Stoch Environ Res Risk Assess
DOI 10.1007/s00477-014-0995-z

ORIGINAL PAPER

Assessment of the salinization processes in the largest inland freshwater lake of China

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Abstract Salinization threatens the viability of water resources and is common in many important inland freshwater lakes worldwide, especially in arid and semi-arid areas. Bosten Lake is a typical inland freshwater lake that has evolved into a subsaline lake and is located in the arid region of Northwest China. The water resources of Bosten Lake are important for supplying regional drinking water and agricultural irrigation and for economic development. In this study, changes in salinity with time and space were analyzed in Bosten Lake. Overall, the salinity increased from 0.39 g/L in 1958 to 1.87 g/L in 1987, reaching its highest value in 1987. After 1987, the salinity decreased to 1.17 g/L in 2003 and increased to 1.45 g/L in 2010. Increased salinity adversely affects aquatic lake systems, regional eco-environments and water resource use, and has become a serious environmental problem in Bosten Lake. Thus, the causes of increasing salinity are discussed in this paper. Overall, the influences of climate variations and human activities resulted in the salinization of the lake. Understanding the salinization processes in Bosten Lake can be useful for implementing actions that improve water quality and water resource use in the lake.

Keywords Salinization · Lake salinity · Freshwater · Anthropogenic influence · Climate change

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1 Introduction

The frequency and severity of droughts in arid and semi-arid regions are expected to increase with global climate change (Liu et al. 2013b; Ma 2010). Furthermore, most lakes have been substantially modified through anthropogenic management or manipulation (Obeysekera et al. 2011; Sullivan 2014). These changes may result in the substantial deterioration of hydrological environments, including decreased lake volume, increased lake salinity and other environmental changes (Dyer et al. 2014; Liu et al. 2012; Mosley et al. 2014). Two extreme examples include the reduced volume and increased salinity of Lop Nor (which disappeared) and the Aral Sea (Fan et al. 2009; Hu and Zhang 2004; Micklin 2007).

Over several decades, researchers have studied several freshwater and saline lakes (Aladin and Plotnikov 2004; Naftz et al. 2013; Small et al. 2001; Wang et al. 2008; Williams 1991). Unfortunately, few studies have focused on oligosaline lakes (i.e., the salinity of inland freshwater increases). Salinization is a major growing threat to the viability of water resources, especially in arid and semi-arid regions (Crosbie et al. 2009; Williams 1999). In the last 30 years, many freshwater lakes in Central Asia have become oligosaline or saline due to climate change and anthropogenic influences (Bai et al. 2011; Dai et al. 2013). Increased lake salinity can adversely affect agriculture and aquatic lake systems (James et al. 2003) by restricting irrigation and resulting in toxic effects, severe biodiversity losses, and reduced water quality. All of these changes are ongoing, and many are accelerating. Furthermore, many changes were introduced before their importance was recognized.

Salinization problems result from many different factors, some of which are interrelated (Williams 2001). In

Published online: 02 December 2014

Table 1 Some examples of lakes subjected to salinization

Names	Regions	Causes of salinization	Selected references
Great Salt Lake	USA	Sewage effluent, construction of causeway	Brock (1975) and Naftz et al. (2013)
Lake Urmia	Iran	Climate change, saline soils, construction of causeway	Delju et al. (2013) and Zeinoddini et al. (2009)
Aral Sea	Central Asia	Irrigation for agriculture, climate change	Micklin (2007) and Small et al. (2001)
Caspian	Central Asia	Continental drift	Aladin and Plotnikov (2004) and Leroy et al. (2007)
Qinghai Lake	China	Excess land reclamation, grazing, water inflow diversion, climate change	Li et al. (1996) and Liu et al. (2006)
Lop Nor	China	Climate change, water conservation project, river diversion	Fan et al. (2009) and Hu and Zhang (2004)
Lake Eyre	Australia	Seasonal fluctuation, groundwater salinity	Timms (2005) and Tweed et al. (2011)

many lakes, salinity levels increase as water is diverted from their inflow for irrigation and other uses. In addition, the discharge of saline agricultural wastewater, increases in groundwater salinity, and increases in climatic aridity can increase the salinity of freshwater lakes. Some saline lake studies have been conducted at a global scale to ascertain the causes of salinization (Table 1). For example, salinization in the Great Salt Lake resulted from sewage effluents and the construction of a causeway (Brock 1975; Naftz et al. 2013), and the salinization of the Caspian Sea resulted from continental drift (Aladin and Plotnikov 2004; Leroy et al. 2007). In contrast, climate change, water conservation projects, and river diversion resulted in the salinization and disappearance of Lop Nor (Fan et al. 2009; Hu and Zhang 2004). However, in arid and semi-arid regions, water diversion for irrigation and water evaporation are the main causes of lake salinization (Lerman 2009). In these regions, crop production consumes large quantities of water, and the free water evaporation at the lake surface is much greater than precipitation, which results in salt accumulation rather than export (Crosbie et al. 2009; Yechieli and Wood 2002).

