https://doi.org/10.5194/cp-2021-121
Preprint. Discussion started: 8 September 2021

Climate of the Past
Discussions

Water level change of Lake Machang in eastern China during the past 200 years

Jie Fei[1]
Institute of Historical Geography, Fudan University, Shanghai 200433, China

Abstract

Lake Machang, which occupies an area of approximately 30 km^2 in Jining City of eastern China, was a historical reservoir on the Grand Canal existing from early 15th century to early 20th century. The premodern monthly water level observation of Lake Machang commenced in 1814 AD and ended in 1902 AD. The available observation data from the monthly records could cover 75.6% of the whole study period 1814-1912. Although the water level was seemingly artificially intervened by human activities, monthly and annual water level changes still correlated well with precipitation. That is, climate is still the dominant factor of water level changes on seasonal and annual scales. The flooding of the Yellow River in 1871 AD carried large amount of silt into Lake Machang, which resulted in the rise of lake bed and reclamation initiated by local residents. In particular, after the reclamation activity was officially approved in 1900 AD, Lake Machang was massively reclaimed and eventually dried up in the early 20th century.

Key words

Lake Machang, reservoir, Grand Canal, reclamation, water level

[1] Email: jiefei@fudan.edu.cn

https://doi.org/10.5194/cp-2021-121
Preprint. Discussion started: 8 September 2021

Introduction

Historical reservoir evolution is a promising subfield of climatic change studies (Cardoso-Silva et al., 2021; Margarint et al., 2021; Bábek et al., 2021; Fei et al., 2021; Halac et al., 2020). Textual records on reservoir water level are fragmentary and qualitative, which thus hamper the reconstruction of water level change with high resolution. To improve the practice of using historical records on water level to understand past climate change, the water level change of Lake Machang in Jining City, eastern China during the past 200 years has been reconstructed in this work. A combination of premodern monthly water level observation data, textual records, and historical maps has been utilized in the reconstruction (Figure 1).

Lake Machang, which occupies an area of nearly 30 km^2, was a historical reservoir on the Grand Canal (Figure 1) that had existed for several centuries until it dried up in the early 20th century. The climate in this area is a warm temperate semi-humid East Asian monsoon type. The monthly average temperature varies from −2 °C in January to 27 °C in July. The annual precipitation is around 700 mm and mainly occurs in summer as monsoon precipitation (Shen et al., 2008).

The middle section of the Grand Canal was repaired and modified in 1411 AD, and the channel of River Guang was also slightly modified. A group of reservoirs were established along the canal to ensure the water supply of the Grand Canal (Zhu, 2014; Fei et al., 2021). Water was collected in the reservoirs in every autumn when the monsoon precipitation was over and supplied the canal in spring prior to the monsoon precipitation came (Lu, 1775).

From the River Guang and a few small rivers, water was introduced into the Machang area and collected into a new reservoir, named as Lake Machang (Yang, 1430; Figure 1). The official gazetteer recorded that the area was previously a horse pastureland; therefore, the new *shuigui* (reservoir) was named Machang Hu[2] (Xu, 1859). In this regard, the official documents indicated that Lake Machang appeared in 1411 AD.

However, a poem indicates that a lake already existed in this area which could date back to the early 14th century. The poem is entitled West Lake of Jizhou Prefecture[3]. It reads, the lake is clean and vast, and I cannot see the shoreline[4]… The author LI Gang was the mayor of Jizhou Prefecture in the period of 1324–1327 AD. Therefore, this poem was probably written in 1324–1327 AD.

Materials and results

The Grand Canal in China is a world heritage site, and it is one of the greatest artificial waterways constructed in historical times in the world.

---

[2] *Ma* means horse, *Chang* means pasterland, and *Hu* means lake.

[3] Jizhou Xihu (濟州西湖). Jizhou Prefecture is the historical name of Jining City during the Yuan dynasty (1271-1368 AD).

[4] The original Chinese text reads, 渺渺澄湖望不窮，畫船曾駐夕陽中。*miao miao cheng hu wang bu qiong, hua chuan ceng zhu xi yang Zhong*.

Climate of the Past Discussions

Water level observations of a few reservoirs along the canal were organized by administration of the Grand Canal since the middle 18th century (Fei, 2009; Fei et al., 2012; Fei et al., 2021). The water level observation records of Lake Machang are available since 1763 AD; however, early observations are fragmental and insufficient to establish a chronology (Academy of Water Conservancy and Hydroelectric Power, 1988).

