q \times A \tag{4}$$

where W was the total transpiration water consumption of the artificial vegetation, q was the water consumption quota of the afforestation vegetation (mm), and A was the corresponding vegetation area (m^2).

As Qinghai Lake is a closed inland lake, its water balance equation could be written in the following form:

$$\Delta h = P + Rs - E + Rg \pm \varepsilon \tag{5}$$

where Δh was the yearly change in the lake level (mm), P was the annual precipitation over the lake (mm), Rs was the yearly surface runoff water inflow into the lake (mm), E was the annual evaporation from the lake surface (mm), and $Rg \pm \varepsilon$ was the annual groundwater inflow into the lake and error (mm). It was noted that $Rg \pm \varepsilon$ is calculated by the lake water balance model.

In this study, the Mann–Kendall trend test was used to investigate the trends of the climate factors (temperature, precipitation, evaporation) in Qinghai Lake. All the trends were investigated with MATLAB R2014a software. Pearson correlation coefficients were calculated by SPSS Statistic 22.0.

3. Results

3.1. Variation in the Lake Water Level

The variation in the lake level during the period from 1959 to 2010 is shown in Figure 2. There was a significantly decreasing trend in the lake level during the period 1959–2004. Generally, the lake level was 3196.55 m in 1959 and gradually fell to 3192.86 m in 2004, resulting in a total decline of 3.69 m, with an average decreasing rate of 8.2 cm·year^{-1} over 45 years. However, there appeared to be a significant increasing trend during the period of 2005–2010; the lake level had risen by 1.04 m, which greatly stimulated recent interest in studies of the lake.

Figure 3 shows annual water level changes in Qinghai Lake over 52 years, of which lake level declined for 31 years, with an average decreasing rate of 16.9 cm·year^{-1}, and increased or flatted for 20 years with an average increasing rate of 12.5 cm·year^{-1}. Correspondingly, the lake area decreased from 4548.30 km^2 in 1959 to 4255.42 km^2 in 2000 and then increased to 4288.77 km^2 in 2010.

During the period 1959–2010, there were five change-points, namely 1966, 1968, 1988, 1990, and 2004, respectively (Figure 2). Considering the real fluctuant situation of Qinghai Lake, the time series (1959–2010) could be divided into two distinguishable periods, namely 1959–2004 and 2005–2010.

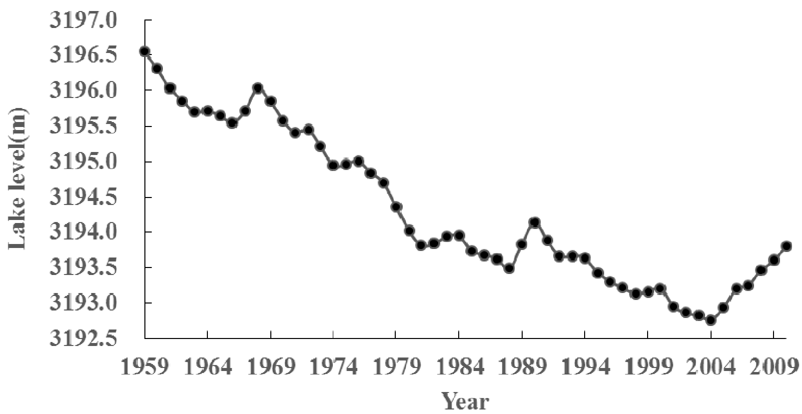

Figure 2. Variation of the water level in Qinghai Lake from 1959 to 2010.

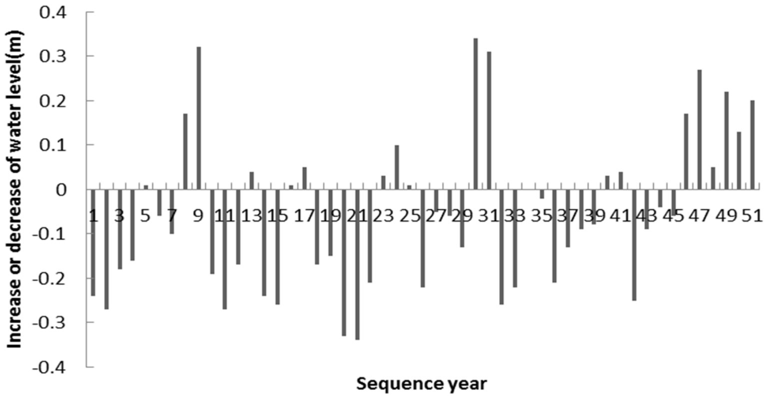

Figure 3. Annual water level changes in Qinghai Lake over 52 years.