A study conducted by Hammer (1986) defined athalassic (inland) saline lakes as having salinities equal to or in excess of 3 g/L and defined freshwater lakes as having dissolved salt concentrations of less than 0.5 g/L. In addition, Hammer (1986) defined subsaline lakes as having salinities between 0.5 and 3 g/L. Based on this classification method, half of China's lakes are saline (viz., have salinities >3 g/L). Most of these saline lakes exist in the arid and semi-arid region of northwestern China (Williams 1991). However, in this region, freshwater lakes are threatened by salinization due to climate change and anthropogenic influences (Liu et al. 2013a). Thus, these lakes may evolve to subsaline or saline lakes in the future.

Bosten Lake is a freshwater lake that has evolved into an oligosaline (subsaline) lake in northwestern China (Dai et al. 2013) and is located in an arid area south of the Xinjiang Uygur Autonomous Region. Climate change and anthropogenic impacts have drastically altered the natural functions of Bosten Lake in the last 55 years (Guo et al. 2014). Specifically, the lake salinity was 0.39 g/L in 1958 (Zhao et al. 2007) and increased from 0.39 to 1.87 g/L in 1987 (its highest recorded salinity). Thereafter, the salinity decreased to 1.17 g/L in 2003 before recovering and increasing to 1.45 g/L in 2010 (Fig. 2). Many studies have been conducted in Bosten Lake, including investigations of the Holocene sedimentary record, humidity variations, regional climate change, water conditions, and bacterial community compositions (Dai et al. 2013; Huang et al. 2009; Wünnemann et al. 2006; Zuo et al. 2006). However, little is known about the changes in the lake salinity with time and space. Furthermore, the precise causes of these changes are not fully understood. Salinization has become a serious environmental problem in Bosten Lake. Therefore, it is important to understand the salinization processes of the lake and to identify the major drivers of the lake salinization.

In this study, we focused on the increasing salinity of Bosten Lake, which is a typical example of an inland freshwater lake that has evolved into a subsaline lake in an arid region. The objective of our study was to investigate the spatial and temporal changes in lake salinity based on an established observation network and to properly estimate the risks of extremely adverse conditions (i.e., very low lake levels and/or very high salinities) by calculating the occurrence and persistence of the lake level and salinity. In addition, we considered climate changes, anthropogenic impacts, and lake hydrological conditions to understand how they affected the salinization of Bosten Lake. A better understanding of salinization in Bosten Lake can be used to implement actions that improve water quality and water resource use. In addition, although we cannot provide all-inclusive coverage, we hope that more attention is given to the importance of increased salinity in inland freshwater lakes and its impacts in arid and semi-arid regions.

2 Materials and methods

2.1 Study site

Bosten Lake (41°56′N–42°14′N; 86°40′E–87°26′E) is the largest inland freshwater lake in China (Fig. 1) and is located in the southern Xinjiang Uygur Autonomous Region, which is an arid area in Northwest China between the Tianshan Mountains and the Taklimakan Desert. Bosten Lake is approximately 55 km long and 25 km wide, with a surface area of more than 1,000 km^2 and a storage capacity of 8.8 km^3. The catchment area of Bosten Lake is approximately 56,000 km^2. The average water depth of the lake is 8.2 m, with a maximum depth of 17 m. The climate of the Bosten Lake Basin is principally influenced by westerlies during the summer and is characterized by high evaporation and low precipitation rates (Wünnemann et al. 2006). The mean annual air temperature of the lake region is approximately 6.3 °C, with annual evaporation reaching up to 2,000 mm and a mean annual precipitation of approximately 70 mm (Cheng 1995).

Bosten Lake is located at the end of the Kaidu River, which accounts for approximately 95 % of the total water inflow, and at the beginning of the Kongque River. Thus, Bosten Lake can serve as a large regulating reservoir for flood control and has been extensively exploited for agricultural, aquacultural, and economic development. In addition, Bosten Lake serves as a valuable and limited water resource for the regional drinking water supply in the arid region. However, the salinity of Bosten Lake is increasing due to climate change and runoff from agricultural drainage and domestic wastewater. Overall, 34 towns with a population of more than 1.1 million are scattered throughout this arid region. Over 190,000 ha of agricultural land obtain irrigation water from the lake inflow. In addition, the lake plays an important role in fish and wild reed production, wildlife breeding, and in the regeneration of the ecological environment in the lower reaches of the Tarim River by transferring the stream water from the Kongque River.

2.2 Observation networks

Salinity observation networks were established on Bosten Lake in the 1980s, mainly to protect the basin from economic development and freshwater resource use. Fourteen monitoring sites were distributed on the left, middle, and right sides of each Bosten Lake transect, which were designed for spatial lake salinity surveys (Fig. 1). Site 1 was located to the southwest, ahead of the water outflow from the lake and at the only outlet of the Kongque River. Sites 7–13 were located near the domestic sewage, trade effluent, agricultural discharge and tourist sites along the western lakeshore. Site 14 was located near the Kaidu River, which provides large amounts of freshwater to the lake. The five remaining sites were located in the middle of the lake.