Monthly observations of the water levels of the reservoirs along the Grand Canal were organized since 1814 AD to further regulate the water supply and ensure the transport of the canal. Until 1902 AD, the administration of the Grand Canal was dissolved, and the function of the Lake Machang as a reservoir of the Grand Canal was ended (Fei et al., 2021). The observations of the reservoirs along the canal, including Lake Machang, were therefore terminated in 1902 AD.

The extant observation data of Lake Machang could cover 75.6% of whole study period 1814–1902 AD. The missing points, which only account 24.4%, were interpolated using the mean of two neighboring points. The observations followed the Chinese lunar calendar months, and they were conducted at the end of every month. A unique length unit *yingzao chi* (1 *yingzao chi* = 0.32 m) was adopted in the observations (Table 1). Notably, the water levels were not those of above sea level but the water depths at the observation station. However, no relics or records of the observation station of Lake Machang are available to date. The original water level observation reports are scattered through the imperial archives of the Qing Dynasty (1644–1912 AD), which are documented in the First Historical Archives of China (*Zhongguo Diyi Lishi Dangan Guan*). After converting the observation data into SI unit and AD dates, the chronologies of the annual mean, annual maximum, and annual minimum water levels were established (Figure 2).

Comparison with relevant precipitation chronologies

The water level variability of Lake Machang was compared with precipitation on monthly and annual levels.

The average monthly water level variability of Lake Machang in the period of 1814–1902 AD was compared with that of Jining City in the period of 1951–2000 AD (Figure 5). We found that the monthly water level responded well with precipitation but with a time-lag of 2 months. As we mentioned above, the water level of Lake Machang as a reservoir was artificially intervened due to human activities. Water was collected in autumn and discharged into the canal when needed. This condition possibly explained the time-lag of monthly water level variability.

The annual water level variability of Lake Machang was compared with the Dryness Wetness Index (DWI hereinafter) dataset described in the Central Meteorological Administration of China (1981). This dataset came from the textual records on precipitation in the historical local gazetteers in China. The dataset covers 120 stations, including four stations in the vicinity of Lake Machang, namely, Heze, Jinan, Linyi, and Xuzhou (Figure 1). DWI is a five-grade dataset, that is, 5 (very dry), 4 (dry), 3 (normal), 2 (wet), and 1 (very wet). We calculated the correlation of the average DWI of Heze, Jinan, Linyi, and Xuzhou (DWI_{HJLX}) with the annual mean, maximum,

https://doi.org/10.5194/cp-2021-121
Preprint. Discussion started: 8 September 2021

minimum water levels of Lake Machang in the period of 1814–1902, and the correlation coefficients (R) of $R_{mean} = -0.50$, $R_{max} = -0.52$, $R_{min} = -0.41$ (N=89). All these values are significant. Furthermore, the relatively high correlation value indicates that precipitation was a crucial factor of the annual water level changes of Lake Machang in the period of 1814–1902 AD.

We further examine the 10 years with highest water levels and another 10 years with lowest water levels. These picked-up years with highest or lowest water levels will be compared with the historical records of local flood and drought. The 10 years with highest annual maximum water levels are 1898, 1820, 1852, 1860, 1883, 1864, 1863, 1819, 1839, and 1892. Among them, all but 2 years (1883, and 1864) corresponded with records of local floods. The 10 years with lowest annual minimum water levels are 1901, 1902, 1814, 1857 1874, 1850, 1866, 1847, 1837, and 1856. Among them, only 4 years (1901, 1814, 1874, and 1856) corresponded with records of droughts.

According to the comparison, it may indicate that the extreme value of water level did not link closely with local disasters, no matter flood or drought. Furthermore, the droughts seldom caused drying up of Lake Machang in the period of 1814–1902 AD, but they only lead to abnormally low water levels in winter and spring. The lake usually recovered in several months when summer monsoon came. This observation proved that precipitation affected annual maximum water level more than annual minimum water level.

Beijing lies approximately 490 km north of Lake Machang, and the correlation coefficient of the annual precipitation of Beijing and Jining over the period of 1951–2010 AD is 0.148 (N=60). Beijing has the longest premodern and modern meteorological observation histories in China. Continuous modern meteorological observation in Beijing began in 1841 AD. Premodern daily observations of precipitation days are available from 1724 AD (Beijing Meteorology Service, 1982). We established the chronology of annual precipitation of Beijing over the period of 1814–1902 AD using a combination of the two types of sources mentioned above (Figure 4). The correlation coefficient of the annual mean water level of Lake Machang and the annual precipitation of Beijing over the period of 1814–1902 AD is merely 0.021 (N=89). This indicated that the water level of Lake Machang was not a large-scale climate indicator, and it did not reflect the precipitation of a large area, but that of its drainage basin.

