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Study on the Water Level–Discharge Relationship Changes in Dongting Lake Outlet Section over 70 Years and the Impact of Yangtze River Backwater Effect

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Abstract: The hydrological characteristics of the river–lake connecting section are determined by their interaction and studying them can help to understand the changing relationship between these two water bodies over time. The Lujiao–Luosan section is the connecting section of Dongting Lake and the Yangtze River, and the hydrological data for this section over the past 70 years has been analyzed. It has been found that the lowest water level is consistently rising at the same discharge at Chenglingji station, which is the joint point of Dongting Lake and the Yangtze River. While this could alleviate the drought situation in the Dongting Lake area during dry seasons, it could pose a more significant flood-control challenge during high water levels in the flood season. The water surface slope shows a decreasing trend especially during the dry season, except for the high flood period (July–September), which indicates that the water slope in the connecting section of Dongting Lake has become flatter. The backwater effect of the Yangtze River on Dongting Lake becomes increasingly stronger as the water surface slope difference between the Chenglingji–Luoshan section and the Lujiao–Chenglingji section changes from negative to positive between January and April.

Keywords: water level; discharge; Dongting Lake; water surface slope

1. Introduction

Lakes play a vital role within their corresponding river basins, including flood control, water supply, water quality enhancement, etc. However, the hydrological regimes in many lakes have changed significantly with climate change and human activities in recent years [1–4]. The disasters in these lake areas are becoming increasingly severe in two extreme directions: flooding during the flood season and drought during the dry season [4–7]. The hydrological situation at the confluence section of lakes and rivers is complex, and it is influenced by both the lakes and rivers. The hydrological regime changes in this section reflect the relationship between the rivers and lakes, as well as their corresponding hydrological changes [8]. Therefore, studying hydrological changes in the confluence section of lakes and rivers can broadly reflect changes in the relationship between rivers and lakes.

Dongting Lake, the second largest freshwater lake in China, is located in the middle and lower reaches of the Yangtze River. It plays a significant role in ensuring water security in the middle and lower reaches of the Yangtze River. The Yangtze River flows into Dongting Lake through three channels (Songzi, Taiping, and Ouchi). The three channels converge with four rivers (Xiang, Zi, Yuan, and Li) within Dongting Lake before discharging into the Yangtze River at the Chenglingji station. Therefore, the hydrological regime of the Yangtze River and Dongting Lake influence and constrain each other, resulting in the establishment of a complex river–lake relationship system between these two water bodies [9]. The middle and lower reaches of the Yangtze River have undergone the effects of both natural and human activities [10,11], such as the lower Jingjiang River bend cutoff [12], the operation of the Gezhouba Dam project [13], and the operation of the Three Gorges project [14]. These activities have led to a significant reduction in the sand diversion at the three channels [2,15] and anadromous scouring of the Jingjiang River section [16–18]. Regarding scouring and siltation, the Jingjiang section continues to erode and move downstream [17,19], while siltation occurs in the section from Chenglingji to Luoshan, with a possible trend of scouring in the future. Due to the reduction of sand diversion of the three channels, Dongting Lake is experiencing a decrease in sediment siltation [2,20,21], but some river channels are undergoing severe scouring [22]. In terms of inlet and outlet flows, the reduction in water diversion through the three channels has led to an increase in the flow of the Jing River section and a decrease in the inlet/outlet flow of Dongting Lake [23,24]. Due to the increased flow in the Jingjiang River section, changes in the river-bed condition of the Chenglingji–Luoshan section, and a decrease in the outflow from Dongting Lake, the backwater effects from the Yangtze River have been altered [25]. Therefore, the relationship between the Yangtze River and Dongting Lake is continuously evolving.

The outlet section (Lujiao–Chenglingji) of Dongting Lake is a connecting zone between the Yangtze River and Dongting Lake. The changes in their hydrological characteristics, reflecting the integration of the lake and river, can directly indicate the change in the relationship between the Yangtze River and Dongting Lake. Mao, et al. [26] found that the water level tends to rise, although the lake outflow decreases under medium- and low-flow conditions, which is attributed to a stronger backwater effect caused by the Yangtze River in recent years. In addition, the channel rectification in Dongting Lake, dredging of shallows [27], and artificial sand mining have contributed to significant changes in the topography of the outlet riverbed [22]. Therefore, the changes in the hydrological characteristics of the outlet section have become more complex, so it is necessary to conduct further studies to better understand the changes in the hydrological characteristics of the outlet section. In this paper, we analyze the hydrological changes of the outlet section of Dongting Lake over 70 years, utilizing water level and flow data.

This paper aims to: (1) examine the water level-discharge relationship at Chenglingji station, (2) investigate the water surface slope change in the outlet section, and (3) analyze the main factors that affect the water surface slope. Our findings could provide valuable information to better understand the overall hydrological changes in this region. It is also important for practitioners and stakeholders.