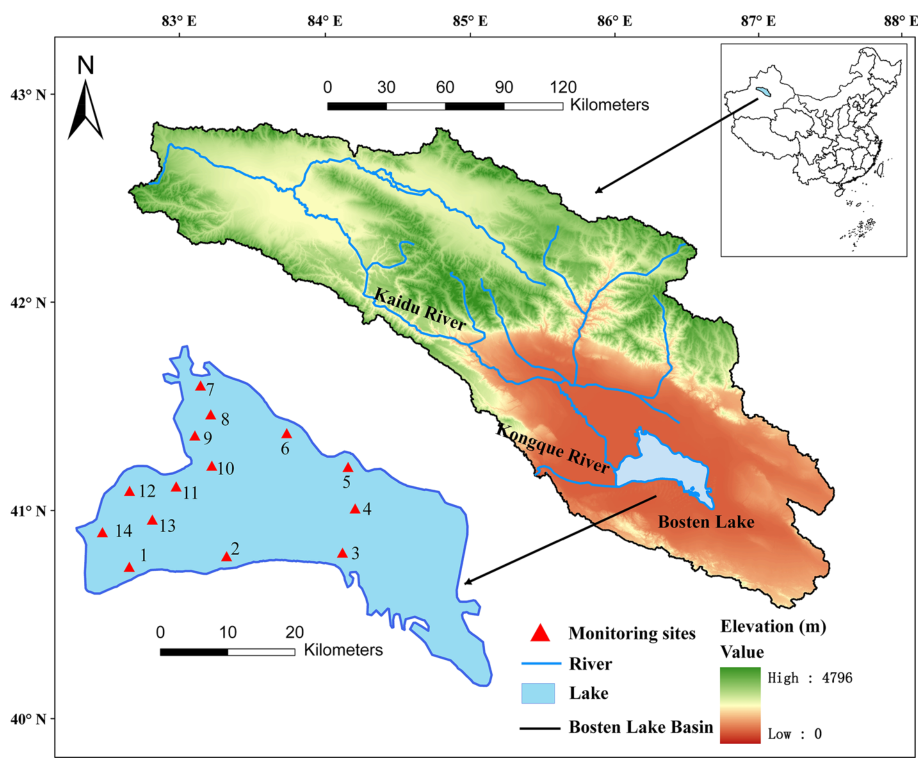

Fig. 1 Map of the study area and the location of the monitoring sites

2.3 Salinity and lake levels

2.3.1 Data use

To characterize the causes of long-term and spatial salinity changes in Bosten Lake, streamflow, evaporation, and solute concentration measurements are required (Rimmer et al. 2006). The measured water inflows, water outflows, evaporation, and rainfall should be summed or spatially or temporally averaged. The averaged lake level, lake inflow and outflow, pan evaporation, rainfall, and temperature data were obtained from the Xinjiang Meteorological Bureau and the Xinjiang Hydrology Bureau for 1958–2011. Generally, pan evaporation is greater than the actual evaporation from the lake surface under the same climatic conditions (Liu et al. 2011). Traditionally, the actual lake evaporation is estimated by multiplying the pan evaporation by a conversion coefficient. For Bosten Lake, a conversion coefficient of 0.47 was used, which was determined by Xia et al. (2003).

Moreover, accurate long-term and spatial salinity trends are difficult to obtain due to inherent uncertainty measurement and the prohibitive costs of continuous solute concentration measurements. The collected observation data for lake salinity at the 14 sites were provided for May and October of 1958–2010 by the Xinjiang Environmental Protection Academy of Science.

2.3.2 Defining the salinity and lake level states

The lake levels were classified into four different ranges, as shown in Table 2. These ranges were selected to provide a broad range of lake levels based on the lowest ecological lake level, which was reported by Li et al. (2007), and the minimum and maximum lake level data of 1958–2010. In addition, the spatial salinities at the 14 sites in Bosten Lake were classified into 4 ranges (Table 2), which were adapted from the definition of a saline lake (Hammer 1986) and the average lake salinity (as shown in Table 3). The selected salinity ranges are used to delineate the salinity-based states and to address the question of whether Bosten Lake is threatened by salinization. The state of "low subsaline" indicates that the lake water is trending towards freshwater due to freshwater inputs that dilute the lake water and decrease the salinity. A "high subsaline" state indicates that the lake water is threatened by salinization and may become saline due to increased salinity and high evaporation rates, which promote salt accumulation. "Fresh" and "saline" indicate that the lake water is fresh or saline, respectively.

Table 2 Definition of salinity and the lake level states for Bosten Lake

States	Ranges
Salinity states	(g/L)
(1) Fresh	≤0.5
(2) Low subsaline	0.5 → 1.45
(3) High subsaline	1.45 → 3
(4) Saline	≥3
Lake level states	(m)
(1) Low	≤1,046
(2) Med/low	1,046 → 1,047
(3) Med/high	1,047 → 1,048
(4) High	1,048 → 1,049

2.3.3 Occurrence and persistence statistics

The occurrence probability of the lake salinity level is a measure of the state's importance as a physicochemical driver of the system and is estimated from the long-term data of the accumulated time in each state. In addition, Lawrie and Stretch (2011) proposed that the average persistence time of a particular salinity and lake level state indicate the time that is available for the system to adjust to that state. This time was estimated by calculating the average duration of the salinity/water level data for the occurrences of the state. Therefore, in this paper, a statistical indicator of the salinity and lake level states was used to understand how the conditions changed with time and to estimate the risks of extreme adverse conditions (i.e., very low lake levels and/or very high salinities).