Flooding of the Yellow River, silt sedimentation, and reclamation

Over the period 1814–1902 AD, Lake Machang was flooded by the Yellow River in 1851 and 1871 AD, although the latter was only nearly 100 km away. The channel change of the Yellow River in 1855 AD did not directly affect Lake Machang.

The flooding of the Yellow River in 1851 AD was a large-scale hydrological disaster. It resulted in the southward migration of the Huaihe River (ca.300 km south of Lake Machang), which was a major hydrological event in the history of China. Lake Nansi (ca.30 km southeast of Lake Machang) recorded an extremely high water level interval lasting 4 years over the period of 1851–1855 AD. However, Lake Machang was only moderately flooded by the Yellow River in 1851 AD (Figure 2).

The autumn of 1871 AD was very rainy and the Yellow River burst its banks at

Yuncheng County, which was around 70 km to the northwest of Lake Machang (Cen, 1957). The breach was not filled up until the next spring. Notably, the flooding of the Yellow River in 1871 AD was also a large-scale hydrological disaster.

The flooding of 1871 AD did not result in extremely high water level in Lake Machang (Table 1). However, it carried a great amount of silt into the reservoir. The bed of the reservoir increased significantly due to the silt sedimentation caused by the flooding of the Yellow River. From then on, the inflow of River Guang no longer reached the reservoir. Local residents began to reclaim the reservoir (Pan, 1927).

The flooding of 1871 AD significantly affected the evolution of Lake Machang, and it marked the shrinkage of the reservoir and the beginning of the reclamation. It severely destroyed the banks of the Grand Canal in this region. Four reservoirs were previously connected along the Grand Canal to the south of Lake Machang. The dikes separating them were destroyed by the flood, and these reservoirs merged into a united Lake Nansi (Fei, 2009; Fei et al., 2012; Fei et al., 2021).

The annual minimum water levels of Lake Machang decreased greatly since 1871 AD (Figure 2). Low water level could make reclamation easier and further accelerate the shrinkage of the reservoir. In 1900 AD, the central government approved the local authority's application regarding the reclamation of Lake Machang. The administration of the Grand Canal was dissolved 2 years later, and the function of the Lake Machang as a reservoir of the Grand Canal was ended. Hereby, local residents poured in and reclaimed the reservoir.

As a result, Lake Machang soon dried up in the following decades. The local authority organized a field investigation regarding the Grand Canal in Shandong Province in 1916 and drew a map entitled "*The Plan of the Southern Part of the Grand Canal, Including the Shallow Lakes and Swamps* (Scale 1:200,000) (Pan, 1916)" (Figure 7). Lake Machang was drawn as a dry lake in this map. In 1927 AD, Lake Machang was also drawn as a dry lake in the local gazetteer of Jining (Yuan, 1927). From this maps, it could easily conclude that Lake Machang dried up no later than 1916. Notably, the annual precipitation did not decrease significantly in the early 20th century. Therefore, although the climate had a fundamental role in affecting the water level of Lake Machang, the human activities, such as large scale reclamation, accelerated the drying up of Lake Machang.

Overall, the road map of the dry up of Lake Machang was as follows: the flooding of 1871 AD carried large amount of silt into the reservoir and therefore resulted in the rise of the lake bed and shrinkage of the reservoir, which caused the reclamation by local residents and further shrinkage of the reservoir. After the central government formally approved the reclamation activity in 1900 AD, local residents poured in and further reclaimed it, and it caused the dried up of Lake Machang in the early 20th century.

Comparison with Lake Nansi

Lake Nansi lies 30 km southeast to the Lake Machang, and it is actually the general name of four connected reservoirs along the Grand Canal. The four reservoirs are Lake Nanyang, Lake Dushan, Lake Zhaoyang, and Lake Weishan. Water level observations were made in the four reservoirs. The average annual mean water level change of Lake Nansi was calculated and compared with that Lake Machang over the period of 1814–1902 AD. The correlation coefficient is 0.374 (N=89) (Figure 6). The annual water level change of Lake Machang showed great similarity to those of its neighbor reservoirs.

