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ORIGINAL ARTICLE

Water level changes of Lake Nansi in East China during 1758–1902

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Abstract

Premodern water level observations are unique and effective sources of lake evolution research. Lake Nansi is a large shallow freshwater lake in East China, and its water level observation is among the earliest observations of reservoir and lake water levels in the world. It is composed of four connected lakes: Lakes Weishan, Zhaoyang, Nanyang, and Dushan. On the basis of premodern water level observations and historical documentary records, we reconstruct the water level changes of Lake Nansi on annual and decadal scales over the past 300 years and discuss their relationship with precipitation and the flooding of the Yellow River. A united lake, Lake Weishan–Zhaoyang–Nanyang, appeared in the late seventeenth century, and since then, the lake expanded northward in the following decades. The north boundary extended approximately 3 km during 1684–1755. It expanded significantly further north in 1851 and merged with Lake Dushan, thus forming the united Lake Nansi in 1871. Water level observations of Lake Nansi began in the middle eighteenth century, and regular monthly observations began in 1814, as a result of the drying up of Lake Nansi during 1810–1814 due to a prolonged drought. The purpose of water level observations of Lake Nansi was practical, i.e., to regulate the water supply and ensure the continuous transportation of goods along the Grand Canal. Lake Nansi was flooded by the Yellow River for seven times during 1758–1902. The flooding always resulted in very high water levels, including two prolonged extremely high water level events. The 1851–1855 event marked the highest water level of Lake Nansi, which resulted in a massive northward expansion of the lake. The 1871–1873 event resulted in the formation of the united Lake Nansi. The correlation between the water level of Lake Nansi and a dryness/wetness index in its drainage basin is significant, indicating that precipitation is a dominant factor regulating the water level. The correlation of water level changes between Lake Nansi and Lake Hongze is also significant. Overall, the water level observations of Lake Nansi have proven to be a very valuable archive of regional hydrology and precipitation changes.

Keywords Lake Nansi · Grand Canal · Water level observation · Drying up · Flood · Yellow River

Introduction

Lake evolution is an important component of studying regional environmental change. Various records are used for lake evolution study. In some cases, historical documentary records and premodern water level observation records are available, and lake evolution can be reconstructed with high resolution (Brooks 1923; Dixey 1924; Nicholson 1999, 2000; Nicholson and Yin 2001; Chang 1987).

Here, we use historical documentary records and premodern water level observations to reconstruct and analyze the long-term water level evolution and annual water level variability of Lake Nansi during the past 300 years.

Lake Nansi[1] occupies an area of approximately 1200 km^2 in modern times, with a length of 126 km and a width of 6–25 km. Its average depth is less than 1.5 m (Shen et al. 2008; Sun et al. 2011). Lake Nansi is actually the general term of four connected shallow freshwater plain lakes in East China, namely, Lakes Weishan, Zhaoyang, Nanyang, and Dushan[2]

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[1] The Chinese characters that correspond to Lake Nansi are 南四湖. 南(Nan) means south, 四(si) means four, and 湖(Hu) means lake.

[2] In Chinese, 微山, 昭阳, 南阳, 独山.

Fig. 1 Map showing the location of Lake Nansi. OD and ND denote the Old Dyke and New Dyke, which were the north boundaries in approximately 1684 and 1755, respectively. The darkest area to the north of ND denotes the new expanded area of Lake Nanyang after 1851

(Fig. 1. Wang et al. 2006; Liang and Zhang 2011; Meng et al. 2011). A dam named Erjiba was constructed in the middle of Lake Nansi, dividing it into the upper (north) and lower (south) parts (Shen et al. 2008). Lake Nansi is one of the largest lakes in China, and it is an important resource to support the sustainability of local society.

The climate of Lake Nansi is largely affected by the East Asian monsoon. The monthly average temperature varies from − 2 to 0 °C in January to 26 to 27 °C in July. The annual precipitation amounts to 700–760 mm and mainly occurs in summer (Ren et al. 1985; Shen et al. 2008).

The topography background of Lake Nansi is as follows: the altitude gradually decreases from north to south (Wang et al. 2006). Water flows from north to south, and the lake outlet lies in the south end, i.e., from Lakes Nanyang and Dushan to Lake Zhaoyang and eventually to Lake Weishan. Among the four lakes, Lake Nanyang has a relatively high altitude.