3 Results

3.1 Long-term changes in lake salinity

The measured salinities and water levels of Bosten Lake between 1958 and 2010 are shown in Fig. 2. Prior to 1987, the largest salinity increase in Bosten Lake occurred when the lake level decreased. The lake salinity increased from 0.39 to 1.87 g/L between 1958 and 1987, reaching its highest recorded value of 1.87 g/L in 1987. Due to this increased salinity, Bosten Lake transitioned from a freshwater lake (viz., salinities ≤0.5 g/L) to a subsaline lake (viz., salinities range from 0.5 to 3 g/L). In the 1990s, the salinity levels in the lake began to decrease gradually from 1.87 to 1.17 g/L until 2003. In comparison, the lake level increased from 1,044.73 to 1,049.33 m during this period. This increase occurred during a wet period when the freshwater inflow into Bosten Lake was high. In 2003, the salinity level in the lake decreased to 1.17 g/L, which was the lowest recorded salinity level since 1975. Next, the salinity increased as the lake level decreased. By 2010, the measured lake salinity was 1.5 g/L.

Table 3 Summary of the lake salinity and level

Components	Periods					Mean (1958–2010)
	1958	1975	1980s	1990s	2000s	
Lake level (m)	1,048.00	1,047.19	1,046.06	1,046.61	1,047.29	1,047.03
Lake salinity (g/L)	0.39	1.44	1.83	1.48	1.33	1.45

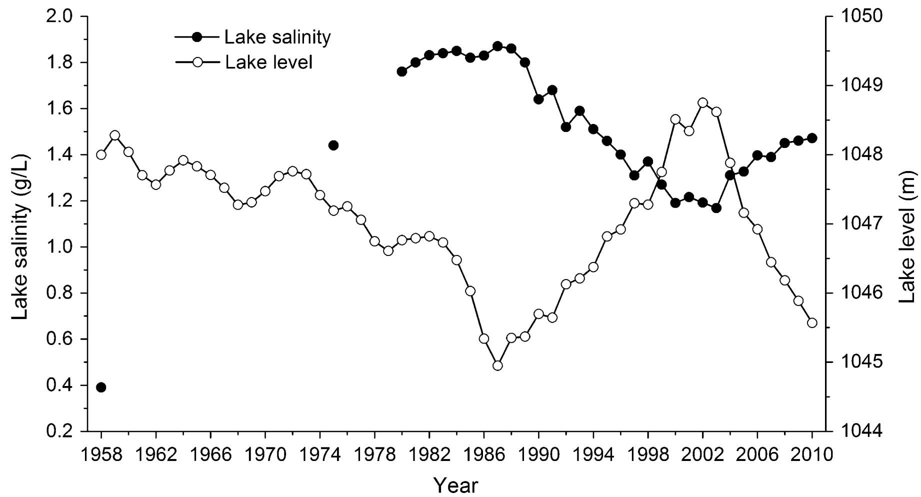

Fig. 2 Annual salinity and water level changes in Bosten Lake from 1958 to 2010

In the last 50 years, the average lake salinity and water level were 1.45 g/L and 1,047.03 m, respectively (Table 3). In the 1980s, the salinity in the lake was 1.83 g/L greater than the average lake salinity, while the lake level was 1,046.06 m less than the average. Similarly, in the 1990s and 2000s, the salinity changed inversely to the lake level. Figure 3 illustrates the relationships between lake level and salinity. Statistically, the salinity of the lake increased as the lake level decreased and vice versa. According to partial correlation theory, a negative correlation existed between the two variables, with a coefficient of 0.81. Thus, the salinity variations were sensitive to changes in the lake level.

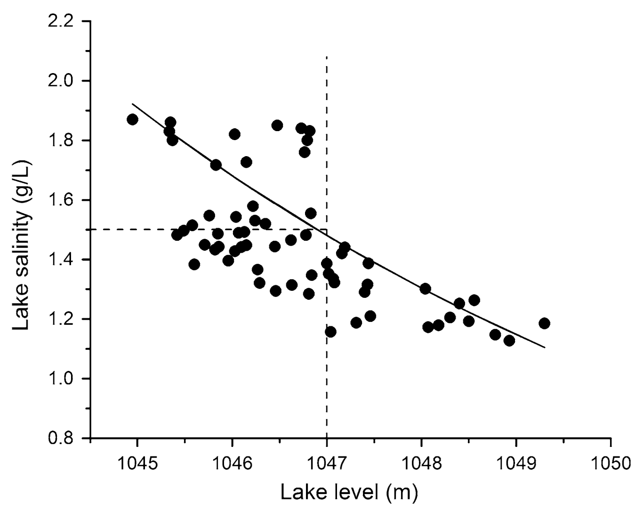

Fig. 3 The relationships between the lake level and lake salinity from 1958 to 2010. The *black line* shows the trend of the salinity with the lake level. The *black vertical* and *horizontal dashed lines* represent the average lake level and salinity, respectively

3.2 The spatial variability of the lake salinity

The salinity levels followed a distinct spatial distribution in the lake, with high values in the northwest and low values in the southwest (Fig. 4). Approximately 12 % of the observations exceeded the average lake salinity level (ALSL) of 1.45 g/L in the southwest, compared to approximately 80 % in the northwest and 30 % in the center. These findings indicated that salinization issues in the northwestern areas are worse than that in the other areas. The potential sources of high salinity in the northwestern area of the lake include domestic sewage, trade effluent, agricultural discharge, and tourism (Dai et al. 2013; Xia et al. 2003; Zuo et al. 2006). In addition, the evaporative enrichment of solutes in the root zone with subsequent flushing of the salts by irrigation water is one major mechanism of salt loading to the lake in the northwestern region.