On the contrary, the long-term evolution of Lake Machang and Lake Nansi were very different. Lake Machang was reclaimed and dried up in the early 20th century, but Lake Nansi gradually expanded (Fei et al., 2021). Lake Nansi was even more frequently flooded by the Yellow River. For example, the flooding of 1871 AD destroyed the dikes separating these reservoirs, and this phenomenon formed a united Lake Nansi (Fei, 2009; Fei et al., 2012; Fei et al., 2021).

From the perspective of geomorphology, the altitude of Lake Machang is a little higher than that of Lake Nansi, and the Grand Canal in this region flows southeastward. That is, water flew from Lake Machang to Lake Nansi along the Grand Canal. When Lake Machang was reclaimed, water that could otherwise be collected in it directly flew into Lake Nansi, and resulted the expansion of Lake Nansi. Geologically, the basin of Lake Nansi is slowly subsiding, whereas that of Lake Machang is stable (Shen et al., 2008). The subsiding compensated the silt sedimentation in Lake Nansi, whereas Lake Machang was silted up and reclaimed.

Conclusions

We reconstructed the water level change over the period of 1814–1902 AD and the evolution history of Lake Machang by using premodern monthly water level observations. Precipitation was still a dominant factor of water level change of Lake Machang on monthly and annual scales.

The flooding of the Yellow River in 1871 AD carried a great amount of silt into Lake Machang. The central government formally approved the reclamation activity of Lake Machang in 1900 AD. The administration of the Grand Canal was dissolved 2 years later, and the function of the Lake Machang as a reservoir of the Grand Canal was ended. Local residents poured in and reclaimed Lake Machang, and it resulted the dried up in the early 20th century.

From the fate of Lake Machang, vulnerability of local ecological system could come from both natural and human aspects. Under the current climate change and its natural impacts to our environment, how human society limit our own shocks should be a key question in the era of Anthropocene.

Acknowledgments This research was supported by the Shanghai Municipal Philosophy and Social Science Grant (No. 2017BLS003).

References

Academy of Water Conservancy and Hydroelectric Power: Historical flood archive material in the Huaihe River basin during the Qing dynasty. Zhonghua Book Company (Zhonghua Shuju), Beijing, 1988 (in Chinese).

Bábek O., Sedlácek J., Lendáková Z., Elznicová J., Tolaszová J., Pacina J.: Historical pond systems as long-term composite archives of anthropogenic contamination in the Vrchlice River, Czechia. Anthropocene, 33, 100283, 2021.

Beijing Meteorological Service: Beijing climate sources. Beijing Meteorological Service, Beijing, 1982 (in Chinese).

Cardoso-Silva S., Mizael J. O. S. S., Frascareli D., Alves de Lima Ferreira P., Rosa A. H., Vicente E., Figueira R. C. L., Pompeo M. L. M., Moschini-Carlos V.: Paleolimnological evidence of environmental changes in seven subtropical reservoirs based on metals, nutrients, and sedimentation rates. Catena, 206, 105432, 2021.

Cen Z.: Evolution history of the Yellow River. The People's Press (*Renmin Chubanshe*), p582, 1957 (in Chinese).

Central Meteorological Administration of China: Yearly charts of dryness/wetness in China for the last 500-year period. Sino-Maps Press, Beijing, 1981 (in Chinese).

Fei J.: Water-level Observations of Lake Weishan-Zhaoyang-Nanyang in China over 1814–1902 AD. Lake and Reservoir Management, 2009, 25, 131–135.

Fei J., Lai Z.-P., Zhang D. D., He H.-M., Zhou. J.: Historical Water Level Change of Lake Weishan in East China from 1758–1902 AD: relationship with the Flooding of the Yellow River. Limnology, 2012, 13: 117–124.

Fei J., Pei Q., Zhong Y.: Water level changes of Lake Nansi in east China during 1758–1902. Regional Environmental Change, 21, 17: 1–9, 2021.

Halac S., L. Mengo, Guerra L., Lami A., Musazzi S., Loizeau J.L., Ariztegui D., Piovano E. L.: Paleolimnological reconstruction of the centennial eutrophication processes in a sub-tropical South American reservoir. Journal of South American Earth Sciences, 103, 102707, 2020.

Lu Y.: Comprehensive introduction of the canal in Shandong Province (Shandong Yunhe Beilan). Printed in 1775. Published by the Wenhai Publishing House (Taipei), 1969. (In classical Chinese)

Margarint M. C., Niculita M., Nemeth A., Cristea A. I., Doru S. C.: The reconstruction of an abandoned historical reservoir network in a continental temperate climate region using a multi-method approach. Applied Geography, 130, 202447, 2021.