Sedimentological research has indicated that some lakes possibly existed in this region as early as 2600 years ago (Shen et al. 2000; Zhang et al. 2002). However, the hydrological environment changed greatly due to the construction of the Grand Canal from Beijing to Hangzhou in the late thirteenth century (Ji 2008). Parts of Lake Nansi gradually appeared due to the construction of the Grand Canal (Zou 1980; Cao 1989a, b; Han 2000).

Few early lake water level observations have been reviewed in the literature on the history of hydrology (Needham and Wang 1959; Jones et al. 1963; Landa and Ince 1987; Rosbjerg and Rodda 2019). Records of early lake water level observations are scattered through previous research on environmental changes. After a thorough literature survey, we determine that the water level observations of Lake Nansi could be among the earliest extant reservoir and lake water level observations in the world.

Extant archives indicate that the water level observation of Lake Hongze in East China began in 1736 (Xu 1986). Water level observations of the Great Lakes of North America may be traced back to 1819, and regular observations began in 1860 (Bishop 1990; Quinn and Sellinger 1990; Changnon 2004; Gronewold et al. 2013). Water levels of Lakes Nyasa and Tanganyika in Eastern Africa have been observed regularly since 1895 and 1922, respectively (Dixey 1924; Nicholson 1999; Nicholson and Yin 2001). The water level of Lake George in Australia has been observed since 1904 (Brooks 1923).

Materials and methods

Historical documentary records about Lake Nansi are abundant; however, the evolution history of the lake is unknown. Premodern water level observations of Lake Nansi commenced in the middle eighteenth century. In our earlier studies, the premodern water level observations of Lakes Weishan, Zhaoyang, and Nanyang were examined and tentatively analyzed (Fei 2009; Fei et al. 2012).

The historical documentary records mainly include the historical local gazetteers, historical atlas, and the imperial archives during Qing dynasty (1644–1911). These documents were compiled by the central and local governments. Thus, the quality and reliability are relatively guaranteed. After examining historical documents, only those contain most detailed and reliable records are cited in this research. Previous studies have described the early history of Lake Nansi qualitatively, and their results are textual descriptions. We synthesize the relevant historical documents and produce a map showing the long-term water level evolution of Lake Nansi.

The premodern water level observations are another source of this research. The original water level observation reports are scattered through the imperial archives of the Qing dynasty, which are archived in the First Historical Archives of China[3]. The water levels the water depths at the observation station rather than those of above sea level. A unique length unit named *Yingzao chi*[4] was adopted in the observations, and 1 *Yingzao chi* = 0.32 m. The observation station of Lake Weishan is located at a sluice called Hukou Shuangzha[5], whereas those for the three other lakes are unidentified (Fig. 1).

We employ textual examinations to reconstruct the long-term water level evolution of Lake Nansi. Chronology comparison and statistical analysis methods are used to analyze the water level variability of Lake Nansi as a first attempt. A map is produced showing the long-term water level evolution, i.e., the expansion and retreat of Lake Nansi (Fig. 1).

Results

Formation of the united Lake Weishan–Zhaoyang–Nanyang in the late seventeenth century

Several historical documents recorded the time of formation of the united Lake Weishan–Zhaoyang–Nanyang. Among the records, the most detailed ones are quoted as follows.

The Continued Gazetteer of Jining Prefecture (Pan et al. 1927) recorded that, "the water of Lake Nanyang flooded northward. The prefecture sheriff ordered to construct a dyke named *Hengba* (also known as *Jiu Hengba*, which means Old Dyke) in the north of the lake bank in 1684, in order to prevent the lake from expanding further northward" (Pan et al. 1927).

A color painting titled *Complete Map of the Grand Canal*[6] (Zhang 1703) illustrated the united Lake Weishan–Zhaoyang–Nanyang for the first time in history. Although the lake to the north of Lake Zhaoyang was not given the name "Lake Nanyang," a note was given in the area corresponding to Lake Nanyang, "this is the old channel of the Grand Canal in the Ming Dynasty (1368-1644), but now submerged in water (Zhang 1703)."