The observed salinities at the 14 sites were plotted against the average lake salinity in Fig. 5. The highest salinity occurred at Site 7, whereas the lowest salinity was measured at Site 14. Only small differences occurred at the

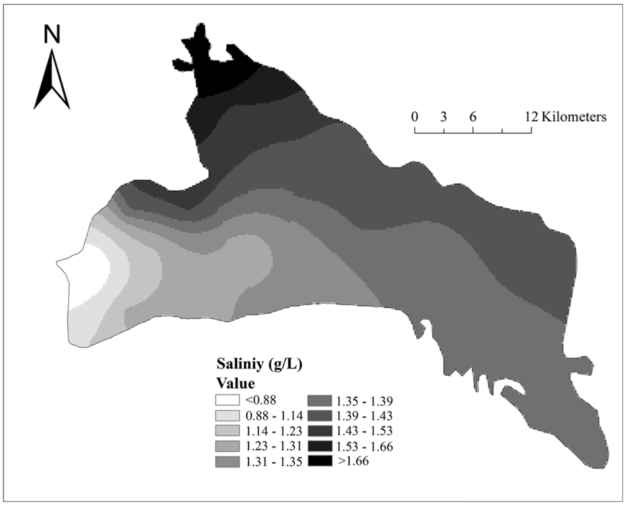

Fig. 4 Spatial distributions of salinity in Bosten Lake

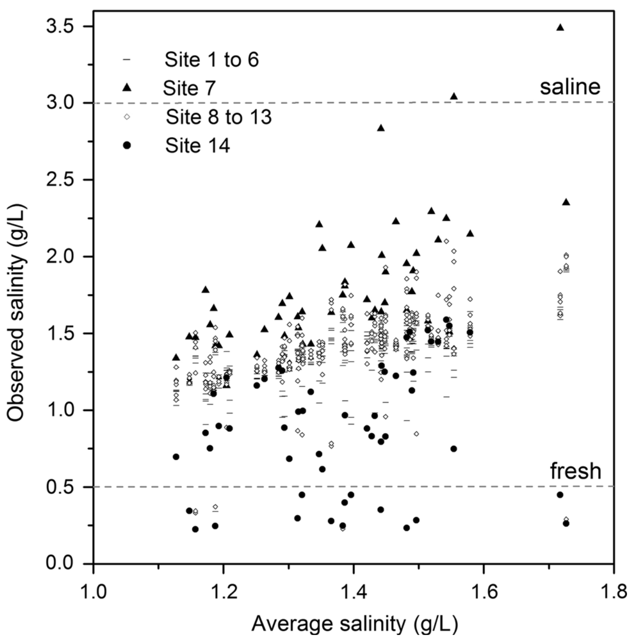

Fig. 5 The relationships between the average and observed salinities at the 14 sites

other sites regarding salinity variations. The average salinity was 1.87 g/L at Site 7 and varied from 1.2 to 3.5 g/L. In addition, 87 % of the observations exceeded the ALSL (1.45 g/L) and over 5 % exceeded 3 g/L. However, the average salinity was 0.8 g/L at Site 14 and varied from 0.22 to 1.5 g/L. Here, only 10 % of the observations exceeded the ALSL. At Site 14, approximately 60 % of the observational data were less than the freshwater level (0.5 g/L), which indicated that the closer region can act as an isolated freshwater region (Dai et al. 2013) because the Kaidu River contributes a large amount of freshwater to the lake.

Table 4 Occurrence probabilities for each salinity and lake level state

States	Occurrence probabilities (%)
Salinity ranges (g/L)	
(1) Fresh (≤0.5)	2.8
(2) Low subsaline (0.5 → 1.45)	64.1
(3) High subsaline (1.45 → 3)	32.8
(4) Saline (≥3)	0.3
Lake level ranges (m)	
(1) Low (≤1,046)	16.0
(2) Med/low (1,046 → 1,047)	27.7
(3) Med/high (1,047 → 1,048)	41.2
(4) High (1,048 → 1,049)	15.1

3.3 Statistical occurrence and persistence of salinity and the lake level states

The statistical occurrence probabilities for the salinity and lake level states are summarized in Table 4. There is a 2.8 % probability that salinities are below 0.5 and a 0.3 % probability that salinities exceed 3. However, both of these conditions are rare. There is a 66.9 % probability that the salinities remain below 1.45 g/L, and a 32.8 % probability that high subsaline conditions occur. Furthermore, there is a 16 % probability that the lake levels are below 1,046 m, and a 15.1 % probability that the lake level is above 1,048 m.

The joint percentage of persistence times for all lake levels and salinity states is shown in a bubble plot in Fig. 6. Low subsaline and high subsaline conditions are the most common in each lake level state. In the low lake level state, high subsaline conditions occur 61 % of the time, while fresh and saline conditions only occur 4 and 1 % of the time, respectively (Fig. 6). These results indicate that the lake water may become saline because the probability of salinity increases will increase with time in this state.