2. Materials and Methods

2.1. Study Area

Dongting Lake is located in the middle and lower reaches of the Yangtze River, characterized by a complex water network within the lake area. The lake is fed by several sources, with the flow originating from the Yangtze River through three channels (Songzi, Taiping, and Ouchi), as well as four rivers (Xiang, Zizhi, Yuan, and Li), as shown in Figure 1. Natural and human factors, such as the lower Jingjiang River bend cutoff, the construction of the Gezhou Dam, and the Three Gorges Dam (TGD), have had a significant impact on Dongting Lake's hydrological conditions. The Gezhou Dam project was completed in 1981 and is located approximately 38 km downstream of the Three Gorges Dam. It is an experimental project of the Three Gorges Dam. As Dongting Lake is situated downstream of the Gezhou Dam, the dam has resulted in the reduction of downstream flow into Dongting Lake, as well as limited the inflow of sediments into the lake. During the period of 2009–2017, the proportion of sand and water diverted from the Yangtze River through the three channels decreased significantly, dropping by 67.4% and 96% respectively compared to the period of 1961–1966 [6]. As a result, the water and sand from the four rivers have become increasingly dominant in Dongting Lake, which is significantly altering the overall water and sand conditions within the lake. In addition, the topography of the Xiangjiang River flood channel in Dongting Lake has changed significantly in recent years due to channel rectification and sand mining activities. These changes have resulted in significant alterations in the hydrological characteristics of the Dongting Lake outlet section. Previous studies found that the water level changes at the Lujiao and Chenglingji stations exhibit synchronization and are also influenced by the backwater effects of the Yangtze River [6]. Consequently, we have selected the Lujiao–Chenglingj section as the outlet section of Dongting Lake (shown in Figure 1b) in this study.

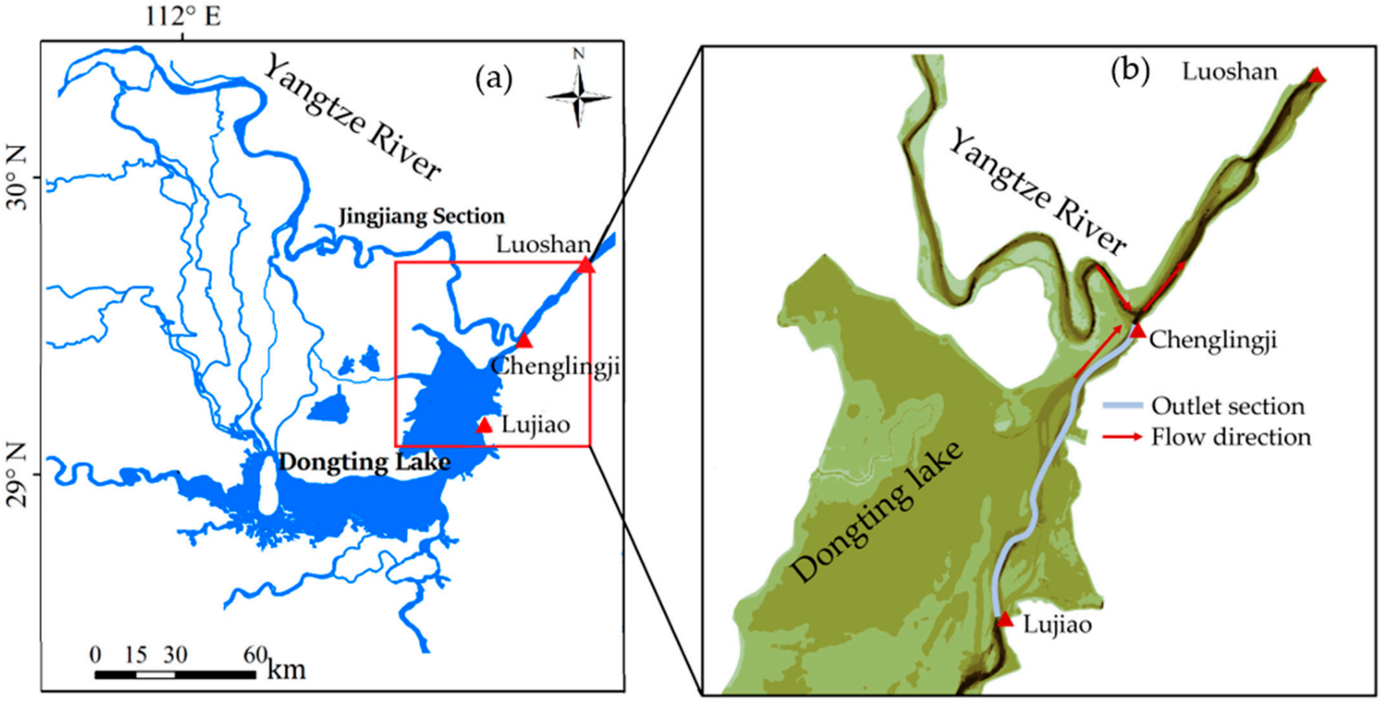

Figure 1. Study area: (**a**) Dongting Lake area, (**b**) the outlet section of Dongting Lake.

2.2. Data Sources

In this study, the hydrological measurement data were provided by the Dongting Lake Water Conservancy Affairs Center, which spans from 1954 to 2020. The dataset includes the average daily water level data at Lujiao Station (excluding the missing data from 1955), and the average daily water level and discharge data at Chenglingji Station and Lushan Station. Based on three significant events that occurred in the middle and lower reaches of the Yangtze River, namely, the lower Jingjiang River bend cutoff in 1967, the construction of Gezhouba in 1981, and the Three Gorges Dam in 2003, the time series spanning from 1954 to 2020 can be categorized into four distinct periods [7], i.e., 1954–1966, 1967–1980, 1981–2002, and 2003–2020. The discharge ratio between Chenglingji and Luoshan as well as the runoff at Chenglingji station from 1954 to 2020 were shown in Figure 2.