We hereby infer that Lakes Nanyang, Zhaoyang, and Weishan merged into a united lake in the late seventeenth century, and the north boundary of this lake was *Jiu Hengba* (Old Dyke) in the late seventeenth century. An illustrated gazetteer of the Grand Canal titled *Comprehensive Introduction of the Canal in Shandong Province*[7] (Lu 1775) also drew Lakes Weishan, Zhaoyang, and Nanyang as a united lake. Relevant textual records came slightly late. Two archives, dated 1757 and 1808, recorded Lake Weishan–

[3] In Chinese, Zhongguo Diyi Lishi Danganguan (中国第一历史档案馆).
[4] Yingzao means construction, and chi means foot. In Chinese, 营造尺.
[5] Double sluice at the lake outlet. In Chinese, 湖口双闸.
[6] In Chinese, Yunhe Quantu (运河全图).
[7] In Chinese, Shandong Yunhe Beilan (山东运河备览).

Zhaoyang–Nanyang as a united lake. The two records are as follows.

A government official conducted an investigation of Lake Nansi in 1757 and reported that, "22th day, 6th month, 22nd year of Qianlong Reign Period (6th August 1757), I went to Pei County and carefully investigated the condition. The altitude of the county was very low, and there were Lake Nanyang in the north, Lake Zhaoyang in the northeast, and Lake Weishan in the southeast… Now lakes Nanyang, Zhaoyang and Weishan merged together" (Academy of Water Conservancy and Hydroelectric Power, AWCHP 1988).

The archive dated 1808 recorded that, "the three lakes, i.e. Lakes Nanyang, Zhaoyang, Weishan, though had different lake names, were actually a united large lake, and the circumference was more than three hundred *li*" (AWCHP 1988).

The two archives confirmed the existence of united Lake Weishan–Zhaoyang–Nanyang during the eighteenth century and the early nineteenth century. Overall, the aforementioned records proved that the united Lake Weishan–Zhaoyang–Nanyang appeared since the late seventeenth century.

Long-term water level evolution of Lake Weishan–Zhaoyang–Nanyang

A long-term water level evolution is indicated by the evolution of the expansion and retreat of the lake boundary. Of the four parts of Lake Nansi, Lake Nanyang presents a relatively high altitude. It is sensitive to water level change, whereas the other lakes are relatively stable. The long-term water level evolution of Lake Weishan–Zhaoyang–Nanyang is therefore approximately equal to the expansion and retreat of Lake Nanyang.

Lake Nanyang did not stop expanding northward after the construction of the *Jiu Hengba* (Old Dyke) in 1684 (Fig. 1). *The Continued Gazetteer of Jining Prefecture* further recorded that, "The lake expanded northward during the Qianlong Reign Period (1736-1795). A New Dyke (named *Xin Hengba*, *Xin* means new) was constructed in the 20th year of the Qianlong Reign Period (1755). The New Dyke was located more than 5 *li* (Chinese length unit, 1 *li* = 0.5 km) to the north of the Old Dyke" (Pan et al. 1927).

Thus, we infer that the new northern boundary of Lake Nanyang in 1755 was the New Dyke (approximately 3 km north of the Old Dyke) (Fig. 1). With regard to the long-term water level evolution of Lake Weishan–Zhaoyang–Nanyang after 1755, the *Continued Gazetteer of Jining Prefecture*[8] recorded it in most detail. The text reads,

> In the 23rd year (1758), a dam was constructed to the south of Lake Weishan to prevent the flood of the Yellow River, and a sluice was constructed at the outlet of Lake Weishan to store water in the lake. The lake expanded, and as a result, a few villages to the north of Lake Nanyang (in Jining Prefecture) were submerged in the 24th year (1759).
> The Jingshanqiao River (a major outlet of Lake Nansi) was dredged extensively in the 28th year of Qianlong Reign Period (1763) and in the 2nd year of Jiaqing Reign Period (1797). The flood of the Lake Weishan was drained off, and the submerged land dried up…
> 1st year of Xianfeng Reign Period (1851), the Yellow River burst at Feng County and flooded Lake Weishan. The flood flowed northward, the dried up land was submerged again… The submerged land no longer dried up. It has been 72 years from the 1st year of Xianfeng Reign (1851) Period to now. (Pan et al. 1927)