The salinities are more variable in the other lake level states, and a saline condition of 3 g/L or higher is rare. Low subsaline conditions occur 65 % of the time when the lake level is med/low and 87 % of the time when the lake level is high. In contrast, high subsaline conditions occur 32 % of the time when the lake level is med/low and 12 % of the time when the lake level is high. As the lake level rises, the low subsaline conditions increase and the high subsaline conditions decrease. The opposite trends occur when the lake level decreases. Additional freshwater flow into the lake will dilute the lake salinity (i.e., the salinity decreases). High subsaline conditions occur 61 % of the time when the lake level is med/low because the freshwater inflow decreases and the lake evaporation increases, which

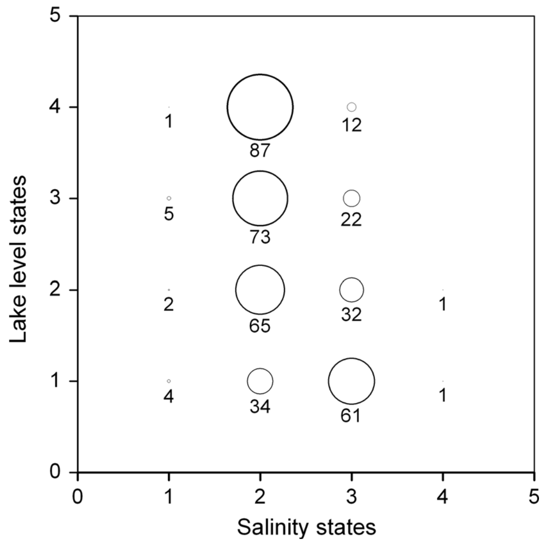

Fig. 6 Persistence (%) of each salinity and lake level state. The area of each bubble is proportional to the magnitude of its associated variable

increases the lake salinity. The combination of the high subsaline and med/low lake level states results in an extremely adverse condition that reflects the risk of aggravated salinization. Therefore, the risks of extremely adverse conditions are greatest when high subsaline conditions are combined with a med/low lake level.

4 Discussion

4.1 Historical anthropogenic impacts on the lake

Irrigation development has resulted in numerous cases of land and water resource salinization (Smedema and Shiati 2002). In Xingjiang, the population increased by 80.1 % between 1949 and 2011 (Ling et al. 2012). With this population increase after the 1960s, accelerated agricultural development occurred in the Bosten Lake Basin. The quantity of water diverted from the Kaidu River (lake inflow) gradually increased for agricultural irrigation (Fig. 7). Tremendous changes in the irrigation area and the quantity of diverted water were observed in the last 53 years (Fig. 7). Zhou et al. (2001) reported that the irrigation area and irrigation water supply were only 1.0×10^4 hm^2 and 0.3 km^3 in 1950, respectively. However, the irrigation area increased from 3.24×10^4 hm^2 in 1958 to 20×10^4 hm^2 in 2010. Correspondingly, the quantity of diverted water varied from approximately 0.82 to 1.19 km^3 between 1958 and 2010. Compared with the irrigation area, the quantity of diverted water for irrigation did not vary linearly (Fig. 7). The average amount of irrigation water reached 1.02 km^3 in the 1960s and increased to 1.22 km^3 in the 1970s. Next, the amount of irrigation water decreased to 1.13 km^3 in the 1980s and 0.98 km^3 in the 1990s before increasing to approximately 1.18 km^3 in the 2000s. The irrigation area gradually increased and the amount of irrigation water decreased, especially after the late 1980s (Wang et al. 2012; Xia et al. 2003). These trends resulted from scythe efficient irrigation management that was implemented by the government, which significantly improved the utilization coefficient of irrigation water in the Bosten Lake Basin (Table 5). According to the statistical data presented by Chen et al. (2013), the utilization coefficient increased from 0.35 to 0.56 between 1985 and 2009. Although the efficiency of the irrigation water improved, agricultural wastewater continues to be discharged into Bosten Lake, and contributes to the increasing salt concentrations in the lake.

In recent decades, water conservation projects have been conducted in the Bosten Lake Basin. For example, the 1958 Baolangshumu water-diversion project on the Kaidu River altered the natural allocation of the water. The proportion of the water inflow decreased from 78.4 % (natural) to 50.9 % in 1982, and only 33.9 % was required in 1967 (Cheng 1995). Another pumping station was built in 1983 to control the lake outlet, which historically maintained a natural outflow until pumping began. A remarkable difference in the lake outflow occurred in 1983 (Fig. 8b). The fluctuation of the lake outflow was very consistent with the lake inflow before 1983 (Fig. 8a). However, the lake outflow was more stable after 1983. These changes directly affected the water inflows and outflows of Bosten Lake, affected the water cycles in the lake, and intensified the salinization of the lake.

4.2 The effects of severe climate conditions

The annual rainfall index, which is defined as the normalized deviation from the annual average, is plotted in Fig. 9. A positive rainfall index indicates a relatively wet year, while a negative rainfall index indicates a relatively dry year. Negative index values occur 53 % of the time. In addition, approximately 27 % of these periods had durations of three or more years.