2.3. Variation of Water Level and Discharge Relationship at Chenglingji Station

The Chenglingji station is located at the joint point of Dongting Lake and the Yangtze River. Therefore, variations in its water level and discharge could reflect the interaction between these two water bodies. Figure 3 shows the relationship between the water level and discharge at the Chenglingji station in different periods. It appears to be relatively scattered with multiple water levels corresponding to the same discharge. However, the outer envelope of the relationship could be well described by a polynomial equation, with a high correlation coefficient of R^2 exceeding 0.93. The upper envelope curve represents the relationship between the discharge and its corresponding lowest water level, while the lower envelope curve represents the relationship between the discharge and its corresponding highest water level. It should be noted that a linear relationship exists between the discharge and its corresponding lowest water level based on the upper envelope curve. Furthermore, it is observed that the slope of the upper envelope line has been decreasing from the period 1954–1966 (Figure 3a) to the period 2003–2020 (Figure 3d). This indicates that the lowest water level at the Chenglingji station has shown a continuous increase over time under the same discharge conditions.

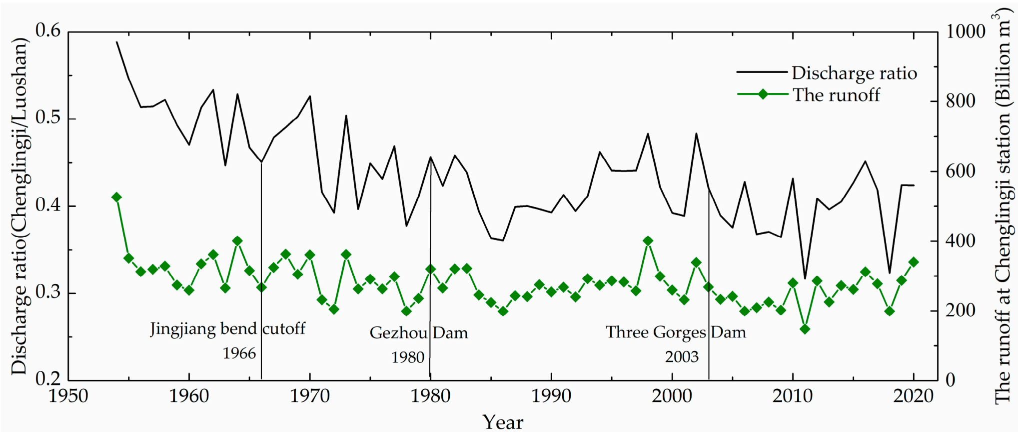

Figure 2. The discharge ratio and the runoff at Chenglingji station from 1954 to 2020.

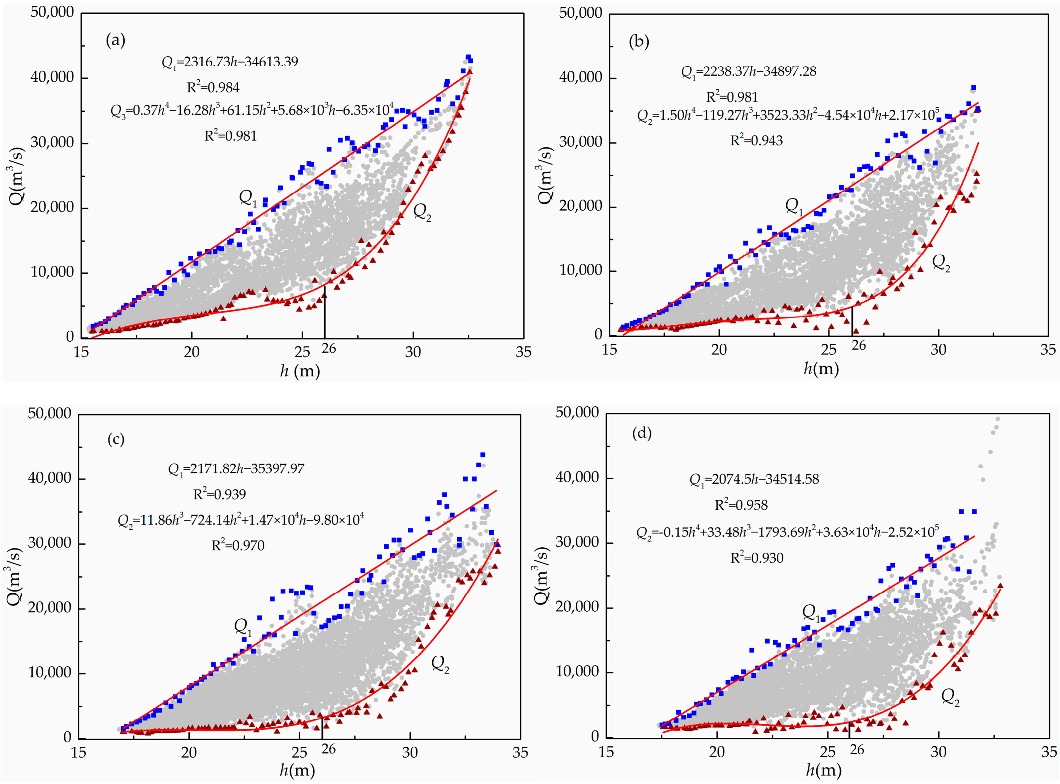

Figure 3. Relationship between water level(h) and discharge(Q) in Chenglingji in different periods: (**a**) 1954–1966, (**b**) 1967–1980, (**c**) 1981–2002, and (**d**) 2003–2020.