This record is informative. First, it indicated that some land to the north of the *Xin Hengba* (New Dyke) was submerged and dried up repeatedly during 1755–1851. Therefore, it is reasonable to infer that the northern boundary of Lake Nanyang was the New Dyke (~ 3 km north of the Old Dyke) during 1755–1851. Secondly, Lake Nanyang expanded northward massively in 1851, when it was flooded by the Yellow River. The land to the north of the New Dyke was permanently submerged from 1851. The new northern boundary of Lake Nanyang after 1851 can be inferred from a map of Lake Nansi included in *The Continued Gazetteer of Jining Prefecture* (Pan et al. 1927) (Fig. 1).

Formation of the united Lake Nansi

The Complete Map of the Grand Canal (*Yunhe Quantu*. Zhang 1703) is possibly the first atlas that clearly drew Lake Dushan; therefore, the lake has appeared at least since the late seventeenth century. Lake Weishan–Zhaoyang–Nanyang lies to the west of the Grand Canal, and Lake Dushan lies to the east bank of the canal.

The Complete Map of the Grand Canal and *the Comprehensive Introduction of the Canal in Shandong Province* drew Lake Dushan on the east side of the Grand Canal, and it was separated from Lake Weishan–Zhaoyang–Nanyang by the canal (Zhang 1703; Lu 1775). A book introducing the rivers in the entire China titled *Brief Introduction of Rivers*[9] (Qi 1761) recorded that, "Lake Dushan and to its southwest, Lake Zhaoyang, were actually one water body. The Grand Canal and its embankments divided them, so they were known as two lakes."

The abovementioned sources confirmed that Lake Dushan was a separate lake during the late seventeenth century and the eighteenth century.

[8] In Chinese, Jining Zhilizhou Xu Zhi. 济宁直隶州续志

[9] In Chinese, Shuidao Tigang. 水道提纲

Lake Nansi was severely flooded by the Yellow River in 1871 and 1873. The embankments of the Grand Canal separating Lake Dushan and Lake Weishan–Zhaoyang–Nanyang were destroyed; consequently, the united Lake Nansi appeared.

An official of the Qing dynasty named Weng Tonghe traveled along the Grand Canal from north to south in 1872 and from south to north in 1874. He witnessed the destroyed embankments and recorded it in his diary.

In the diary of 29 June 1872, he recorded that "from Nanyang to here (Shijiakou, a village to the south of Nanyang town) were the old channel of the canal, but now there were only grasses and destroyed embankments, which connected to the lake everywhere." In the diary of 4 July 1874, he recorded that "The embankments of the canal were totally destroyed, and merged together with the two lakes" (Weng 1904).

Water level observations of Lake Nansi

From the extant archives, the earliest record of the water level emerged in 1746. However, the starting point of our chronology was set at 1758, considering that no records are available for 1747–1757.

During the period of 1758–1813, observations of Lake Weishan were not conducted on regular dates. All observation records lack information for 9 years. For this period, the annual water level is the average of those available records of a year. A total of 229 records are found. On average, there are five records per year (excluding the gap years) during the whole study period.

Monthly observations and reports of the water level of Lakes Weishan, Zhaoyang, Nanyang, and Dushan commenced in 1814 pursuant to the decree of Emperor Jiaqing (reigned in 1796–1820. Li and Pan 1813). The observations were conducted in every Chinese lunar calendar month. The detailed observations are listed in Table 1.

The annual max/min water levels would be lower/higher than the real max/min levels due to the gaps in data. The annual mean levels are less affected by data absences and are therefore more accurate. We employ the chronologies of the annual mean water levels of Lake Nansi to analyze the water level changes (Fig. 2).

Drying up events of Lake Nansi

A detailed examination of relevant documents shows that Lake Nansi dried up several times during 1758–1902. Of the four parts of Lake Nansi, Lake Weishan once dried up in 1814; Lakes Zhaoyang and Dushan dried up in 1810, 1813, and 1814; Lake Nanyang dried up in 1813, 1814, 1824, 1825, 1826, 1838, and 1839 (AWCHP 1988. Fig. 2). In sum, the drying up of Lake Nansi (or parts of the lake) occurred only during the early nineteenth century, i.e., before 1851. Among them, 1810–1814 was an interval when Lake Nansi experienced an unprecedented water supply crisis that resulted in profound effects.