3.2. Variation of Climate Factors

The linear regression exhibits an annual average temperature with an upward trend in the Qinghai Lake basin during the period 1961–2010 (Figure 4), at a rate of 0.32 °C/decade. In particular, the annual average temperature increase was greater from 1991 to 2010, reaching 0.41 °C/decade. Meanwhile, the annual average temperature during the period of 2005–2010 was 1.1 °C higher than that during 1961–2004. The seasonal warming of the Qinghai Lake basin was also obvious, with the warming trend of 0.22 °C/decade, 0.19 °C/decade, 0.33 °C/decade, and 0.45 °C/decade, respectively, from spring to winter. Analyzing further, in virtue of the Mann–Kendall test, the Z statistic of the temperature was 4.69 ($|Z| > 1.96$), which showed that the annual average temperature showed not only an upward trend, but also that the trend is significant at a 95% confidence level.

Figure 5 shows the variation in annual precipitation in Qinghai Lake during the period studied. The MK test showed that the Z statistic of the annual precipitation was 1.49 ($|Z| < 1.96$), which showed that the downward trend of the annual precipitation was not significant at a 95% confidence level. It was shown that the annual precipitation showed a fluctuant trend during the period 1961–2010, with an average precipitation of 381.70 mm·year^{-1}. In general, it declined from the 1960s to the 1970s, followed by an increase towards the 1980s, as well as a slight decrease within the 1990s, increasing again from the 1990s to the 2000s. The annual average precipitation was 377.1 mm·year^{-1} and 415.6 mm·year^{-1} during the periods 1961–2004 and 2005–2010, respectively.

As shown in Figure 6, annual evaporation from a 20 cm evaporation pan obviously fluctuated, decreasing during the period of 1961–2010, with a general decreasing trend (−30.80 mm/decade). The annual evaporation showed a significant decreasing trend based on the MK test; the Z statistic of annual evaporation was −2.31 ($|Z| > 1.96$). The maximum evaporation was 1743.5 mm in 1979 and the minimum evaporation was 1136.9 mm in 1989. Meanwhile, annual average evaporation was about 202.9 mm during the period 2005–2010, lower than that during 1961–2004.

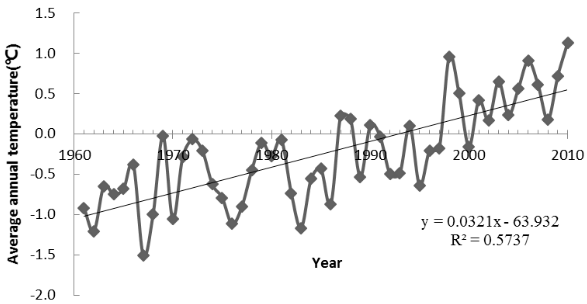

Figure 4. Annual average temperature change in Qinghai Lake basin from 1961 to 2010.

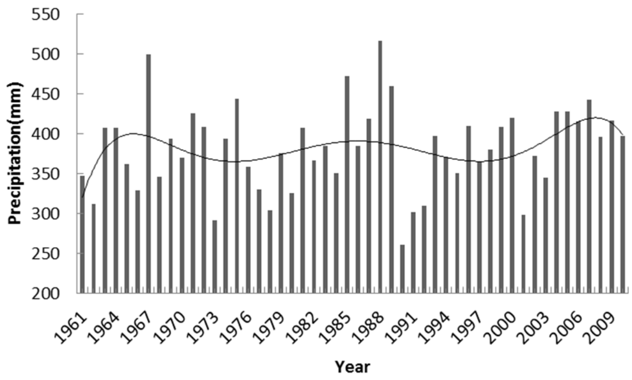

Figure 5. Annual precipitation change in Qinghai Lake basin from 1961 to 2010.