3. Results

3.1. The Envelope Curve of the Relationship between Water Level and Discharge

For the lower envelope curve, there is a turning point with the water level of approximately 26 m. When the water level is below 26 m, a slight increase of the discharge results in an obvious rise in water level, with an average increment of 1.33 m, 2.75 m, 4.11 m, and 6.44 m per 1000 m^3/s for the period of 1954–1966 (Figure 3a), 1967–1980 (Figure 3a), 1981–2002 (Figure 3c), and 2003–2020 (Figure 3d), respectively. Conversely, when the water level is over 26 m, a substantial rise in discharge yields a slight increase in water level, with an increment of approximately 0.25 m for all the periods. This phenomenon can be attributed to the fact that Dongting Lake is a riverine-like lake (see Figure 4). When the lake level is low, the water is constrained by the flood channel, causing the water level to rise quickly with an increase in discharge. As the water level continues to rise, water begins to flow out of the flood channel and onto the floodplain, resulting in a significant increase in the flow cross-section. Hence, the water level rises more slowly with an increase in discharge.

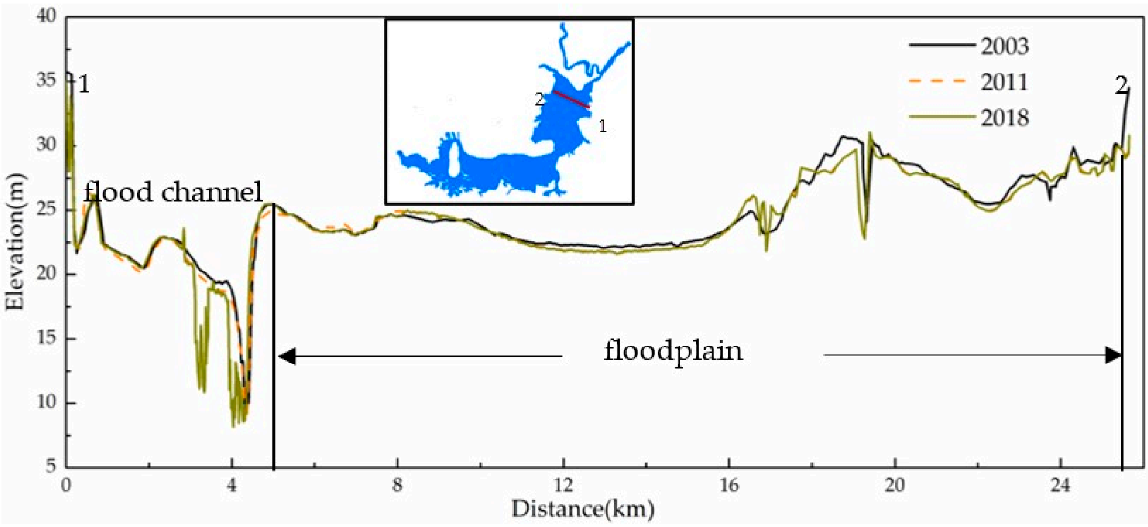

Figure 4. Typical cross-sections of Dongting Lake: 1 is start point of the cross-section and 2 is the end point of the cross-section.

Upon comparing the upper and lower envelope lines, it was discovered that the discharge corresponding to the highest water level at Chenglingji station is comparable with the maximum discharge observed during the period of 1954–1966. However, the difference between these two discharges becomes more obvious in the subsequent periods. Table 1 shows the maximum discharge and the discharge corresponding to the highest water level in different periods. During the period of 1954–1966, the difference between the discharge corresponding to the highest water level and the maximum discharge is about 600 m^3/s, while it increased to 25,800 m^3/s during the period of 2003–2020. This could be attributed to the backwater effect from the Yangtze River, which became stronger as the river-bed increased in the Chenglingji–Luoshan section as a result of sediment deposition after the Jingjiang bend cutoff.

3.2. The Lowest Water Level Corresponding to the Same Discharge

Table 2 shows the changes in the lowest water level corresponding to different discharges at Chenglingji in different periods. Comparing the period of 1954–1966 and 2003–2020, the lowest water level at Chenglingji increased from 15.36 m to 17.11 m, when the discharge was 1000 m^3/s. Similarly, for the 10,000 m^3/s condition, the lowest water level increased from 19.25 m to 21.45 m during the same period. For the 30,000 m^3/s condition, the lowest water level increased from 27.88 m to 31.09 m comparing the periods of 1954–1966 and 2003–2020. This indicates that the lowest water level at Chenglingji station has a rising trend at the same discharge and the water level increment rises with the increase in discharge. The rising of the lowest water level at Chenglingji station might help to alleviate drought conditions in the Dongting Lake region under low discharge situations. However, during high discharge conditions, rising water levels may pose significant challenges to the flood control situation in the region.

Table 1. The maximum discharge and the discharge corresponding to the highest water level in different periods at Chenglingji station.

Period	Highest Water Level (m)	Discharge Corresponding to the Highest Water Level (m^3/s)	Maximum Discharge (m^3/s)	Discharge Difference (m^3/s)
1954–1966	32.60	42,700	43,300	600
1967–1980	31.81	35,200	38,600	3400
1981–2002	33.98	29,800	43,800	14,000
2003–2020	32.78	23,400	49,200	25,800

Table 2. Variation of the lowest water level (m) corresponding to the same discharge at Chenglingj station in different periods.