Flooding of the Yellow River and the 1851–1855 and 1871–1873 events

The Yellow River frequently flooded in historical times (Cen 2004). Over the period of 1758–1902, Lake Nansi was flooded by the Yellow River seven times, in 1781, 1796, 1851, 1852, 1853, 1871, and 1873 (Cen 2004; AWCHP 1988). The flooding of the Yellow River always resulted in very high water levels in the same year and/or the next year in Lake Nansi.

The flooding of the Yellow River in the periods of 1851–1855 and 1871–1873 resulted in two highest water levels in Lake Nansi. The 1851–1855 event corresponds to the channel changes of Huaihe River in 1851 and the Yellow River in 1855. The 1871–1873 event corresponds to the formation of the united Lake Nansi.

The Huaihe River flowed eastward into the Yellow Sea prior to 1851. After the channel change in 1851, it flows southward into the Yangtze River (Fig. 1). The channel change of the Huaihe River in 1851 could not affect Lake Nansi because the lower reaches of the Huaihe River is far away from it. The extremely high water level of Lake Nansi indicated that the channel change of the Huaihe River was not a local event but a large-scale regional event that was related to the flooding of the Yellow River.

Table 1 Gaps in the water level observations of Lake Nansi during 1814–1902

Lake	Amount of gaps*	Percentage of gaps	Gap years (years when all data are missing)
Weishan	146	13.1%	1854, 1862, 1873, 1877
Zhaoyang	271	24.6%	1816, 1822, 1823, 1824, 1841, 1846, 1854, 1862, 1873, 1877
Nanyang	264	24.0%	1816, 1822, 1823, 1841, 1846, 1854, 1862, 1873, 1877
Dushan	265	24.1%	1816, 1822, 1841, 1846, 1854, 1862, 1873, 1877