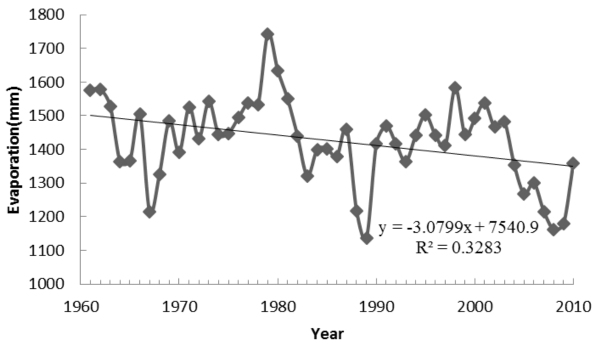

Figure 6. Annual evaporation change from a 20 cm evaporation pan in Qinghai Lake basin from 1961 to 2010.

3.3. Variation in Human Activities

Generally speaking, water consumption by human activities mainly included human and livestock, agricultural irrigation and industrial water use.

The population number in the study area experienced a rapid increase in the 1980s, was basically stable during the 1990s and slightly increased in the 2000s, while the number of livestock showed two opposing variation trends, a rapid growth before the 1970s and a slow growth afterwards. Human and livestock water consumption in the Qinghai Lake basin was a net consumption, with a water consumption quota of 40 L/day per human and 15 L/day per livestock. Human and livestock water consumption is shown in Figure 7. The average annual human and livestock water consumption was approximately 0.15×10^8 m^3 from 1961 to 2010.

The area of agricultural irrigation grew rapidly in the 1960s; however, it greatly decreased in recent years, due to environmental protection (Figure 8). According to the comprehensive plan of national water resources, the water consumption quota for agricultural irrigation in the Qinghai Lake area was about 4852.62 m^3/(hectare·year). On the basis of the irrigation area and the irrigation water consumption quota, the average annual agricultural irrigation water consumption was 0.59×10^8 m^3 in the study area from 1961 to 2010.

Industry in the Qinghai Lake area started later and the handicraft industrial system gradually came into being in the early 1960s. Then, industrial water use started to develop from 1973 (Figure 9). According to the regional industrial water consumption quota (145 m^3/10,000 yuan) and the water consumption rate (about 40%), the average annual industrial water consumption was about 4.76×10^4 m^3 in the whole period of study.

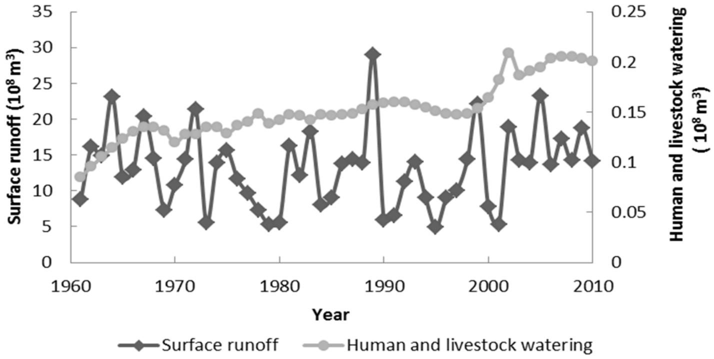

Figure 7. Total surface runoff and human and livestock water consumption in the Qinghai Lake catchment.

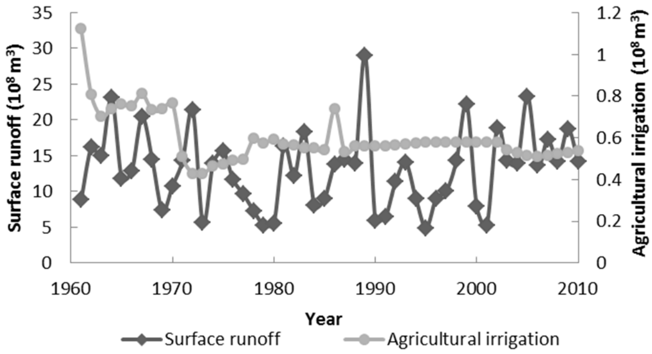

Figure 8. Total surface runoff and agricultural irrigation in the Qinghai Lake catchment.