Bosten Lake experiences wet and dry cycles over a decadal time scale. Most of the dry periods occurred between 1966 and 1986, as shown in Fig. 9. The average annual temperature was 9.8 °C, and its growth rate was 0.26 °C per decade. The rise in temperature is at twice the global average (Fig. 10a). It is indicated that the significantly increased temperature which is due to global warming. The increased temperature has accelerated lake evaporation. The average annual lake evaporation was 1,027 mm during the dry period and varied from 732 to 1,220 mm (Fig. 10b). Compared to the dry period, most of

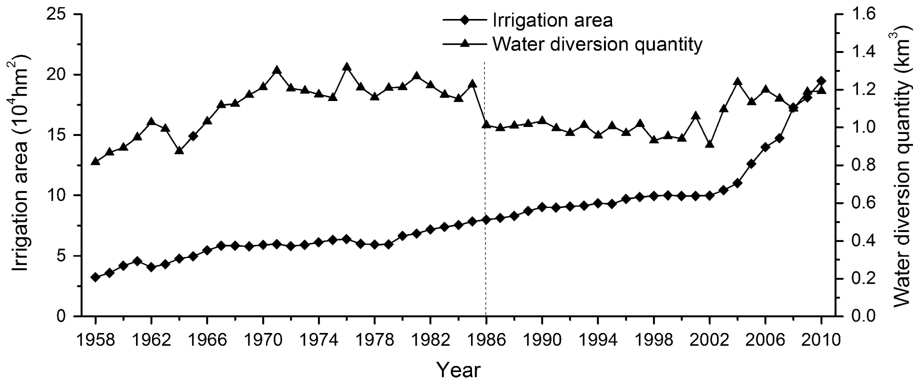

Fig. 7 Annual irrigation area and the quantity of diverted water from the lake inflow for irrigation in the Bosten Lake Basin between 1958 and 2010

Table 5 Utilization coefficients of irrigation water in the Bosten Lake Basin

Year	1985	1990	2000	2005	2009
Utilization coefficient	0.35	0.40	0.50	0.55	0.56

the wet years occurred between 1987 and 2010 (Fig. 9). The lake evaporation obviously decreased during this wet period, with an average evaporation of 957 mm that varied between 1,213 and 852 mm.

In addition, the streamflow of the Kaidu River was impacted by climate change. Guo et al. (2014) reported that climate change was responsible for approximately 90 % of the annual streamflow variability according to the climate elasticity method. Therefore, the lake inflow was also influenced, decreasing by 0.99 km^3 from 1966 to 1986 (dry period) and increasing to 1.51 km^3 from 1987 to 2010 (wet period). The average lake inflow was 1.71 km^3 during the dry period and 2.52 km^3 during the wet period (Fig. 8a).

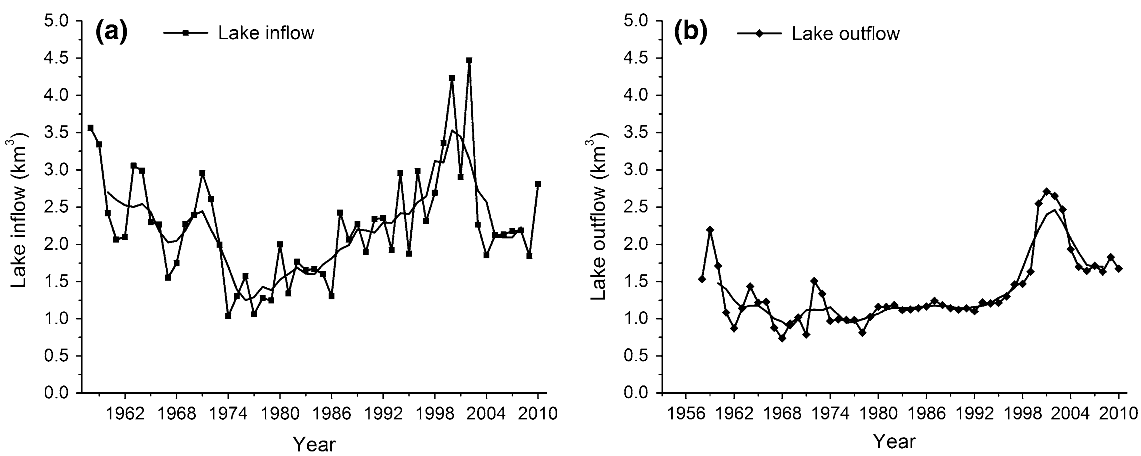

Fig. 8 Annual **a** lake inflow variations at Bosten Lake and **b** the lake outflow between 1958 and 2010. The *black line* shows the 5-year moving average

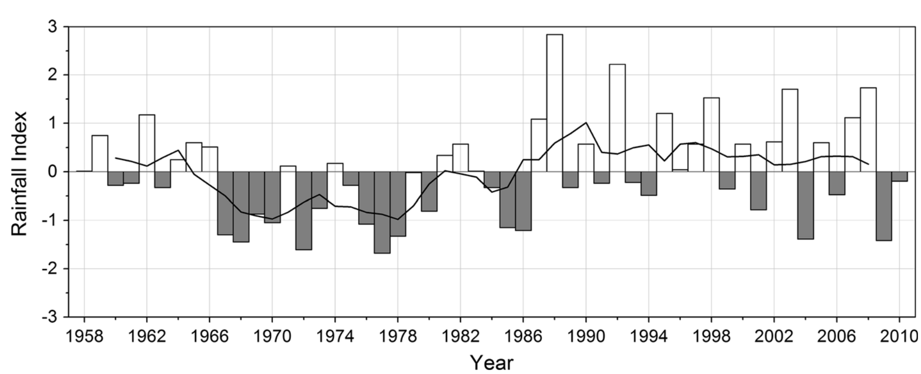

Fig. 9 Time series of the normalized annual rainfall indices from 1958 to 2010. The *black line* shows the 5-year moving average