Pan F.: The Plan of the Southern Part of the Grand Canal, Including the Shallow Lakes and Swamps (Map. Scale 1:200,000) (printed in 1916. In English and Chinese)

Pan Shoulian: Continued Gazetteer of Jining Prefecture. Vol. 3. Printed in 1927. (In classical Chinese).

Shen J., Zhang Z.L., Yang L.Y., Sun Q.Y.: Lake Nansi: environment and resource research. Seismology Press, Beijing, pp 6–20, 2008 (in Chinese).

Xu Z.G: Gazetteer of Jining Prefecture. Vol. 2. Printed in 1859. (In classical Chinese)

Yang S.Q.: Annals of the Emperor Taizong, Vol. 118. Printed in 1430. (In classical Chinese).

Yuan S.A.: Complete map of Jining County. In: Gazetteer of Jining County. Printed in 1927 (in Chinese).

https://doi.org/10.5194/cp-2021-121
Preprint. Discussion started: 8 September 2021

Zhu N.Z.: the Grand Canal in Shandong Province during the Ming Dynasty and the formation of the reservoirs along the canal. Forward Position (*Qian Yan*), 4, 226–229, 2014 (in Chinese).

Table 1. Water level observations of Lake Machang in a Chinese lunar calendar year (The 10th year of the Tongzhi Reign Period, that is, from 19 Feb 1871 to 8 Feb 1872).

Observing dates in Chinese lunar calendar	Observing dates in AD	Water levels in *yingzao chi**	Water levels in SI unit (m)
30th, 1st month**	20 Mar 1871	1.2	0.384
30th, 2nd month	19 Apr 1871	1.2	0.384
29th, 3rd month	18 May 1871	1.2	0.384
30th, 4th month	17 Jun 1871	1.4	0.448
30th, 5th month	17 Jul 1871	1.6	0.512
29th, 6th month	15 Aug 1871	1.8	0.576
30th, 7th month	14 Sept 1871	1.7	0.544
29th, 8th month	13 Oct 1871	2.1	0.672
30th, 9th month	12 Nov 1871	2.1	0.672
29th, 10th month	11 Dec 1871	2.1	0.672
29th, 11th month	9 Jan 1872	1.9	0.608
30th, 12th month	8 Feb 1872	1.9	0.608

* denotes water levels in the length unit *yingzao chi* (1 *yingzao chi* = 0.32 m).

** denotes the 30th day (i.e., the month end) of the 1st month.

https://doi.org/10.5194/cp-2021-121
Preprint. Discussion started: 8 September 2021