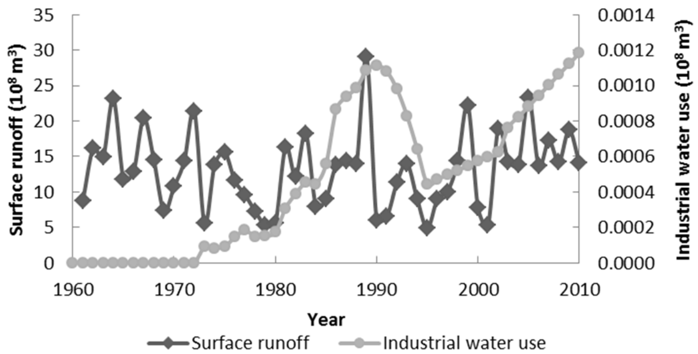

Figure 9. Total surface runoff and industrial water consumption in the Qinghai Lake catchment.

3.4. Variation of Artificial Afforestation and Grass Plantation

In order to prevent and control soil erosion, restore the natural vegetation and reduce the area of vegetation degeneration, large-scale artificial afforestation and grass plantation has taken place in Qinghai Lake basin in recent years. However, artificial vegetation mainly took up water to maintain its normal growth, which in turn reduced the surface runoff into the lake.

Artificial vegetation transpiration was another essential water consumption, which could be calculated by the water consumption quota of the afforestation vegetation and the corresponding artificial afforestation and grass plantation area (Formula (4)). Because of the lack of measured data about vegetation transpiration in this area, the vegetation transpiration quota was determined according to the relevant articles with a similar area or the same vegetation [28]. The water consumption quota of artificial vegetation in Qinghai Lake area is shown in Table 4.

Table 4. Water consumption quota of artificial vegetation in Qinghai Lake basin (mm).

Vegetation Types and Zoning		Annual Water Consumption Quota
Artificial afforestation	Haiyan County	282.9
	Gangcha County	274.0
	Gonghe County	277.9
Artificial grass plantation		231.7

The transpiration of newly-planted artificial afforestation and grass plantation in 2001–2005 and 2006–2010 is shown in Table 5. The annual average water consumption of artificial afforestation and grass plantation was 1.81 × 10^8 m^3.

Table 5. Artificial afforestation and grass plantation water consumption in Qinghai Lake catchment from 2001 to 2010.

County	Vegetation Types	2001–2005	2006–2010
		Water Consumption (10^8 m^3)	Water Consumption (10^8 m^3)
Gangcha	Total in Gangcha	0.19	0.17
	Artificial afforestation	0.13	0.12
	Grass plantation	0.06	0.05
Haiyan	Total in Haiyan	0.42	0.39
	Artificial afforestation	0.39	0.36
	Grass plantation	0.03	0.03
Gonghe	Total in Gonghe	0.33	0.31
	Artificial afforestation	0.20	0.18
	Grass plantation	0.14	0.13
Sum	Total of the 3 counties	0.94	0.87
	Artificial afforestation	0.71	0.66
	Grass plantation	0.23	0.21

3.5. Lake Water Balance

The lake water balance was calculated based on measured data over a long period. Although errors might exist, the data were close to the actual situation. Thus, groundwater inflow into the lake and the possible error could be calculated according to the water balance equation. The mean annual groundwater inflow was 145.1 mm (Table 6). Over the last 50 years, the average annual precipitation over the lake was 389.4 mm, surface runoff inflow into the lake was 300 mm, evaporation from the lake surface was 918.7 mm and the change of lake level was −50 mm (Table 6). Overall, the water balance of Qinghai Lake is negative, as indicated by the water level drop-line; 50 mm below the initial lake level between 1961 and 2010.

Table 6. Characteristic of the factors of the water balance of Qinghai Lake from 1961 to 2010.