Discharge (m^3/s)	Period			
	1954–1966	1967–1980	1981–2002	2003–2020
1000	15.36	16.03	16.75	17.11
2000	15.79	16.47	17.21	17.59
5000	17.09	17.81	18.59	19.04
10,000	19.25	20.05	20.89	21.45
15,000	21.41	22.28	23.20	23.86
20,000	23.56	24.52	25.50	26.27
25,000	25.72	26.75	27.80	28.68
30,000	27.88	28.98	30.10	31.09

3.3. The Water Level Variation Range with the Same Discharge

Depending on the downstream backwater effect, the same discharge could correspond to multiple water levels. The water level variation range with the same discharge could reflect the influence of backwater effects from the downstream to the upstream. Table 3 shows the water level variation range with the same discharge at the Chenglingji station. During the period of 1954–1966, the maximum water level variation range is about 7.58 m corresponding to the discharge of 10,000 m^3/s. During the period of 1967–1981 and 1981–2002, the maximum water level variation range is about 8.8 m, which corresponds to the discharge of 7000 m^3/s. During the period of 2003–2020, the maximum water level variation range is about 9.0 m, which corresponds to a discharge of about 6000 m^3/s. Therefore, the maximum water level variation range increased over time, while its corresponding discharge has a decreasing trend. There were two distinct periods where the water level variation range increased significantly. Firstly, from 1954–1966 to 1967–1980, the range increased by 1.22 m. Secondly, from 1981–2002 to 2003–2020, it further increased by 0.2 m. This indicates that the Jinjiang bend cutoff has the most significant impact on increasing the backwater effect of the Yangtze River, with the Three Gorges Dam following closely behind.

3.4. The Relationship between the Daily Average Water Level and Discharge

Figure 5 shows the relationship between the daily average water level and discharge at the Chenglingji station during different periods. It could be found that the highest daily average water level and discharge occur in July at the Chenglingji station. During the period of 1954–1966 (Figure 5a) and 1967–1980 (Figure 5b), the water rising period is from February to mid-July and the falling period is from mid-July to January next year, with the lowest daily average water level occurring at the end of January or early February. During the periods of 1981–2002 (Figure 5c) and 2003–2020 (Figure 5d), the water rising period is from January to mid-July and the falling period is from mid-July to December, with the lowest daily average water level occurring at the end of December or early January.

Therefore, during the period of 1981–2002 and 2003–2020, the water rising period increased by approximately one month.

Table 3. The water level variation range (m) with the same discharge at Chenglingji station.

Discharge (m^3/s)	Period			
	1954–1966	**1967–1980**	**1981–2002**	**2003–2020**
2000	1.58	2.88	7.34	7.73
4000	4.59	8.19	8.52	8.94
6000	6.85	8.76	8.80	9.06
8000	7.46	8.74	8.78	8.89
10,000	7.58	8.49	8.60	8.56
12,000	7.48	8.12	8.32	8.16
14,000	7.25	7.67	7.96	7.69

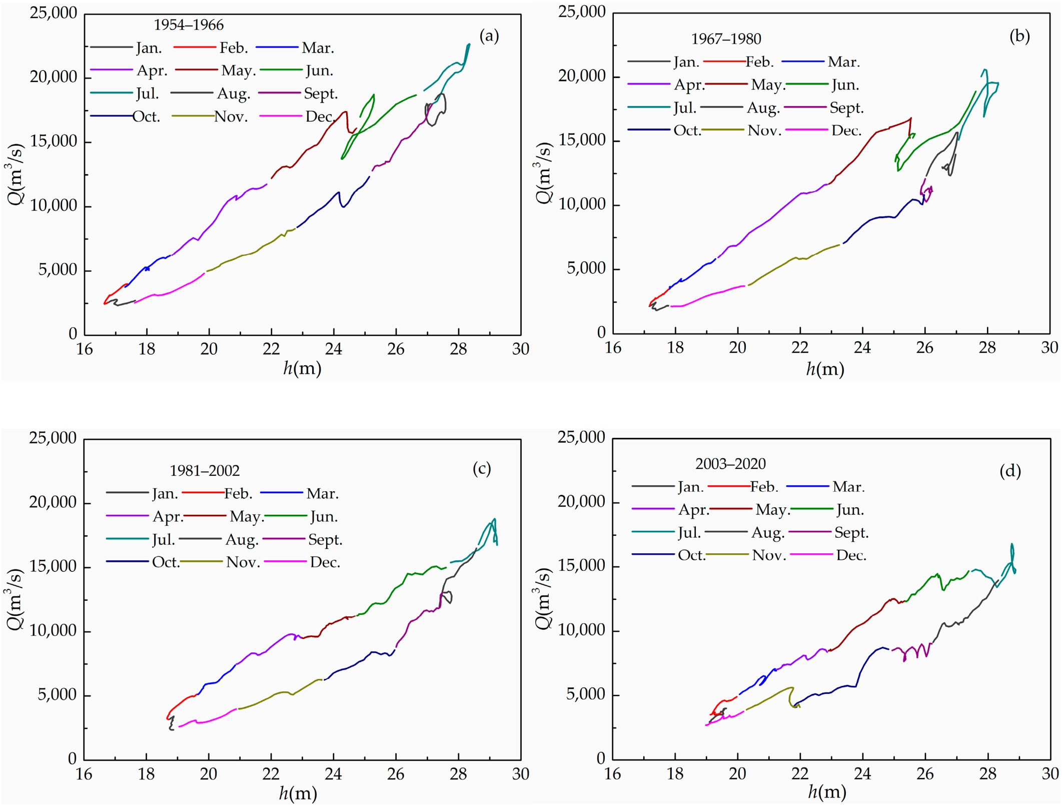

Figure 5. The daily average rating curve at Chenglingji station in different periods: (**a**) 1954–1966, (**b**) 1967–1980, (**c**) 1981–2002, and (**d**) 2003–2020.