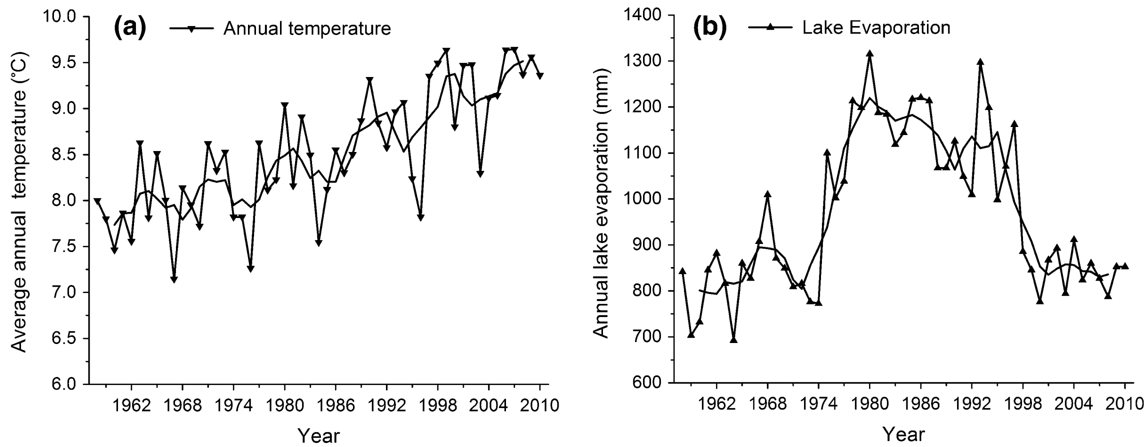

Fig. 10 Annual **a** temperature variations in the Bosten Lake Basin and **b** evaporation from the lake surface between 1958 and 2010. The *black line* shows the 5-year moving average

4.3 Salinization processes of the lake

The unique geographic location, anthropogenic influences, and climatic variations combined to result in the salinization of Bosten Lake. The lake is located in a closed arid inland basin where salt water gathers in the low-lying areas. A large amount of saline land is distributed around the Bosten Lake Basin, and high salt concentrations have accumulated in the soil over a long period.

The anthropogenic influences on lake salinization mainly result from irrigation and water conservation projects. Agricultural development has accelerated and irrigation water use has increased as the population has increased. In addition, the flushing of salt into the lake in irrigation water has increased the lake salinity, with 2.3 million tons of salt from agricultural wastewater accumulating in Bosten Lake between 1975 and 1985 (with an average of approximately 0.46 million tons per year; Xia et al. 2003). However, in recent years, salt inputs have reached over 1.0 million tons per year (approximately twice the previous levels). The high amounts of wastewater from agricultural irrigation have led to this increase in salinity. A study by Rimmer et al. (2006) indicated that the major water budget of the lake is intricately tied to long-term salinity changes in inland freshwater lakes. The lake water budget is controlled by exchanges between precipitation and evaporation and between the lake inflow and outflow. However, the water conservation projects in the Bosten Lake Basin have directly altered the lake inflows and outflows and have indirectly affected lake evaporation. The average lake inflow/lake outflow was 45 % before 1983 and 67 % after 1983. The increased lake outflow resulted in greater lake salinity.

The impacts of the climatic variations on the salinization of the lake were mainly reflected by evaporation and lake inflow. Lake evaporation was greater during the dry period than during the wet period. This increased evaporation will result in the removal of more water from the lake and decrease the lake volume. Therefore, the salinity of the lake will increase with time as the water evaporates and will result in salt deposits. However, during the wet period, the lake evaporation decreased as the lake inflow increased. When the lake inflow increased, additional freshwater was added to the lake and the water cycle improved. During this period, the lake water was diluted and the salinity of the lake decreased.

5 Conclusions

In this study, we presented the temporal and spatial salinity variations of Bosten Lake and investigated the salinization processes in the lake. We have main conclusions as follows:

(1) The lake has evolved to an oligosaline lake and the salinity increased as the water level decreased (and vice versa). In addition, the salinity levels were high in the northwest and low in the southwest.
(2) Regarding the occurrence and persistence of salinity, the risks of extremely adverse conditions were greater when highly subsaline conditions were combined with med/low lake levels.
(3) Based on the rainfall index, the dry period in Bosten Lake mainly occurred from 1966 to 1986, and the wet period occurred from 1987 to 2010. The lake salinity increased from 0.39 to its maximum value of 1.87 g/L during the dry period. This result may be attributed to agricultural wastewater discharge, increased evaporation, and decreased lake inflow. However, during the wet period, the lake salinity

decreased from 1.87 to 1.45 g/L due to reduced evaporation and increased freshwater inputs.

(4) Anthropogenic influences and climatic variations resulted in the salinization of Bosten Lake. From a functional water resources utilization standpoint, future research should focus on management options that would maintain the lake level within a reasonable range that would protect the regional ecological environment and address the salinity issues.

Acknowledgments This work has been supported by National Basic Research Program of China under Grant (No. 2012CB723201).

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