*The total amount of points is 1101

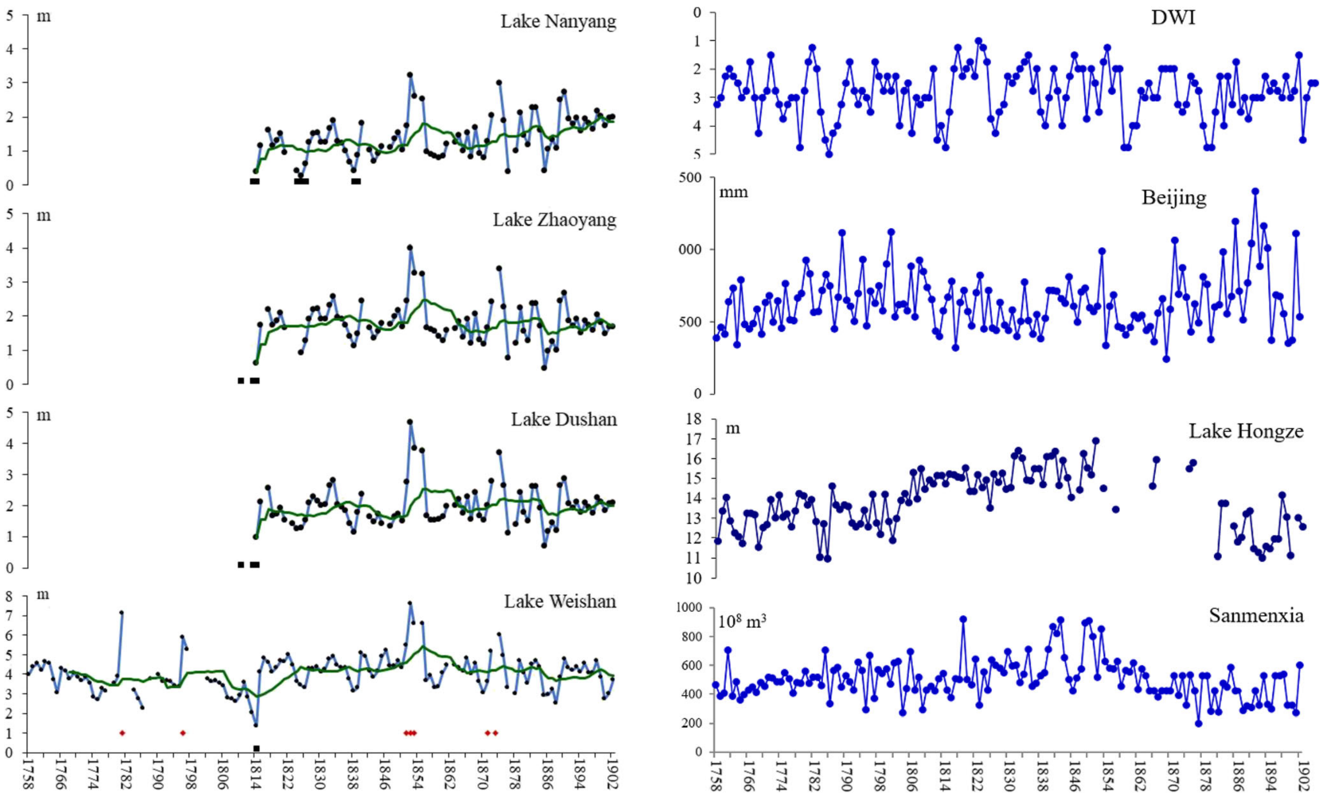

Fig. 2 Chronologies of the annual mean water level of Lakes Weishan, Zhaoyang, Nanyang, and Dushan and comparison with relevant chronologies. The bold green lines denote the 11-point moving averages. Annual precipitation of Beijing during 1758–1902 (data from Beijing Meteorology Service 1982); average dryness/wetness index (DWI) of Heze, Jinan, Linyi, and Xuzhou during 1758–1902 (data from the Central Meteorological Administration of China 1981); annual maximum water level of Lake Hongze during 1758–1902 (data from Xu 1986); annual runoff of the Yellow River at Sanmenxia Station during 1758–1902 (data from Wang et al. 1999). The red diamonds denote the years when Lake Nansi was flooded by the Yellow River. The black squares denote the years when parts of Lake Nansi dried up

The northward channel change of the Yellow River in 1855 could be the cause of the expansion of Lake Nanyang. The Yellow River was in the lower reaches of Lake Nansi before 1855 and migrated to its upper reaches after 1855 (Fig. 1).

The discovery of the existence of this high water level interval during 1851–1855 in Lake Nansi is valuable in understanding the hydrological background of great geographical events on an annual time scale.

Lake Nansi was significantly affected by the flooding of the Yellow River in 1871 and 1873. Water levels of Lake Nansi were atypically high in 1871–1875. As we discussed above, the embankments between Lakes Weishan–Zhaoyang–Nanyang and Dushan were destroyed and thus formed the united Lake Nansi.

The long-term trends of water level change of the four parts of Lake Nansi are shown in the chronologies of 11-point moving averages (Fig. 2). Of the four parts, Lakes Weishan, Zhaoyang, and Dushan did not show any significant linear trends, and the area of the three lakes did not change significantly. However, the water level of Lake Nanyang gradually increased after the 1851–1855 event. This trend is consistent with the abovementioned northward expansion of Lake Nanyang.

Comparison with other relevant chronologies

Lake level is a good representation to understand the precipitation and wetness change in historical China (Fang 1993). As indicated by the location of Lake Nansi, it belongs to the north China, where precipitation dominates social activities more than temperature (Sternberg 2008; Pei et al. 2016). The water level variability of Lakes Weishan, Zhaoyang, Nanyang, and Dushan is compared with several other chronologies.

The chronologies of annual mean water level are compared with the dryness/wetness index (DWI) dataset described in the Central Meteorological Administration of China (1981). This dataset comes from the documentary records about flood and drought in the local historical chronicles in China. DWI is a five-grade dataset, i.e., 5 (very dry), 4 (dry), 3 (normal), 2 (wet), and 1 (very wet). Four stations, i.e., Heze, Jinan, Linyi, and Xuzhou, exist in the drainage basin of Lake Nansi (Fig. 1). The arithmetic mean of the four stations is employed to represent the precipitation of the drainage basin (Fig. 2).