The relationship between the daily average water level and discharge at Chenglingji shows a large change in discharge with a small change in water level or a decrease in discharge with a rise in water level instead due to the backwater effect of the Yangtze River. During the period of 1954–1966 and 1967–1980, the backwater effect was apparent in late May and early June at the Chenglingji station. Additionally, it also was apparent near the highest water level in July during the 1967–1980 period. During the period of 1981–2002, the backwater effect was mainly apparent during the highest water level in July. During the period of 2003–2020, the backwater effect is obvious in mid-June and July. Therefore, the occurrence of the backwater effect was delayed by half a month to a month after the operation of the Three Gorges Dam. During the period of 1954–1966, 1967–1980, and 1981–2002, the phenomenon of the backwater effect is mainly characterized by a situation where there is either no change or a slight decrease in water level as the discharge decreases. While during 2003–2020, it is mainly characterized by a situation where there is a significant increase in water level as the discharge decreases. For example, in early July the daily average discharge decreased from 14,801 m^3/s to 13,426 m^3/s, while the water level increased from 27.60 m to 28.28 m. It indicates that the backwater effect of the Yangtze River on the water level at Chenglingji station became stronger during the high-water level after the construction of the Three Gorges Dam.

Table 4 shows the maximum and minimum daily average water level and discharge at Chenglingji station for different time periods. However, the highest daily average water level increased from 28.36 m during 1954–1966 to 29.24 m during 1981–2002, with an increase of 0.88 m while the highest daily average water level decreased to 28.88 m in the period 2003–2020, but still increased by 0.52 m compared with the maximum daily average number in the period 1954–1966. Compared with the period of 1954–1966, the maximum daily average discharge decreased from 22,700 m^3/s to 16,873 m^3/s during the period of 2003–2020. Although the maximum daily average discharge decreased over time, the highest daily average water level increased significantly, which would intensify the flood control situation in the Dongting Lake area.

Table 4. The extremal water level and discharge at the Chenglingji station.

Period	Water Level (m)		Discharge (m^3/s)	
	Highest	Lowest	Highest	Lowest
1954–1966	28.36	16.64	22,700	2343
1967–1980	28.34	17.17	20,593	1875
1981–2002	29.24	18.66	18,830	2387
2003–2020	28.88	18.98	16,837	2716

Regarding the minimum daily average water level at Chenglingji station, it rose from 16.64 m during 1954–1966 to 18.98 m during 2003–2020, resulting in a 2.34 m increment. Similarly, the minimum daily average discharge increased from 2343 m^3/s during 1954–1966 to 2716 m^3/s during 2003–2020. Nonetheless, the discrepancy between the highest and lowest water levels decreased from 11.72 m during 1954–1966 to 9.90 m during 2003–2020.

3.5. Water Surface Slope in the Outlet Section of Dongting Lake

Figure 6 illustrates the fluctuation in the monthly average water surface slope from Lujiao to Chenglingji at different time periods. The water surface slope in each month demonstrates a decreasing trend for the four periods, with significant monthly variations within the year. The highest slope appears in March, while the lowest slope is present during the month of high flood period (July–September). In the four periods of 1954–1966, 1967–1980, 1981–2002, and 2003–2020, the variation ranges of the surface slope were 0.075‰, 0.066‰, 0.049‰, and 0.028‰, respectively, suggesting a declining trend over the successive periods. Except for the high flood period, the water surface slope reduced consistently in the rest of the year, especially in the dry period (January–April). For instance, in March, the water surface slope decreased from 0.082‰ during the 1954–1966 period to 0.034‰ during the 2003–2020 period, indicating a decline of approximately 59%. This implies that the water surface slope in the Dongting Lake outlet area became gentler, providing an amplified influence of the backwater effect from downstream on the water level of Dongting Lake. However, the surface slope increased from 0.006‰ to 0.0092‰ in October from 1981–2002 to 2003–2020 due to the impoundment of Three Gorges Dam in late September, which led to a significant drop in the water level of the middle and lower reaches of the Yangtze River, intensifying the water surface gradient in the outlet area.

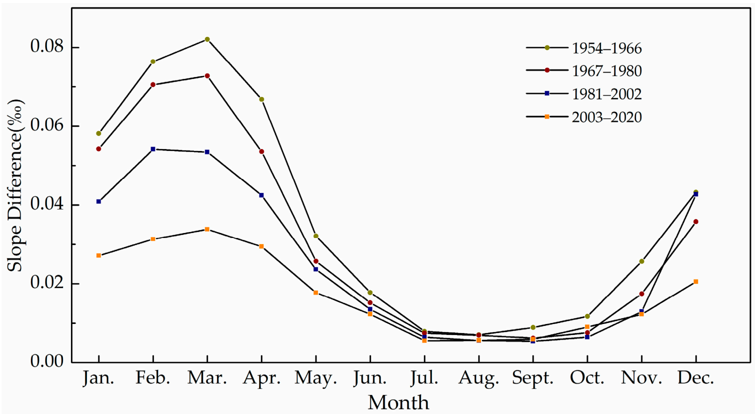

Figure 6. Monthly average water surface slope in the outlet section of Dongting Lake.

The main factors that affect the water surface slope mainly include the upstream incoming flow condition, riverbed slope, and downstream water level change. Figure 7 shows a variation in the monthly average discharge at Chenglingji station during different time periods. Although the monthly average outflow of Dongting Lake in January–March and December has increased after 1980, the water surface slope of the lake outlet section (Lujiao–Chenglingji, see Figure 5) in January–March has continued to decline in the past 70 years. Therefore, the change in upstream incoming flow might not be the reason for the decrease in the water surface slope at the outlet section.