Descriptive Statistics	Δh (mm)	P (mm)	Rs (mm)	E (mm)	$Rg + \varepsilon$ (mm)
Maximum	342	535.7	673	1068.9	276.1
Minimum	−352	268.3	115	796.6	7.4
Mean ± Std. deviation	−50 ± 176	389.4 ± 62.7	300 ± 124	918.7 ± 71.2	145.1 ± 67.7

4. Discussion

Water level and its variation play important roles in lake ecosystems [29]. As the largest inland lake in China, the variation in the water level of Qinghai Lake has attracted a great deal of attention [30,31]. In our study, the lake water level was shown to have declined from 1959 to 2000, which was consistent with Li [32], who came to the same conclusion that the lake water level had tended to decrease in the years from 1959 to 2000. In addition, we found that there appeared to be a significantly increasing trend during the period 2005–2010.

The mean annual water level of Qinghai Lake declined to its lowest level in 2004. Afterwards, the lake level has increased year by year since 2005 and, so far, it has recovered to its level in the 1980s. The rise of the lake level was an important sign for the improvement of the plateau ecological environment in Qinghai Lake. However, the rise of the lake level also resulted in land submergence around Qinghai Lake, especially for the bird island located on the western shore of the Qinghai Lake, which led to continuous limits on bird-breeding. Therefore, effective measures (such as, among others, the construction of an artificial island) should be taken to alleviate the contradiction between the reduction of the breeding ground for birds and the rising water levels in Qinghai Lake.

Climate factors such as precipitation, runoff inflow into the lake, evaporation from the lake, atmosphere and lake water temperature might result in the variation in the lake level [33]. In recent years, scientists have studied the sediment geochemistry linked to the hydroclimate variability of Qinghai Lake more and focused less, to some extent, on the effects of climatic factors on lake level variation [34]. As Qinghai Lake was a closed basin with no surface water outflow, the climate factors that had an effect on lake level variation mainly included precipitation over the lake, surface runoff, groundwater inflow into the lake, evaporation from the lake and temperature.

Table 7 showed the Pearson correlation between the changes in the lake level and the climatic factors. Changes in the lake level (Δh) were significantly and positively correlated to precipitation (P), surface runoff water inflow into the lake (Rs) and groundwater inflow into the lake (Rg) and negatively correlated to evaporation from the lake surface (E), with a correlation coefficient of 0.454, 0.559, 0.302 and -0.394, respectively, and all were significant at a level of less than 0.01 (Table 7). We drew the conclusion that increasing precipitation and surface runoff or decreasing evaporation had a significant effect on the increase of the water level, which mainly occurred from 2005 to 2010. The results were highly consistent with the results of previous studies [33,34].

Table 7. Pearson correlation coefficients between Δh, P, E, Rs and Rg.

	Correlations	Δh	P	E	Rs	Rg
Δh	Pearson Correlation	1	-	-	-	-
	Sig. (2-tailed)	-	-	-	-	-
P	Pearson Correlation	0.454 **	1	-	-	-
	Sig. (2-tailed)	0.001	-	-	-	-
E	Pearson Correlation	−0.394 **	−0.480 **	1	-	-
	Sig. (2-tailed)	0.005	0.000		-	-
Rs	Pearson Correlation	0.559 **	0.492 **	−0.618 **	1	-
	Sig. (2-tailed)	0.000	0.000	0.000	-	-
Rg	Pearson Correlation	0.302 *	−0.467 **	0.394 **	−0.453 **	1
	Sig. (2-tailed)	0.033	0.001	0.005	0.001	-

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). Δh was the change in the lake level (mm), P was precipitation over the lake (mm), E was evaporation from the lake surface (mm), Rs was surface runoff water inflow into the lake (mm), and Rg was groundwater inflow into the lake (mm).

The temperature increase in the basin resulted in an intensified glacier retreat, increased melt water and rising lake level. The reasons for the change in the lake level were roughly similar to the other lakes in the Qinghai-Tibetan Plateau [35,36].

Human activities such as human and livestock water use, agricultural irrigation water consumption, and industrial water consumption, may affect the variation in the lake level. The effect of human activities on lake level variation could be reflected by the effect of lake evaporation and precipitation, surface runoff inflow and groundwater inflow.