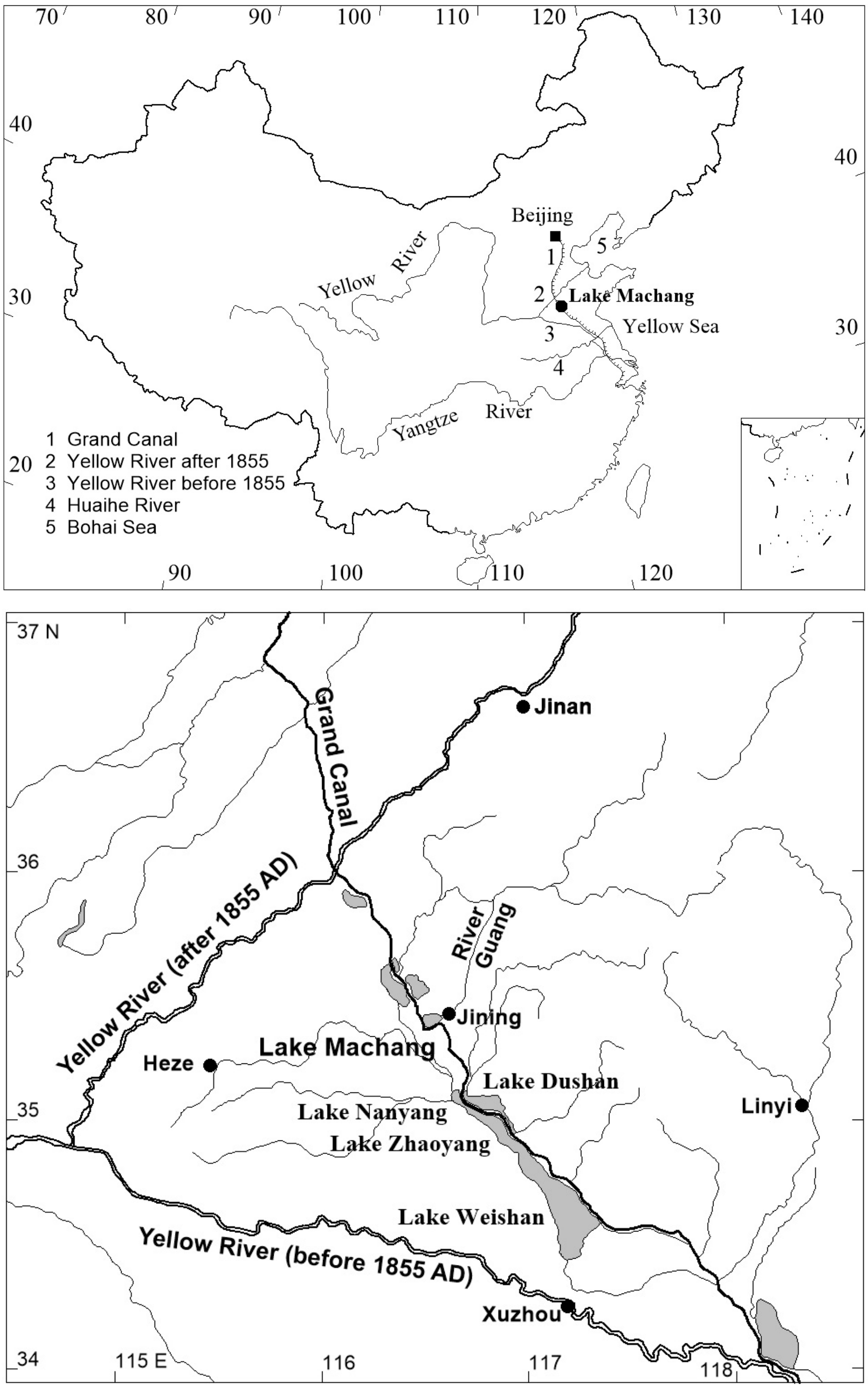

Figure 1. Maps showing the location (upper part) and vicinity (lower part) of Lake Machang.

https://doi.org/10.5194/cp-2021-121
Preprint. Discussion started: 8 September 2021