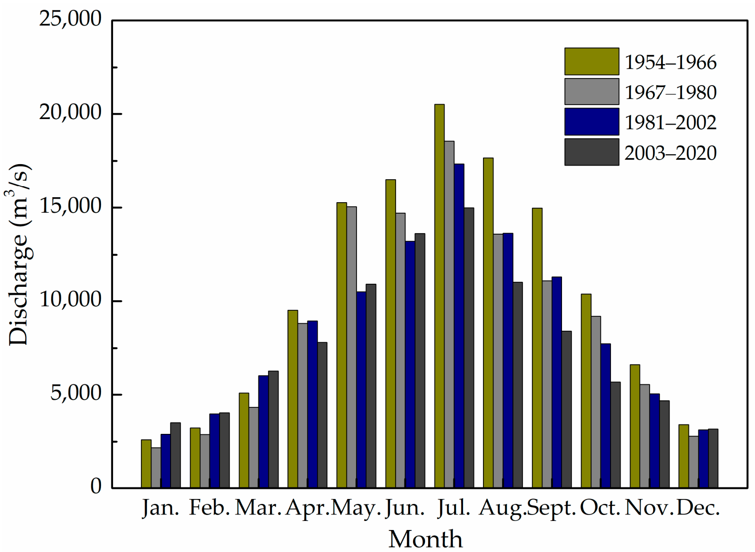

Figure 7. Monthly average discharge at Chenglingji station.

Regarding downstream water level, it has been rising during low and medium flow conditions since 1951 [8,28]. Figure 8 reveals the changes in the monthly average water level at the Chenglingji station in different time periods. It is found that the average monthly water level increased significantly after the Jingjiang bend cutoff in January–March and December, especially in the period 2003–2020. Compared with the 1954–1966 period, the monthly average water level at Chenglingji station has risen by about 2.53 m in January–March and by about 0.88 m in December during the 2003–2020 period. As a result, the downstream water-level increase is directly responsible for the decrease of the water surface slope at the Dongting Lake outlet area.

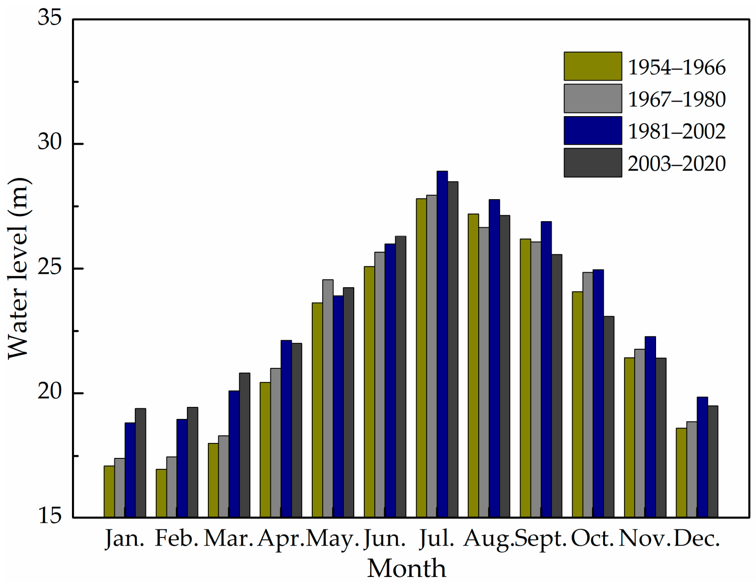

Figure 8. The monthly average water level at Chenglingji station.

The riverbed slope is primarily influenced by the topographic changes of the river channel. The outlet section of Dongting Lake has two large shoals, i.e., Coal Bay and Yueyang shoal. During the dry period, the upstream water level is mainly controlled by Coal Bay under the same incoming flow [29]. In the 1990s, Coal Bay underwent a series of channel dredging and trenching projects, causing the bottom elevation of Thalweg near Coal Bay to drop significantly [30]. Figure 9 shows the change in the thalweg in the Lujiao–Chenglingji section from 2003 to 2018. It reveals that the elevation of Coal Bay decreased by approximately 3.56 m on average from 2003 to 2018. From 2003 to 2018, the highest elevations in both the Coal Bay area and the Yueyang shoal area decreased. In the Coal Bay area, the highest elevation decreased from 18.82 m to 14.65 m, while in the Yueyang shoal area, it decreased from 14.82 m to 13.81 m. This led to a reduction in the difference between the two areas from 4.0 m to 0.84 m, resulting in a significant flattening of the slope in the Lujiao–Chenglingji section. Additionally, previous studies found that the Lujiao–Chenglingji channel is generally in a scouring state since 1956 [30,31], while the Chenglingji–Lushan section has been undergoing siltation leading to a rising riverbed downstream [32,33]. Thus, the water surface slope decreases with the decline of the riverbed slope. Hence, the riverbed change is one of the primary reasons for the decrease in water surface slope drop during the dry period of Dongting Lake.