The average annual water input and lake evaporation were 37.64×10^8 m^3, 39.69×10^8 m^3 from 1961 to 2010 in the lake, respectively. Meanwhile, the average annual consumption of human activities was 0.74×10^8 m^3 from 1961 to 2010. In conclusion, the total water consumption by human activities only accounted for a very small part of the precipitation, surface runoff inflow and groundwater inflow (1.97%) and of the lake evaporation (1.87%) in Qinghai Lake basin. The results revealed that water consumption by human activities had little effect on the water level in Qinghai Lake. Liu et al. (2009) also reported that water consumption by human activities was not the primary cause of the water level in Qinghai Lake.

The average annual water input and lake evaporation were 35.76×10^8 m^3 and 33.40×10^8 m^3 from 2000 to 2010 in the lake, respectively. The average annual water consumption of artificial afforestation and grass plantation was 1.81×10^8 m^3, accounting for 5.07% of the total precipitation, surface runoff inflow and groundwater inflow and 5.43% of the lake evaporation. The proportion was so small that it could be considered negligible. Thus, it was implied that water consumption by artificial afforestation and grass plantation also had little effect on the water level in Qinghai Lake.

In order to prevent and control soil erosion, restore the natural vegetation and mitigate vegetation degeneration, an artificial afforestation and grass plantation campaign has been conducted in Qinghai Lake basin in recent years. In previous studies, some researchers had maintained the position that the implementation of artificial afforestation in the Qinghai Lake basin might reduce the inflow runoff into Qinghai Lake and bring in a sustained decline of the lake water level, due to its high water consumption, canopy interception as well as its reduced soil moisture infiltration. However, in recent years, the rising water level in Qinghai Lake has attracted public attention, and the concerns that artificial afforestation could lead to the decline of the water level might have been eliminated to some extent. On the contrary, to our knowledge, the result showed that artificial afforestation might be conducive to the rising water level of Qinghai Lake.

5. Conclusions

In this study, the variation in the water level in Qinghai Lake, which has a great ecological importance, over a 52-year period from 1959 to 2010 and the variation in climate and anthropogenic factors over a 50-year period from 1961 to 2010 were investigated to evaluate the impacts of anthropogenic and climatic factors.

The results showed that lake level was 3196.55 m in 1959, and fell to 3192.86 m in 2004, with an average decreasing rate of 8.2 cm·year^{-1} over 45 years. However, the lake level increased by 1.04 m from 2005 to 2010. During the period 1961–2010, the annual average temperature showed an increasing trend in the Qinghai Lake basin, at a rate of 0.32 °C/decade. The annual precipitation showed obvious fluctuations, with an average precipitation of 381.70 mm·year^{-1}, while annual evaporation experienced a decreasing trend (−30.80 mm/decade). The change in lake level was positively correlated to precipitation, surface runoff water and groundwater inflow into the lake, and negatively correlated to evaporation from the lake surface. The results revealed that water consumption by human activities had little effect on the water level in Qinghai Lake. It was implied that water consumption by artificial afforestation and grass plantation also had little effect on the water level in Qinghai Lake.

In conclusion, the water level depended more on climatic factors than on anthropogenic factors, because water consumption by human activities and artificial afforestation and grass plantation accounted for a very small proportion of the average annual precipitation, surface runoff inflow and groundwater inflow and lake evaporation of Qinghai Lake.

Acknowledgments: This study was financially co-supported by the Science and technology project of Qinghai Province (2015-ZJ-902), the National Science-technology Support Plan Projects (2015BAD07B030302) and the Qinghai province science and technology plan program (2014-NK-A4-4). Thanks for providing hydrological data to the Institute of Water Resources and Hydropower of Qinghai Province and for providing meteorological data to the Institute of Meteorological Sciences of Qinghai Province.

Author Contributions: Bo Chang and Kang-Ning He conceived and designed the experiments; Run-Jie Li performed the experiments; Zhu-Ping Sheng and Hui Wang analyzed the data; Bo Chang wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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