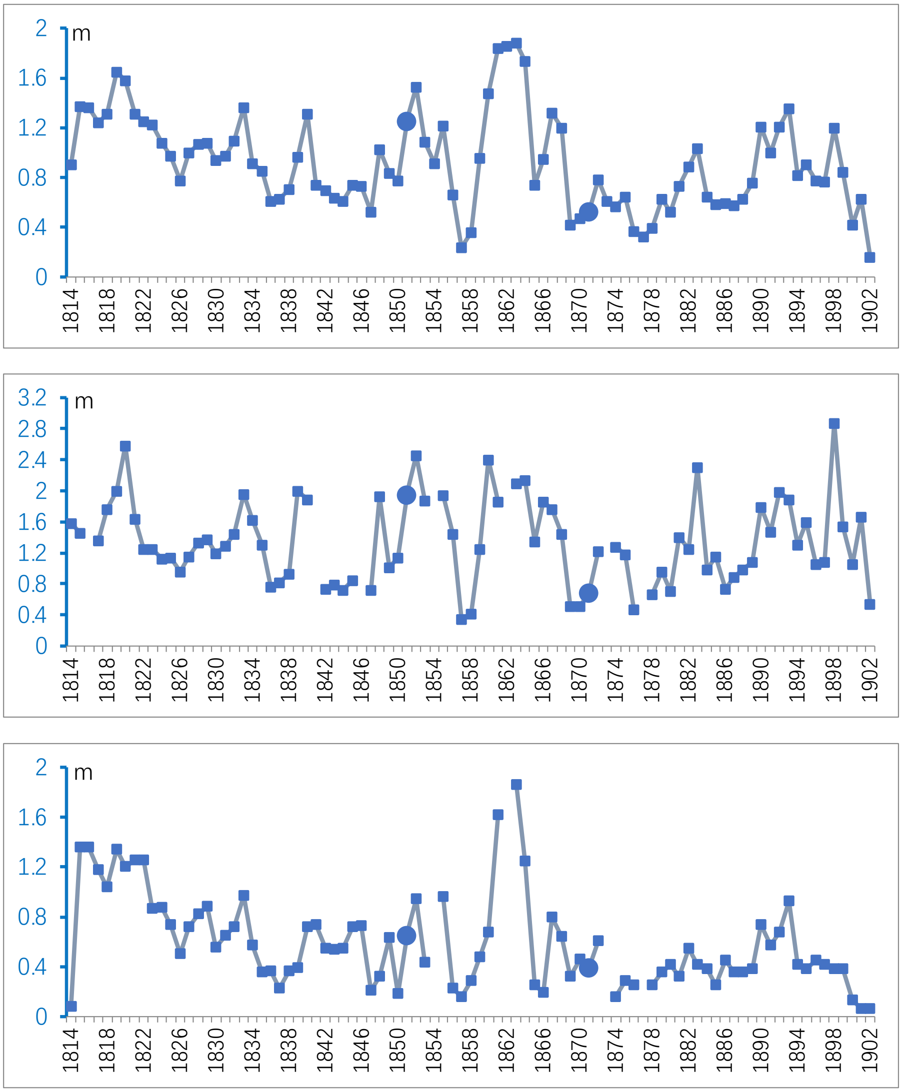

Figure 2. Annual mean (upper), maximum (middle), and minimum (lower) water levels of Lake Machang in the period of 1814–1902. Larger dots denote the years of 1815 and 1871 when Lake Machang was flooded by the Yellow River.

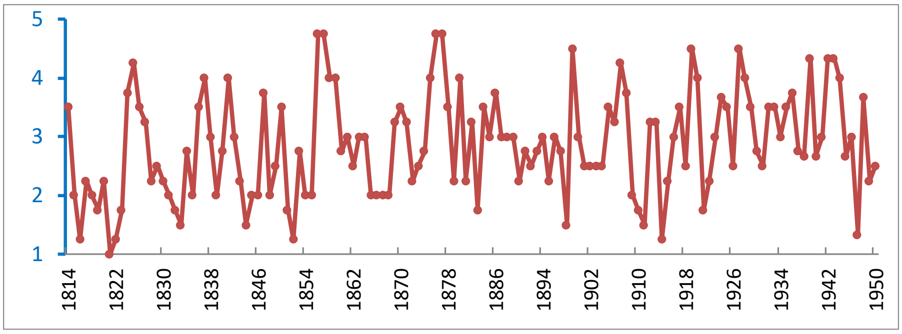

Figure 3. Average Dryness Wetness Index (DWI hereinafter) of four stations in the vicinity of Lake Machang, namely, Heze, Jinan, Linyi, and Xuzhou. DWI is a five-grade dataset, that is, 5 (very dry), 4 (dry), 3 (normal), 2 (wet), and 1 (very wet).

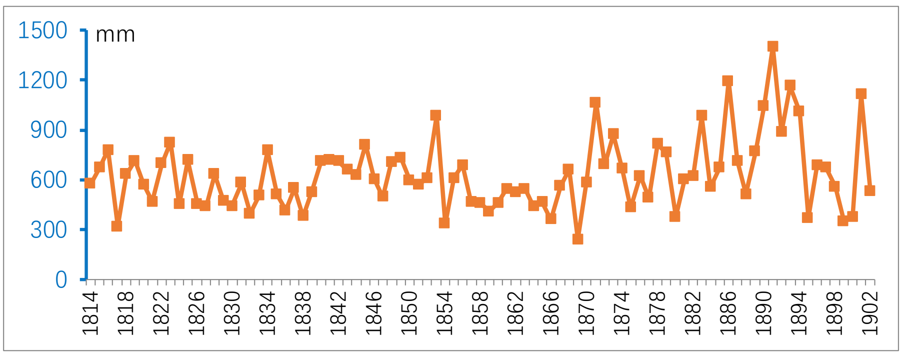

Figure 4. Annual precipitation of Beijing over the period of 1814–1902.

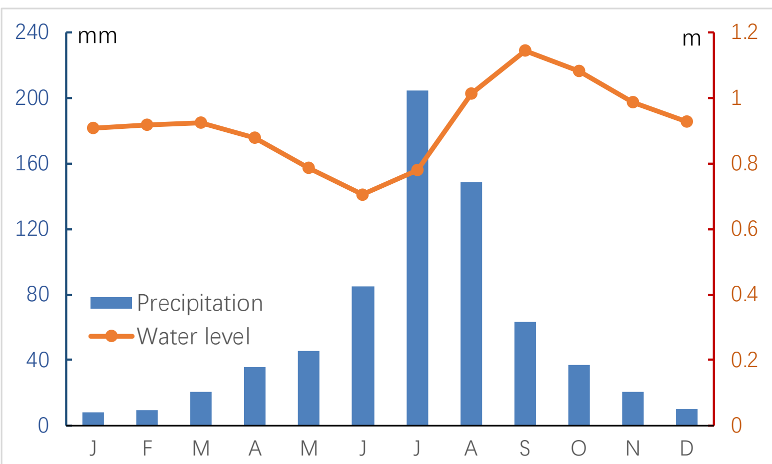

Figure 5. Comparison of the average monthly water level variability of Lake Machang (1814–1902) with the monthly precipitation variability of Jining City (1951–2010).