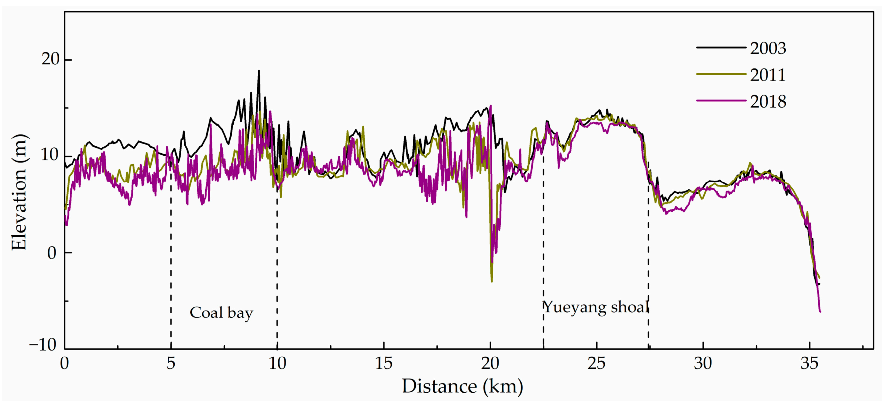

Figure 9. Map of the Thalweg line in the Lujiao–Chenglingji River section.

4. Discussion

4.1. The Backwater Effect of the Yangtze River on Dongting Lake

Chenglingji is located at the confluence of the Dongting Lake and Yangtze River, and its water levels are affected by both the incoming water from Dongting Lake and the Yangtze River. The Lujiao station is located approximately 33 km upstream of the Chenglingji station, while the Lushan station is located about 34 km downstream (see Figure 1). By analyzing the variation in water surface slope from Lujiao to Chenglingji and from Chenglingji to Lushan, it could reflect the change of the backwater effect of the Yangtze River on Dongting Lake.

Figure 10 shows the difference between the water surface slope in the Chenglingji–Luoshan section and that in the Lujiao–Chenglingji section. In general, the difference in water surface slope increases continuously every month over the four periods, which indicates that the backwater effect of the Yangtze River on Dongting Lake is becoming more and more obvious, which is consistent with the findings of the previous literature [24].

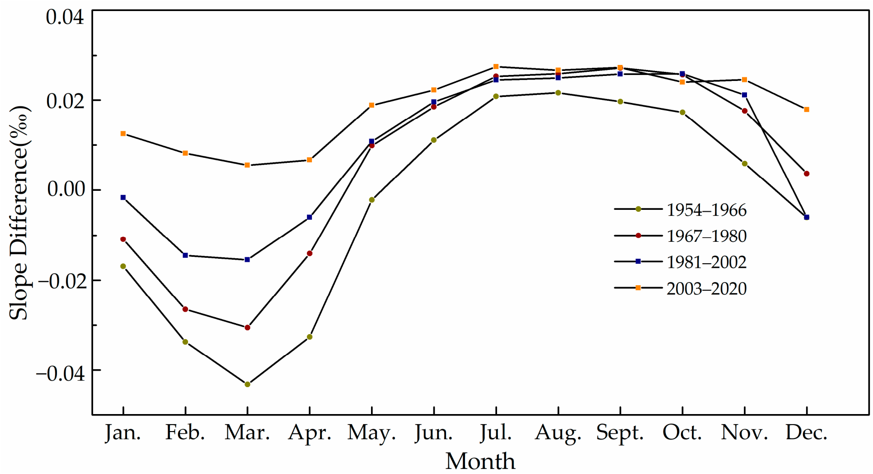

Figure 10. Variation of water surface slope difference in the outlet section of Dongting Lake.

For the high flood period of Dongting Lake (July–September), the difference in water surface slope between the Chenglingji–Luoshan section and Lujiao–Chenglingji section was basically maintained at about 0.02‰ during 1954–1966, the difference in water surface slope increased to 0.026‰ for the following three periods. This is mainly due to the fact that the Jingjiang bend cutoff increases the surface slope of the Jingjiang water surface, resulting in increasing the flow of the Jingjiang section [25], thus strengthening the backwater effect of the Yangtze River on Dongting Lake.

During the pre-flood period of January to April in Dongting Lake, the water surface slope difference between the Chenglingji–Luoshan section and Lujiao–Chenglingji section was negative before the year 2003. This suggests that the relationship between the Yangtze River and Dongting Lake was primarily influenced by the backwater effect of Dongting Lake on the Yangtze River during this time-period.

4.2. The Limitations of the Study

This study primarily focuses on examining the correlation between the water level and discharge at the outlet area of Dongting Lake based on historical hydrological data. This analysis can prove beneficial in flood control and disaster mitigation. While the study has also examined the impact of topographical alterations on the water surface slope, it should be noted that intensive sand mining has been carried out in recent years [32,33], owing to the high market demand, which has significantly affected the topography. Therefore, it is necessary to conduct a quantified analysis to understand the hydrological changes in the connecting zone between the Yangtze River and Dongting Lake and predict the alterations in the hydrological regime in the future.

5. Conclusions

(1) It is found that at Chenglingji station, the water level seemed to increase steadily over the four periods under the same discharge condition. While this could potentially help alleviate drought conditions in the Dongting Lake area during periods of low discharge, it also presents a significant challenge to flood control efforts in the same area during periods of high discharge.

(2) Except for the high flood period (July–September), the water surface slope drop shows a decreasing trend, especially during the dry period when the water surface slope decreases significantly. It indicates that the water surface slope in the outlet section of Dongting Lake becomes gentler, which strengthens the backwater effect of the Yangtze River on the water level in Dongting Lake.

(3) The change in downstream water level and riverbed topography are the main factors that change the water surface slope in the outlet section of Dongting Lake. After the completion of the Three Gorges Dam in 2003, there has been a notable shift in the interaction between the Yangtze River and Dongting Lake. The backwater effect of the Yangtze River has become the dominant factor in this relationship, as evidenced by the positive difference in monthly average water surface slope from January to April.

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