Beijing has the longest premodern and modern meteorological observation histories in China. Continuous modern meteorological observation in Beijing began in 1841. Premodern daily observation records about weather phenomena during 1724–1902 are available in the Qing dynasty archives. The Beijing Meteorology Service (1982) reconstructed the chronology of annual precipitation of Beijing from 1724 by using the Qing dynasty archives (prior to 1841) and modern meteorological observations (after 1841). We compare the annual mean water level of Lake Nansi with the annual precipitation of Beijing over 1758–1902 (Fig. 2).

Water level observation of Lake Hongze was also conducted by the Qing government. The extant observation archives cover the period of 1736–1911, with many gaps in the late nineteenth century. The observation of Lake Hongze was not conducted monthly and was usually performed in the flood season (summer half year). Previous studies have examined the archives and reconstructed a chronology of annual maximum water level of Lake Hongze since 1736 (Xu 1986). Here, we cut the period 1758–1902 out of the chronology (Fig. 2). The channel change of the Huaihe River in 1851 corresponded to the highest water level in Lake Hongze. A comparison of the water level variabilities of Lakes Hongze and Nansi will help in further understanding the spatial scale of the 1851–1855 event.

Water level observation was also conducted in the Yellow River at Sanmenxia Station by the Qing government during 1736–1911. The existing archives of the dataset are incomplete, with gaps of 31.8% over this period. Wang et al. (1999) reconstructed the chronology of the runoff of the Yellow River by using the water level archives of Sanmenxia and supplemented it with the water level data of other stations and other qualitative textual records of floods. Here, we cut the period of 1758–1902 out of the chronology (Fig. 2). The 1851–1855 event corresponds to a period of extremely high runoff of the Yellow River, and the 1871–1873 event seems to be a local event.

Correlation analysis is used to analyze the relationship between the water level changes of Lake Nansi and the abovementioned regional climate and hydrology factors (Table 2). The correlation between the water level of Lake Nansi and the DWI in its drainage basin is significant, indicating that precipitation is a dominant factor of the water level of Lake Nansi. The water level change between Lakes Nansi and Hongze is significant, indicating similar climate and hydrology background of the two lakes. The correlation between the water level of Lake Nansi and the annual runoff of the Yellow River at Sanmenxia is insignificant, indicating that their relationship may be a nonlinear correlation.

Discussions

Commencement of monthly water level observations of Lake Nansi

The Qing government organized water level observations of Lake Nansi during the 18th–19th centuries because the lake was a major reservoir on the Grand Canal. The Grand Canal in China is one of the greatest historical shipping routes constructed in the world. It is the main artery of the inland communication system of China during the fourteenth to nineteenth centuries. A few lakes and wetlands along the Grand Canal were transformed into reservoirs to ensure the water supply of the Grand Canal. The objectives of early hydrological observations in world history were usually practical, such as water supply and taxes (Dooge 1984; Kondrashov et al. 2005). The purpose of water level observations of Lake Nansi was also practical, i.e., to regulate the water supply and ensure the transport of the Grand Canal.

Continuous drought prevailed in the drainage basin of Lake Nansi during 1810–1814 and resulted in the drying up of Lake Nansi. This event was the greatest water supply crisis during 1758–1902. The drying up of Lake Nansi, as a major reservoir on the Grand Canal, obstructed the transportation of the Grand Canal, which was of key importance to the Qing dynasty (Needham et al. 1971).

The emperor was astonished when he learned that the canal transportation was obstructed. He complained that, *"According to the investigation by Wu Jing, there was merely 1.8-2.0 chi of water at the center of Lake Weishan. This never occurred before. Lakes Nanyang, Zhaoyang and Dushan all*

Table 2 Correlations between the water level of Lake Nansi and relevant chronologies

Variable	Lake Weishan 1758–1902	Lake Zhaoyang 1814–1902	Lake Nanyang 1814–1902	Lake Dushan 1814–1902
Mean of DWI	−0.529**	−0.429**	−0.376**	−0.389**
Annual precipitation of Beijing	0.048	0.107	0.287**	0.094
Annual maximum water level of Lake Hongze	0.205*	0.256*	0.240*	0.145
Annual runoff of the Yellow River at Sanmenxia	0.194*	0.097	−0.195	−0.004

**Significant at 0.01 level (two tailed); *significant at 0.05 level (two tailed) *dried up. Li Hengte, the official in charge, the person responsible, was oblige be arrested"* (*Qing Shilu*. Zhonghua Book Company 2008).