https://doi.org/10.5194/cp-2021-121
Preprint. Discussion started: 8 September 2021

Climate of the Past
Discussions
Open Access
EGU

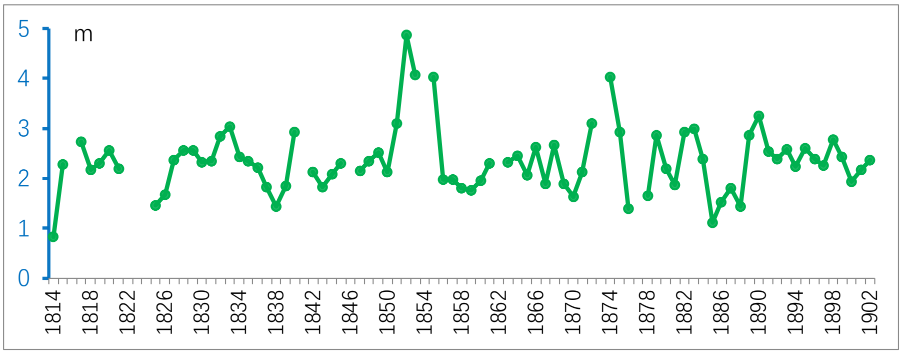

Figure 6. Annual mean water level change of Lake Nansi.

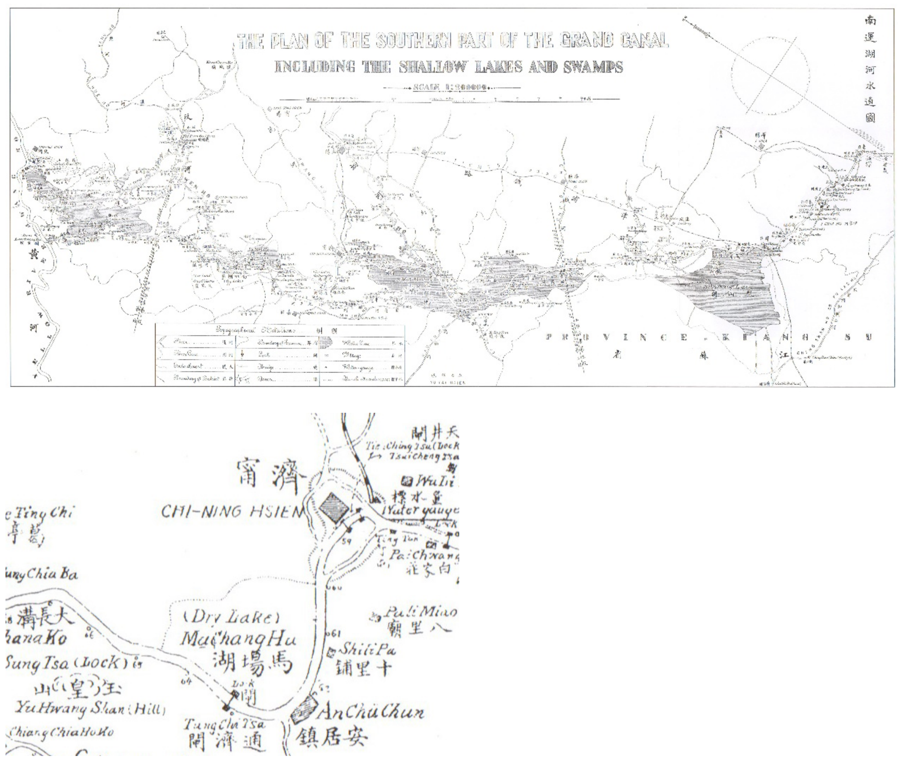

Figure 7. Map entitled "*The Plan of the Southern Part of the Grand Canal, including the Shallow Lakes and Swamps* (Pan, 1916)" (upper part). Enlarged image of the area near Lake Machang (lower part). Lake Machang was drawn as a "dry lake" in this map.