The emperor was upset about this event. He ordered that the water levels of the reservoirs along the Grand Canal should henceforth be observed monthly. Sufficient water should be collected in summer and autumn (rainy season of this area), and water supply should be guaranteed (AWCHP 1988).

The drying up of Lake Nansi during 1810–1814 thus resulted in the commencement of monthly water level observations. Monthly water level observations of Lake Nansi, together with the four other reservoirs along the Grand Canal, Lakes Nanwang, Shushan, Mata, and Machang, began in 1814.

Several extremely low precipitation years and severe droughts occurred in the following decades (Fig. 2), but Lake Nansi rarely dried up. Lake Nanyang lies in the north end of the four lakes, and the altitude is relatively high. Lake Nanyang dried up several times since 1814, whereas the three other lakes no longer dried up. The monthly water level observations generally helped to regulate water levels, so as to reduce the risk of drying up of the lakes.

The drought in 1810–1814 caused the drying up of the reservoirs and induced the commencement of regular water level observation along the Grand Canal, thus forming a landmark in the history of hydrological science. This phenomenon is particularly valuable: as we mentioned above, modern water level observation of lakes in most parts of the world did not begin until the late nineteenth century (Brooks 1923; Dixey 1924; Bishop 1990; Quinn and Sellinger 1990; Nicholson 1999; Nicholson and Yin 2001; Changnon 2004; Gronewold et al. 2013). The monthly water level observations of Lake Nansi are among the earliest lake water level observations in the world.

Social effects of water level fluctuations

The abrupt fluctuation in water level caused submergence and drying up of the lands surrounding the lake and resulted in migration waves to and from the lake areas. A conflict eventually broke out following the 1851–1855 event, when Lake Nansi experienced a short period of exceptionally high water levels. The surrounding areas were flooded by the lake water, and the local residents thus fled away. The floods retreated in 1856, and an influx of new migrants soon occupied these regions. When the original local residents returned, their hometowns were already occupied by the new migrants. A conflict between the new migrants and local residents inevitably broke out and lasted for a decade (Zhang 2007). The conflict was not resolved until the emperor dispatched a high-ranking official named Zeng Guofan to intervene and act as a mediator for the both two sides, which eventually led to a resolution in 1866 (Yu and Zhao 1920).

Conclusions

In this study, the water level changes of Lake Nansi at different time scales and their relationship with climate and hydrology are analyzed on the basis of historical documentary records and premodern water level observations.

Premodern water level observations of Lake Weishan began in the middle eighteenth century. Lake Nansi dried up in the period of 1810–1814. This event induced the commencement of monthly water level observations of Lake Nansi. The drying up of Lake Nansi, as a major reservoir on the Grand Canal, obstructed the transportation of the canal, which was of key importance to the Qing dynasty. Monthly observations of the four parts of Lake Nansi commenced in 1814 in accordance with the decree of the Qing emperor to regulate water supply.

Precipitation is a dominant factor of the water level of Lake Nansi because the correlation between the water level and the DWI of its drainage basin is significant. The flooding of the Yellow River always resulted in extremely high water levels in the same year and/or the next year in Lake Nansi. The flooding of the Yellow River in the periods of 1851–1855 and 1871–1873 resulted in two highest water levels in Lake Nansi. The 1851–1855 event corresponds to the southward channel change of the Huaihe River in 1851 and the northward channel change of the Yellow River in 1855. The 1871–1873 event resulted in the formation of the united Lake Nansi.

The premodern water level observations of Lake Nansi are among the earliest in the world and hence important documents of scientific history. To understand regional environmental change, the observations represent detailed and valuable records of lake evolution, regional precipitation variability, and major hydrological events.

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